OCCASION

This publication has been made available to the public on the occasion of the 50th anniversary of the United Nations Industrial Development Organisation.

DISCLAIMER

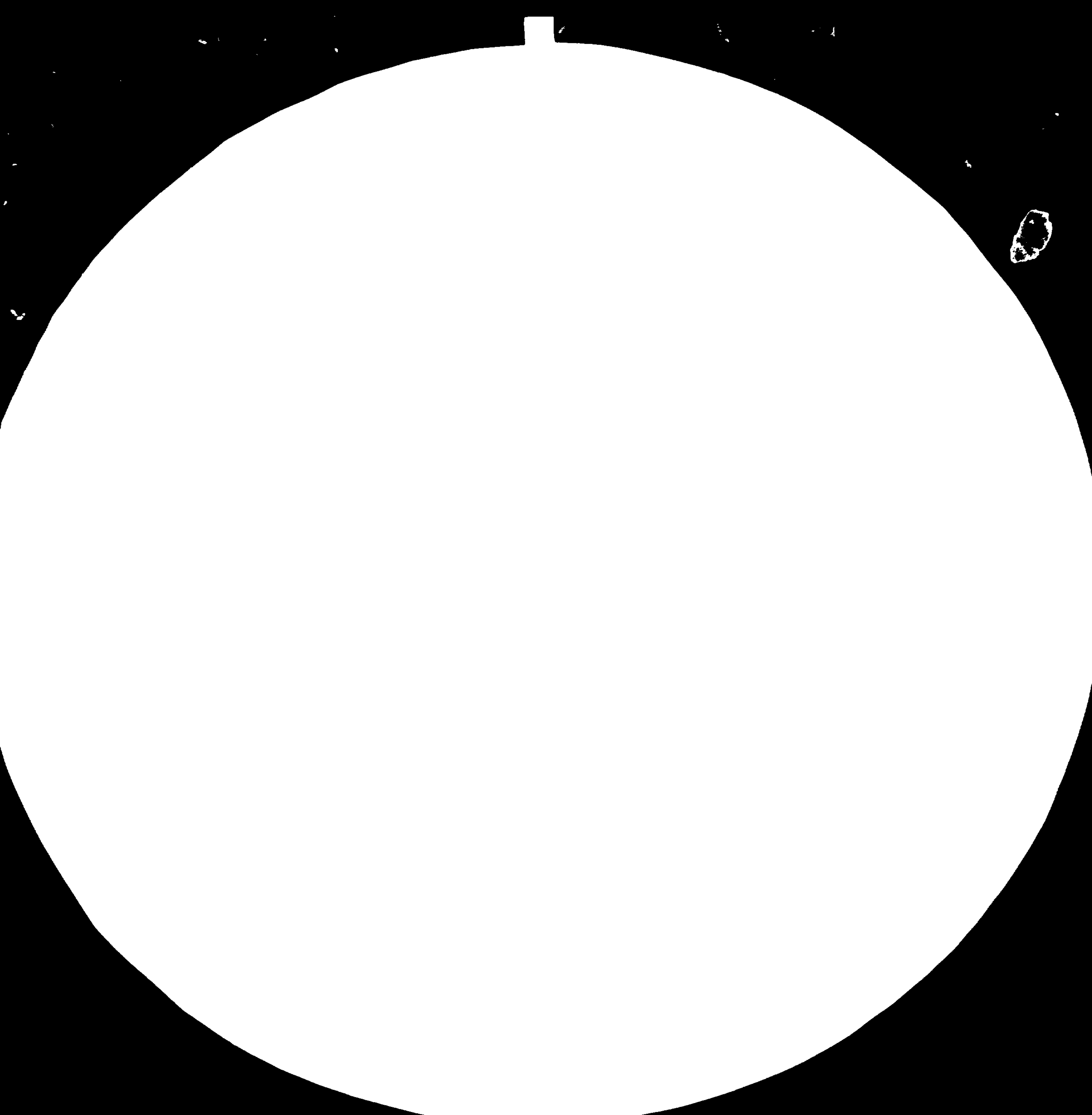
FAIR USE POLICY

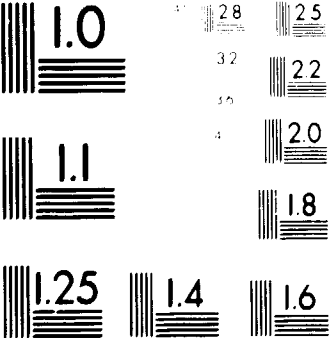
CONTACT

Please contact publications@unido.org for further information concerning UNIDO publications.

For more information about UNIDO, please visit us at www.unido.org

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org





MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS

STANDARD REFERENCE MATERIAL 1010a

ANSI and ISO TEST CHART No. 2

Restricted

CHANGING DETERMINANTS OF OPTIMAL SCALE IN PRODUCTION AND EXPLORING RESULTING OPPORTUNITIES IN DEVELOPING COUNTRIES*

Bela Gold**

13379

CONTENTS

* Prepared as a commissioned discussion paper for the United Nations International Development Organization.

** William E. Umstattd Professor of Industrial Economics and Director of the Research Program in Industrial Economics, Case Western Reserve University, Cleveland, Ohio

June 19, 1983

CHANGING DETERMINANTS OF OPTIMAL SCALE IN PRODUCTION AND EXPLORING RESULTING OPPORTUNITIES IN DEVELOPING COUNTRIES*

Bela Gold**

I. ON THE ROLE OF POTENTIAL SCALE ADVANTAGES

Increasing competitive pressures in domestic and international markets have long stimulated efforts in many industries to gain the widely believed advantages of "scale economies" through building progressively larger operating units. Such tendencies have been apparent in broad sectors of manufacturing -- including chemicals, steel, pulp and paper, automobiles and cement -- as well as in power generation, mining, shipping and agriculture. This reflects the spread of faith in the benefits of scale increases beyond engineers and industrial managers to governments, leading the latter to join in fostering larger operations, often by combining smaller units, in the hope of strengthening the competitive position of their industries.

There can be no doubt that scale increases have indeed yielded substantial benefits in many cases. But it is important for industry and public officials to recognize that such generalized expectations rest on cloudy and even dubious foundations. A strong case can accordingly be made for reconsidering industrial development policies based on such beliefs pending more thorough exploration of:

1. the sources and benefits of successive increases in scale, along with any accompanying disadvantages;

---

* Prepared as a commissioned discussion paper for the United Nations International Development Organization.

**William E. Umstattd Professor of Industrial Economics and Director of the Research Program in Industrial Economics, Case Western Reserve University, Cleveland, Ohio

2. how these may differ among firms and industries, depending on such factors as input availabilities, production processes, product-mixes and market characteristics; and
3. how scale effects have been changing over time.

Recent developments suggest that such analyses are likely to reveal hitherto under-estimated and still growing potential advantages for intermediate and smaller scale operations in a wide variety of industries.

In evaluating the policy implications of resulting perspectives, however, sight should never be lost of the fact that the international competitiveness of industrial operations is determined by the interactions of a larger complex of factors within which the advantages or disadvantages of scale differences may be offset by the effects of others. Hence, appraising prospective opportunities for strengthening the competitiveness of industrial undertakings in developing countries requires careful exploration of the full range of such determinants in order to identify the most promising among recognized alternatives.

Studies suggest that the most influential factors affecting market competitiveness are: product design and service capabilities; relative costs and prices; marketing superiority and maintenance assurances; and governmental aids and restrictions. In turn, cost advantages may be traced to two different sources. The first results from advantages in respect to the availability and price of needed inputs, including natural resources, energy, labor and investment funds. The second may be generated by superiority in respect to one or more of the following determinants of efficiency in production operations:

1. more highly trained and experienced management combined with more aggressive managerial pressures for productivity improvements;

2. larger and more sophisticated technical staffs with greater incentives to keep improving technological capabilities;
3. greater productive efforts by the labor force combined with greater willingness to accept technological innovations and greater mobility among tasks;
4. more limited product-mix, longer production runs of more standardized products and higher rates of capacity utilization; and
5. more modern, technologically advanced and effective scale of facilities and equipment.

Thus, the determination and implementation of optimal scales of production can be a source of significant competitive advantages. But scale benefits may well be insufficient to offset any accompanying shortcomings in respect to the other determinants of relative production costs, to say nothing of possible disadvantages in respect to the wider array of factors which have been identified as affecting market competitiveness. Accordingly, while the primary concentration of the following discussion on exploring the potentials of appropriate scale is intended to uncover hitherto underappreciated, as well as newly emerging, opportunities for strengthening the competitiveness of developing countries in respect to production costs, such potentials would still have to be evaluated within the larger framework of factors affecting market competitiveness which was outlined above before sound action programs could be developed.

II LIMITATIONS OF PREVAILING CONCEPTS OF SCALE AND SCALE EFFECTS

It is important to recognize at the outset that the widespread faith in the economies of scale has not gained impressive or even consistent support from the relevant theoretical and empirical literature. On the contrary, analyses have repeatedly called attention to the fuzziness of the basic concept of scale,

to the variability of the expected benefits and to uncertainties about the very sources of such prospective gains.

A. On Concepts of Scale

One of the odd features of the related literature is the fuzziness of the basic concept. The dominant approach in economic theory has viewed increases in scale as involving increases in the size or capacity of production units, provided that there are no changes in factor proportions (1) or, by direct implication, in the products made (2) or in the technology employed. (3) Thus, increases in scale are envisioned as essentially enlarged duplicates of smaller units. It should be noted that one or another of these restrictions has been challenged from time to time by leading economists -- including Marshall, Clapham, J.M. Clark and Chamberlin -- and that they have also been criticized as rendering the scale concept virtually inapplicable to actual industrial experience. (4) As a result, some recent economic text-

(1) The requirement of fixed factor proportions continues to be specified, for example by Samuelson [43, p. 25].

(2) Although the specific content of "the output" in theoretical discussions of increasing returns is seldom specified, the essential identity of the products made is clearly implied by the illustrations cited and by the absence of discussions of accompanying changes in products.

(3) All static economic theory is restricted, of course, within a fixed state of technology. But the meaning of this is far from clear, inasmuch as the state of technological knowledge may reach far beyond current applications. In discussions of scale, this restriction is often interpreted as permitting unlimited adjustments in the degree of specialization of all inputs. Combining this with the requirement of fixed factor proportions, however, leaves very little latitude in reality for changes in the organization of processes or in the characteristics of their inputs. In fact, this would require exact matching of the increased returns achieved from the division of labor, or from increased specialization of any other input, with increased returns from each of the other inputs -- by means that are economically more attractive than less restrictive alternatives.

(4) For a fuller review, see Gold [23, pp. 7-10].

books have begun to omit some of these restrictions without confronting the resulting implications for static micro-economic theory of blurring the concept representing one of its significant analytical components.(5)

Most of the engineering literature is less restrictive, simply regarding scale increases as synonymous with larger plants producing roughly similar products and using similar technologies.(6) And the scale concept reflected by most empirical economic research has been substantially looser, focussing only on the relative size of plants within some general classification of industries, sometimes a broad two-digit, sometimes a three-digit and sometimes a still narrower four-digit statistical category.(7) These clearly ignore the differences in factor proportions among individual plants, as well as wide heterogeneity in individual products, product-mixes or technologies employed (8) and other important plant characteristics, including the degree of processing or fabrication of purchased materials. In such studies, nothing is left of ostensible measures of relative scales except differences among groups of plants in respect to average employment levels or some measure of output (e.g., product value or value added).

---

(5) For example, a sampling of current elementary textbooks reveals that only Samuelson [43, p. 25] and Richard G. Lipsey and Peter O. Steiner [33, pp. 207-10) specify the requirement of fixed factor proportions; that neither of these specifies technological restrictions; and that both requirements are omitted by Campbell R. McConnell [37], Edwin Mansfield [34] and Milton H. Spencer [47] -- as well as by more advanced textbooks, such as Joseph Hadar [29., PP. 18-21.

(6) For example, see the following discussions of scale effects in the chemical industry: Aries and Newton [2, pp. 6-7, 15], Bauman [6, pp. 39, 180-181], Crowe, et.al. [11, p. 110] and Peters [40, p. 93].

(7) Some empirical studies of scale include different levels of aggregation using: two-digit -- Moroney [39]; three-digit -- Stigler [50, p. 63]; and four-digit -- Miller [38, p. 470].

(8) For example, in studying the effects of scale in the steel industry, Stigler emphasizes having restricted his analysis "to firms making steel ingots by open-hearth or Bessemer processes" -- thus ignoring the important differences between these technologies [50, 57].

In order to increase its usefulness for purposes of economic analysis, industrial decision-making and government policy development, however, the concept of scale needs to be clarified so as to define its distinctive characteristics, to facilitate measurement of changes in this variable, to identify the probable effects of changes in it and to reveal the means whereby the potential benefits of scale adjustments may be maximized.

B. On the Sources and Effects of Increases in Scale

1. Some Shortcomings of Theory

Although academic theories are often derided as impractical by decision-makers, their actions are often rooted in widely accepted beliefs which are traceable to long promulgated scholarly conceptions. Judgments about the effects of increases in scale seem to represent an especially impressive example of the unconscious influence of traditional economic theory and hence warrant re-examination of the weakness of such foundations.

But established economic theory offers virtually no significant contributions to understanding the sources of past or prospective scale economies. It simply posits a particular pattern of scale effects -- i.e., the effects on minimum average total unit costs of increases in the capacity of plants engaged in essentially identical production activities -- in the form of a U-shaped "long-run cost function". This expectation is based on four assumptions, as shown in Figure 1:

1. that the short term cost functions, which show the effect on average total unit costs of variations in the capacity utilization of individual plants, are U-shaped;
2. that the minimum cost points of such short-term cost functions tend to decline for successively larger plants up to some optimal point beyond which minimum costs begin to rise;

3. that plants producing identical products by means of identical inputs and technologies commonly cover a wide range of sizes at any given time; and
4. that the overlapping of adjacent short-run cost functions indicates the diseconomies of under-utilizing large plants as compared with producing the same output through fuller utilization of smaller plants.

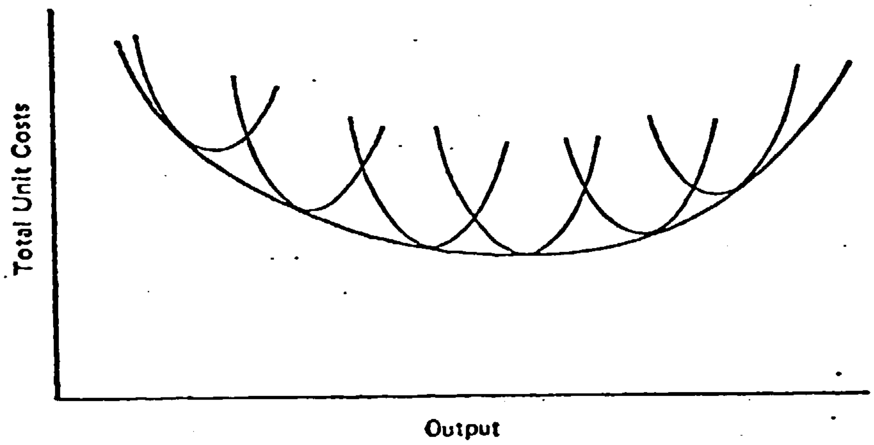


Figure 1: Theoretical Effect of Increasing Scale on Total Unit Costs

Such elementary economic concepts have been widely diffused among engineers, businessmen and government officials, and may well have encouraged receptivity towards proposals for continuing increases in scale. Unfortunately, however, analysis offers but limited support for any of these assumptions.

The vulnerability of the first assumption on theoretical as well as empirical grounds has been dealt with at length elsewhere. Analysis of its underlying assumptions, and an examination of actual cost behavior in a large sample of industries, suggested three conclusions: that variations in capacity utilization rates may be accompanied by a wide range of adjustment patterns in total unit costs, even within the narrow purview of static economic theory; that the U-shaped cost function need not be the most common among these; and that the likelihood of its occurrence tends to decline rapidly as the restrictive assumptions of static analysis are progressively relaxed.(9) At any rate, this is the least important of the assumptions for present purposes, although the frequent empirical finding of constant marginal and average total unit costs certainly poses problems for the relevance of short term cost curves and for the estimation of long run cost curves which are tangent to them.(10)

Analysis suggests that the second assumption is rooted in three deeper assumptions. One is that production facilities are available in only a few widely differing sizes -- a claim with little practical relevance in view of the general availability of major capital equipment and facilities in a wide range of sizes. A second is that larger capital goods yield additional economies, presumably by requiring less investment per unit of capacity. Reliance on this belief has often been buttressed by references to the supposedly hard-headed engineering literature relating to the "six-tenths rule." This holds that each doubling of capacity tends to increase investment cost by only about six-tenths.(11) Further inquiry, however, reveals that this expectation seems to have two roots: first, in the fact that volume increases more rapidly than the enclosing surface of rectangular, cylindrical, and spherical shapes; and, second, in the simple-minded assumption that the output of productive facilities is generally correlated with their volume, while their investment costs tend to be correlated with the size of their enclosing surfaces.

Such a relationship may hold, of course, in respect to some kinds of facilities, especially in respect to the construction of hollow shells, such

(9) For further discussion, see Gold [15].

(10) For example, see Committee on Price Determination [10, pp. 90-102], Johnston [32, pp. 55ff] and Walters [53].

(11) For illustrative references, proposing exponents of 0.6 and 0.7 for estimating the investment cost of larger equipment and larger plants, respectively, in the chemical industry, see Aries and Newton [2, p. 6-7, 15], Bauman [6, pp. 39, 180-181], Crowe et.al. [11, p. 110], and Peters [40, p. 93].

as tanks, furnaces, boilers, pipes, and some simple buildings. But fundamental shortcomings narrowly restrict the range of its applicability to complex production equipment. Even construction activities face increasing costs per unit of volume under conditions of increasing size (e.g., high rise buildings), strain (pressure vessels), and deteriorative forces (intensified corrosion). Much more important in manufacturing is the tendency for larger units to require intricate arrays of interconnected, precisely designed functioning components, as well as costly instrumentation, controls, and ancillary facilities. Of course, larger units of some kinds of capital goods do yield more caapcity per unit of investment cost, but this is not invariably true -- not even in respect to some of the most frequently cited examples, such as electricity-generating plants.(12) Hence, such expectations cannot serve as the foundation for a general theory unless they can be shown to be widely representative, and until reasonably persuasive answers can be provided to the original questions of why and under what conditions larger units or operations are likely to be more economical than smaller ones.

The third, of the premises underlying the second assumption, which is usually only implicit, is that the expected investment benefits of increases in scale would not be offset by accompanying increases in any other costs. But this, too, warrants more serious investigation. For example, the effective operation of larger scale units tends to require disproportionate increases in salaried personnel and costs in order to cope with the rapidly multiplying complexities of integrating an increasing array of more highly specialized tasks and equipment. Nor is it uncommon for wage rates in

(12) For example, see the range of results of David Huettner's comprehensive study of electricity generating plants [30, chap. 3]. Myles G. Boylan has shown that this is not true even in respect to blast furnaces, which tend to be regarded by nonspecialists as approximating hollow shells, [7, p. 162].

large scale plants to be higher than for comparable skills in small plants, whether because of stronger trade union pressures or other influences.(13) And increasing reliance on machinery usually requires that at least part of the reduction in direct labor per unit of output be offset by increases in indirect labor to service such equipment. Moreover, consideration must also be given to the relative magnitudes of prospective reductions in unit investment charges as compared with possible increases in wage and salary costs. For example, if total fixed capital charges approximate 10 per cent (as is the case for depreciation plus interest in the reputedly "capital intensive" steel industry),(14) investment cost per unit of capacity would have to be reduced by half through an increase in scale in order to reduce total unit costs by only 5 per cent, even if all other unit production costs remained unchanged. In short, it would require fairly heroic assumptions about the magnitude of scale economies to support expectations of even reasonably modest reductions in total unit costs on the basis of the theoretical analysis usually presented.

Attention may be turned now to the third assumption on which the usual model of the scale function, or long run average cost curve, is based. This, too, is highly vulnerable. Logic alone suggests that the greater the economies and subsequent diseconomies of successive increases in scale, the narrower the range of plant sizes that can survive under conditions of effective competition. With respect to the theoretical possibilities, engineering analyses indicate that, within the confines of "a given technology" and product-mix, most industrial processes tend to be characterized by relatively narrow zones within which input-output relationships are most

(13) For example, see Miller [38, p. 482].

(14) For cost proportions in the U.S. steel industry, see Gold [18,pp. 7,19]. and Gold et.al.[26a, p.287].

effective -- in contrast to the broad "production possibilities frontiers" assumed in the economic theory of production.(15) While these optima are not always identified at the outset, it would seem to follow that every increase in scale yielding substantial improvements in performance would tend to shift the loci of competitive plant sizes upward, instead of broadening the range within which scale economies are too small to affect long term survival. Nor has empirical evidence supported this third assumption on any broad basis. Of course, a variety of studies have reported a wide range of plant sizes within specified industry categories as defined by statistical agencies.(16) But further analysis reveals very substantial heterogeneities within most such categories with respect to the specific products made, technologies employed and factor proportions utilized, thereby voiding the claims of relevance to assess ing the significance of scale economies.(17)

Finally, the vulnerability of the three assumptions which have been reviewed also undermines both the acceptability and practical relevance of the final assumption. Specifically, it has been suggested that the U-shaped short-term total unit cost function is but one of a variety of theoretically possible and empirically demonstrated patterns, that the shape of such functions may change with increases in scale, and that the range of plant sizes actually engaged in identical production activities is likely to be quite narrow in most industries. Accordingly, although under-utilization of a given plant's capacity would often tend to involve cost penalties of some magnitude,(18) it need not follow that smaller plants could generally

---

(15) For further discussion, see Gold [19].

(16) For example, see Stigler's application of his "survivor test" to assess scale economies [50] and Shepherd's doubts about such findings [44,pp. 250-251].

(17) For example, see Gold [20].

(18) As is commonly asserted in textbooks, e.g., Hadar [29,p.17].

provide products with comparable qualitative characteristics economically for the same markets (for example, automobiles).

In short, reliance on convenient assumptions in place of exploring the realities of industrial practice renders the traditional approach of economic theory to scale economies widely inapplicable in concept and trivial in its posited effects. Indeed, it would not be unfair to summarize the latter as suggesting only that there is some optimal size of production unit for any given technology and product-mix, without specifying what it might be, or what determines it, or the magnitude of its presumed cost advantages as compared with progressively larger and smaller sizes, or how it may change.

2. Some Shortcomings of Empirical Research

Turning from theory to empirical findings, a review of this literature, too, is disappointing. Bain summarized the results of empirical studies of "The long-run relation of cost to output, or to scale of plant or firm" as "fragmentary, based on unrefined data, and substantially worthless."(19) Nearly 25 years later, Weiss' review of published research on scale led him to conclude that it is a "still fairly blank field."(20) Other extensive reviews of the literature have been equally unenthusiastic.(21) Such shortcomings are attributed partly to uncertainties concerning the appropriate measures of scale to be used, partly to inadequacies in the available data on input requirements and costs, and partly to evident weaknesses in each of the leading analytical approaches which have been used.

The single most important reason for the pervasive inadequacies of such empirical research is the overwhelming tendency to concentrate analyses at

(19) Bain [4, p. 141].

(20) Weiss [54, p. 297].

(21) For example, see Committee on Price Determination [10, pp. 243ff] and C.Smith [46, pp. 213ff]. For a recent sampling and critique of findings, see Shepherd [44, pp. 242-251].

levels of aggregation which prevent conformance with the requirements not only of theory, but of practical evaluations by industrial executives and by government officials as well. Whether motivated by a desire to establish widely applicable generalizations, or by the ready availability of published data, most such studies have been concerned with average statistical relationships in individual industries, as classified by government agencies, between plant size categories (based on product value or employment) and some measure of cost or "productivity." In view of the extensive heterogeneities among plants in most such categories,[22] however, the findings which emerge, whether on the basis of cross-sectional comparisons or on the basis of time series analyses, can seldom be ascribed convincingly to scale effects -- or even to the effects of size differences alone.

More useful insights would be provided, of course, by studies dealing with more homogeneous sectors of industry. But one must be careful to avoid imputing homogeneity on the basis of inadequate knowledge. For example, a significant proportion of scale studies have focussed on electricity generating plants, because of the seemingly maximum homogeneity of their products and basic technologies. But closer analyses have revealed a substantial list of differentiating factors other than scale which affect the performance measures of even the coal-fired subsector of such plants.[23] And a recent comparison of blast furnaces, which constitute only one stage of steel mill operations and which have likewise been considered to represent a sector of almost complete homogeneity, reveals a similarly extensive array of

(22) It may be recalled from earlier references that such differences commonly relate to product characteristics, product-mix, vintage of production facilities and equipment, extent to which purchased materials and components have been processed, labor skills and incentives, managerial capabilities, rates of capacity to utilization, factor prices and transport costs as well as various financial and marketing characteristics.

(23) For an extensive summary of the literature on scale effects in electric power generation followed by a detailed analysis of the factors affecting apparent scale differences, see Huettner [30, Chapters 2 and 3].

factors, other than scale, which have a significant bearing on their physical as well as on their cost performance.[24]

Even more serious from the standpoint of improving our understanding of the concomitants of changes in scale or size is the seeming lack of interest of most researchers in trying to identify: the changes in structural and operating characteristics associated with such progressive increases in operating units; and also how each of these contributes to or diminishes resulting returns. Instead of such efforts to uncover the specific analytical linkages by means of which changes in scale or size engender changes in various performance attributes, most studies convey a dominant concern merely with the essentially descriptive task of determining the average relationships between two sets of variables. These results are then often supplemented by seemingly logical, but almost invariably untested, speculations about what might account for them.

Even the obvious question of the relationship between changes in scale and size is rarely raised, thus avoiding even the first step in seeking to build some kind of bridge between the theory focussed solely on the former and the empirical research centered on the latter. Increases in scale are obviously one of the possible reasons for increases in the size of plants. Other reasons may include further vertical or horizontal integration as well as various forms of proliferating products or functions. Although it is difficult to see how one might generalize effectively about such a mixed array of possible adjustment patterns, it would seem useful to develop theoretical models dealing with the prospective productivity and cost effects

(24) Another review of the scale literature followed by a detailed study of the factors associated with scale differences in the U.S. blast furnaces is provided by Boylan [7]. In order to compare the performance of different blast furnaces, he found it necessary to penetrate to still deeper levels of technological differences. [8, pp. 363-414].

of at least the first two of these as a basis for focussing research on these components of changes in size, thus reducing the heterogeneous residual about which few meaningful analytical insights can be provided.(25)

The preceding comments concern the two research approaches using aggregate data for groups of plants, firms or industries: statistical cost or production functions; and the analysis of relative survival rates. In order to avoid their recognized shortcomings, other analysts have turned to using engineering estimates of the probable effects of successive increases in scale beyond current experience. Pioneering efforts by Chenery [9] and Bain [5] were given their widest and most penetrating application by Pratten [37], who studied 25 industries in the United Kingdom in varying degrees of depth. By relying on the judgments of qualified technical specialists, this approach gains several important advantages over statistical analyses. The most important of these would seem to be: sharply defined foci relating to the products covered, the technologies used and the level of processing at which materials and supplies are purchased; and expert knowledge of the modifications recently or currently under consideration. Thus, estimates can be directed to prospective scale effects in particular and are generally much more valuable than the results of statistical studies for such purposes.

But engineering estimates are also subject to certain shortcomings which seriously limit their usefulness for policy purposes. Perhaps the most important of these is that most of the specialists consulted are likely to have very limited expertise in respect to estimating the prospective results of substantially larger scales than have already been experienced. In most

---

(25) For example, a promising start was offered by Adelman quite some time ago, but its development has been relatively slight. [1p. 281ff].

industries, scale potentials have been considered only within relatively narrow zones beyond such borders. And most such estimates have apparently been based primarily on extrapolations of current experience rather than on serious research. One indication of the potential vulnerability of resulting estimates, and of the analytical insights on which they are based, is the inadequacy of such estimates even of the effects of past scale and technological changes.(26)

In looking ahead, estimates of potential further gains tend to be inhibited by: awareness of the unexpected difficulties that may lie beyond current practices; (27) a bias in favor of defending their existing facilities, especially if they do not expect to build new facilities in the near future;(28) and widespread experiences with the difficulties and costs of gaining labor acceptance of changes in manning levels and operating practices. It is also worth noting in this connection that, when engineering and construction firms are asked for advice on gaining economies through increases in scale, their recommendations most commonly propose only modest increases beyond available experience rather than providing authoritative evaluations of successively greater increases in scale. They, too, recognize that many unexpected difficulties may lie beyond

---

(26) No major studies of such capabilities are known to us. But a number of evidences of such inadequacies have turned up as peripheral by-products of our field research. For example, see Gold [17] and Gold et.al. [28a]

(27) For example, in one of our studies, we found that the central engineering staff of a very large corporation which had had to build a series of plants to meet demand refused to build larger ones on the grounds that the established size was optimal -- although each of the plants completed in recent years had had to be enlarged subsequently.

(28) It may not be amiss in this connection to compare the minimal estimates of the prospective gains from scale and technological improvements in the U.S. steel industry by the Council on Wage and Price Stability, and the long continued insistence of industry spokesmen that it is technologically equal to the best, with estimates of the superior performance levels already achieved by the major Japanese steel mills, Gold [21].

established scale frontiers -- and, as design and construction rather than research organizations, they are unwilling to assume such responsibilities unless attendant risks are clearly shifted to the customer. A closely related reason is that few convincing research-based insights are available from any quarter as yet for estimating the effects of major changes in the scale of most industrial processes.

Because of the concern of economists, especially in the United States, with preventing levels of industrial concentration which would tend to curtail competitive pressures, empirical studies have increasingly shifted their objectives from seeking to determine the effects of progressive increases in scale, or the minimum point of the long run cost curve, to identifying what is called the "minimum efficient scale" in particular industries. This is defined as the plant size beyond which the downward slope of the long run cost curve becomes so small as to yield only retively insignificant economies to substantial further increases in scale.(29) Because these represent essentially engineering estimates of such effects, they are subject to each of their shortcomings which were mentioned above. But these M.E.S. estimates are rendered even more vulnerable by the fact that engineering estimates represent rapidly decreasing expertise as they are expected to assess the effects of scale increases substantially beyond available experience -- including the technologies and facilities employed as well as changes in product requirements and input availabilities. In short, little confidence is warranted in their implied estimates of the slope of the long run curve and, hence, in their estimates of the point beyond which, and before which, further scale benefits would become

(29) Leading examples include Bain [5], Pratten [41] and Weiss [55].

insignificant.[30] Indeed, they may reflect little more than the restrictions placed on engineering horizons by past performance, recent and prospective limitations of capital availabilities and expected market demand-patterns.

III ON THE REDEFINITION OF SCALE

In contrast to the preceding theoretical and empirical perspectives on sources and effects of increases in scale, it is odd to discover that the causes of increasing returns from larger operations were clearly recognized long ago. Adam Smith is permanently identified, of course, with calling attention to the contributions of increases in the division of labor as production is expanded. But he also noted that such sub-divisions of tasks into simpler, repetitive units helped to engender the development of machinery to replace manual efforts.[31] Thus, his penetrating insights encompassed not only the re-organization of tasks to take advantage of the benefits of greater specialization in all production activities, but also three interacting concomitants: changes in the skill composition as well as in the relative volume of labor inputs; changes in the technology of production; and shifts in the proportions of labor and capital inputs.

In addition to joining in such views, Babbage also recognized the associated opportunities, and pressures, to increase the specialization of various other functions -- including maintenance, technical improvement efforts and management -- and to keep developing better and still more specialized machines as the basis for achieving further gains in efficiency as production is expanded.[32] Moreover, he warned that increasing

(30) Gold [23, p. 24].

(31) Smith [45 Book I, pp. 12-16].

(32) Babbage [3, Chap. XXII, pp. 212-224].

capacity beyond the optimal extension of specialization, by duplicating such arrangements, would not yield further economies.

In short, even such early explorations of the potential sources of increasing returns from the progressive expansion of factories identified most of those which are recognized today. Moreover, they recognized the fundamental interactions between increases in output and increases in the specialization of functions -- including changes in technology, in the organization of production, and in all input factor proportions. Astonishingly, however, such early insights have not been more fully explored in the later literature of economics, engineering and management. Indeed, sight seems to have been lost of some of them from time to time.(33)

By-passing the aridity of later discussions of the role of the "divisibility" of capital goods as a determinant of scale economies,(34) -- in view of the general availability of major capital equipment and facilities in a wide range of sizes -- an analysis of industrial experience emphasizes that the economies offered by the increasing division of labor tend to be subject to dimiinishing returns after employment levels reach a few hundred and frequently less. Hence, efforts to achieve further major economies tend to concentrate on utilizing <u>more</u> capital facilities and <u>more highly specialized</u> capital inputs as well as on improving the effectiveness of their integration and utilization.

Accordingly, the concept of scale needs to be redefined as "the level of planned production capacity which has determined the extent to which specialization has been applied to the subdivision of the component tasks and facilities of a unified operation."(35)

---

(33) Gold [23, pp. 11-13].

(34) <u>Ibid</u>. pp. 7-10.

(35) For fuller discussion, see Gold [14, pp. 115-117].

This definition offers an operational basis for differentiating "scale" from "size", for it recognizes that increases in size involving a comparable proliferation of activities, or involving mere duplication of smaller scale relationships, may yield no production economies at all. It also offers a practical approach to measuring differences in scale, in addition to identifying the primary means whereby managements may seek to gain the benefits of changes in scale. In this connection, it is important to realize that plant designs are derived from initial decisions concerning the planned level and composition of outputs. Such commitments provide the basis initially for evaluating the potential economies of the alternative relevant technologies; and then for evaluating the optimum levels of scale for each stage of production activities, including the level of processing to be required of purchased materials and components -- in agreement with the definition's omission of concern for maintaining fixed factor proportions. The scale of production might accordingly be increased even by building a plant which is no larger, but which can utilize higher levels of specialization through producing a narrower range of more standardized products. Thus, determinations of the most beneficial levels of specialization are integrally related to planned output capabilities, thereby demonstrating the conceptual coherence as well as the realism of the suggested redefinition of scale.

Even this redefinition cannot be used to evaluate the past or prospective effects of scale except in conformity with three restrictions, which have been clearly implied all along but often ignored. First, scale comparisons must be restricted to plants making products and product-mixes which are regarded by markets as similar enough to be competitive. This excludes comparisons among plants which are included within many common statistical categories of industry, but which differ significantly in the specific characteristics and quality grades of their products as well as in their product arrays. Determinations of the relative costs of plants producing different products, selling at different prices, to quite different market segments does not seem meaningful, however convenient it may be to use such aggregative statistics.

Second, scale comparisons must exclude plants which differ substantially in the levels of processing and fabrication undergone by the purchased materials and components entering into their own production operations. There are obviously important differences in the "productivity" and costs of plants which make their own castings and product components as compared with plants which buy them -- and even value added ratios may fail to distinguish effectively between purchasing patterns involving quite different effects on labor and capital input requirements. Moreover, "make-or-buy" choices are an important element of the specialization decisions involved in defining scale objectives.

Third, the technological boundaries of scale comparisons need to be altered. Instead of including all known technologies and excluding those which represent new developments, it would seem more practical to include all changes in technology attributable to planned changes in output levels, even if not hitherto applied. But such comparisons should exclude plants using distinctively different technologies, even if these have long been in use. For example, plants producing nitrate fertilizers from coke chemicals should be differentiated from those based on petrochemicals;(36) and electricity generating plants using fossil fuels should similarly be distinguished from those using uranium. As was noted above, the consideration

(36) Chairman Fletcher Byrom of the Koppers Company once complained in an interview of being accused by the U.S. government of dominating the by-product coke chemicals industry, on the basis of Census of Manufactures data, at the same time that he was losing market share to petrochemicals, as shown by the Census of Business.

of alternative technologies is certainly relevant to managerial decisions, but such evaluations can be separated from evaluations of the effects of different levels of scale for any specified technology.

It should be recognized, however, that the effects of scale changes cannot be effectively distinguished from the effects of differences in technology on the basis of generalized definitions, except in respect to highly differentiated processes. But it is quite practicable to make such distinctions for particular sectors of industry on the basis of a thorough knowledge of relevant technologies. This is readily demonstrable through field studies of the actual evaluations entering into managerial and engineering choices among the alternative means of achieving the production capabilities of planned new facilities. Such efforts to differentiate scale from technological effects are also facilitated by the practical fact that even substantial technological changes seldom affect more than a very few stages of production; hence their effects are readily ascertainable at those points of impact. Admittedly, these insights do not offer much help to economists seeking to survey scale effects at high levels of aggregation. But such efforts have not been very fruitful anyhow.

IV DEVELOPMENTS TENDING TO ALTER PAST OPTIMAL LEVELS OF SCALE

A. Some Dynamic Aspects of the Scale Economies of Production

The effective analysis of scale potentials from the standpoint of management requires differentiating between expected advances in the effective utilization of inputs and a more fundamental emphasis on the economic effects of such improvements. Realistic consideration of such distinctions requires recognition of the need for a more dynamic analytical framework in appraising the benefits of increases in scale. Even a brief review of the pattern of changes experienced in manufacturing helps to clarify such needs.

The long continuing drive to increase the output and efficiency of manufacturing led at first to the "division of labor" and then to the introduction of essentially "general purpose" machinery to supplement labor's strength and limited speed as well as its susceptibility to fatigue. Later, machines were increasingly specialized (representing a division of tasks among machines) in order to permit the use of less skilled labor, to achieve still greater speed and precision within a narrower range of processing capabilities, and to yield even more capacity per dollar of investment, while requiring more standardized material inputs. This has been followed by the increasing use of mechanical devices and controls to enable machines to repeat complete work cycles quickly,tirelessly and exactly -- along with the increasing use of conveyers to move parts from machine to machine -- resulting in what may be called repetitive automation. Such developments reached their most advanced form in giant automobile and other continuous manufacturing plants which combine large arrays of highly specialized machines and the transfer equipment between them into tightly integrated production lines, often termed "hard automation".

These repetitive automation systems -- representing the ultimate extension of the traditional drive for scale economies through increasingly specialized manufacturing plants -- have demonstrated their capacity to produce enormous quantities of a standardized product of high quality at relatively low unit costs. And yet, they have never been applied to even one-fifth of total manufacturing operations in advanced industrial countries despite decades of experience. Moreover, the construction of such facilities has slowed very considerably in recent years. Why?

The basic reason is that the potential economies of such systems can be fully realized only if they can be operated at high levels of capacity utilization for long periods of time, thereby minimizing the cost per unit of output of the very heavy fixed investments involved. But this has proved difficult to do even in the so-called "mass production industries" to which such systems seem to be best adapted because:

1. cyclical fluctuations in the demand for such products have resulted in substantially reducing the average capacity utilization rates actually maintained over the course of business cycles; and
2. even more serious, such utilization rates have also been subject to progressive declines over time because the extremely limited adaptability of these systems has prevented effective adjustments to:
    a. customer pressures for alterations in product designs and product-mix; and
    b. changes in the quality and prices of available materials and other inputs.

Moreover, the expected economic benefits of increases in scale have also often been reduced or negated by other associated adjustments which are commonly disregarded or assumed away. For example, specialized production lines usually require tighter quality and dimensional specifications for material inputs, thereby increasing the likelihood of higher prices. Also increases in output per man-hour, because of the mechanization of some formerly manual tasks, tends to stimulate at least partially offsetting demands for higher wage rates especially in unionized plants. Effective coordination of such high volume integrated operations generally necessitates increases in salaried staff concerned with production planning and control as well as inventory management, along with increases in the maintenance staff in order to minimize the rapidly spreading interruptions to production threatened by stoppages at any point within continuous production sequences.

Thus, contrary to the once pervasive belief that the economies of large scale manufacturing would increasingly preclude effective competition from small and medium-sized plants, the latter have remained dominant in most sectors of industry all over the world, while the sectors dominated by large scale plants are actually receding.[37] This has re-awakened interest in exploring the potential competitive advantages of small and medium-size plants especially in the face of changing market opportunities, newly emerging technological capabilities and alterations in the international structure of manufacturing.

B. Product and Input Factor Market Pressures on Scale

One of the most important developments tending to alter past estimates of the optimal levels of scale is increasing evidence that the cost and price advantages of standardized products made in enormous volumes is giving way in consumer and in industrial markets to a greater emphasis on product differentiation. Rising standards of living have enabled increasing numbers of consumers to seek out products whose design and service capabilities are more responsive to changing individual tastes and local needs. And advances in the sophistication of manufacturing operations have similarly led to more distinctive specifications in the procurement of materials, components and equipment. The result has been to increase opportunities for producers capable of searching out and responding quickly and at reasonable cost to selected components of the variety of preferences expressed in available markets, as well as to the inevitable changes in such preferences over time.

(37) For example, one of the most advanced automobile engine plants in the world was recently closed in the U.S. because of its inability to shift economically from 8-cylinder models to the smaller ones required by the market. For further discussion, see Gold [28].

Such requirements for distinctive products and for changing such offerings as frequently as necessary can be met more readily by small and medium-size plants than by large scale specialized units. And this is also likely to be true of their marketing efforts, which must identify and then keep in touch with numerous selective market niches which tend to be small and geographically scattered.

Another aspect of market changes which is especially important for appraising the competitiveness of smaller producers in developing countries is the increasing demand for a wide variety of products within their own countries as the result of long term growth trends. Although this may manifest itself at first in the form of establishment by foreign suppliers of local production units, the very viability of such units cannot but call attention to the feasibility of local production by domestic business, at the same time that it ensures the increasing availability of trained personnel who might be hired away from the foreign units.

But how well can small and medium-size plants compete with large producers in terms of production costs? The answer obviously varies by product and location as well as with the characteristics of the competition faced in particular markets.

As noted earlier, one major determinant of cost competitiveness centers around the availability and price of needed inputs. Smaller manufacturers are unlikely to have any advantage over larger producers in the advanced industrial regions in respect to purchased material prices and qualities. But the generally smaller manufacturers in developing countries may well gain substantial competitive benefits from using locally available materials and energy, especially in view of the fact that such inputs often account for 50 per cent or more of total costs. And such advantages tend to be accentuated in the case of materials and energy inputs which producers in advanced industrial countries have to import, or have to depend on lower quality, higher cost or less assured domestic supplies.

There have been major developments in this area in recent years necessitating the re-examination of past estimates of relative advantage. In part, this has been due to the enormous change in the price of oil and gas and their products. But it has also been due to changes in industrial demand for various metals and other minerals, along with the depletion of past major sources.

In respect to labor inputs, producers in developing countries have long suffered disadvantages in respect to labor skills. But the extent of such skill deficiences seems to be declining rapidly, while their relative wage rate advantages remain substantial -- often 50-75 per cent and even more. And similar tendencies seem well established in respect to the availability, capabilities and salaries of mangerial and technical personnel.

As for the remaining critical input -- capital investment -- this is obviously in much shorter supply and tends to be more costly than in advanced countries. But more is likely to be available than ever before, and successful allocations stimulate additional supplies in the absence of unusual risks or active deterrents.

C. Technological Pressures on Optimal Levels of Scale

The preceding discussion has suggested some reasons why the competitiveness of small and medium manufacturers in developing countries has been improving and is likely to keep improving, albeit slowly. But attention should be called to certain emerging technological developments which may accelerate this process very substantially.

One of these involves the relatively belated intensification of research and development focussed on increasing the efficiency of smaller scale production processes. For example,"mini" steel mills, with annual capacities of 200,000 to 400,000 tons, can be built with 15-20 per cent of the capital requirements per ton of capacity of large integrated mills, can require only half as much manpower per unit of output and can consume only a fraction of the energy.(38) Low density polyethelene plants using new low temperature processes can similarly be built in small units which are highly competitive with much larger ones. This is an area, however, which has been relatively neglected in the past partly because the dominance of industrial research by large companies was inevitably focussed otherwise, and partly because the long unquestioning faith in the economies of increasing scale discouraged efforts to explore means of restoring the competitiveness of smaller scale operations.

One of the technological developments with the greatest implications for the competitiveness of small and medium-scale manufacturers over the next 10-20 years has been the emergence of programmable automation, which enables them to gain much of the advantages of mechanically automated production without the costly rigidities reviewed earlier. The simplest forms of programmable automation are programmable robots and programmable controllers which may be attached to individual machines. More advanced forms involve the computerized control of progressively broader sectors of production operations.

Of course, most developing countries seek to grow and to gain competitive advantages through increasing utilization of their commonly underemployed and low-wage labor forces. And concentration on such means is certainly warranted so long as it furthers the objectives sought. But when continued economic growth requires even greater productivity, higher and more consistent product quality, and still lower labor costs,

---

(38) For further discussion, see [25].

manufacturers -- whether large or small, and whether in advanced or in developing industrial countries -- may have to consider advances in technology.

Robots offer one such option. They can be readily re-programmed and re-tooled to perform a variety of tasks -- including materials handling, servicing machine operations, welding, painting, assembling, inspecting and packaging -- in the production of small as well as larger batches of a changing array of products. They may be used to free labor from physically taxing jobs and from hazardous working enviroments. More to the point of economic benefits, they can help maintain consistently higher quality through tireless repetition of precise operating routines while reducing total labor requirements and costs.(39)

But far greater benefits to small and medium-scale manufacturers are offered by progressively more comperhensive computer-assisted manufacturing (CAM) systems. First, they permit entire production lines to shift rapidly from producing one product to numerous others by merely replacing the instruction tapes in the computer -- thereby increasing the cost effectiveness of smaller product runs. Secondly, CAM also permits a given production line to adapt to the inevitable changes over time in product design and product-mix as well as input availabilities and prices, thus increasing the effective utilization rate and economic life of capital facilities as compared with highly specialized hard automation systems. In addition, CAM also provides the basis for a hitherto unprecedented degree of integration of all stages of operation from design through testing, and even including production planning and control.(40)

(39) For further discussion, see Gold [25].

(40) For further discussion, see Gold [24].

Thus, CAM"s prospective contributions to increasing the competitiveness of small and medium-scale producers is apparent. But because it is a recognizedly advanced form of technology, its applicability to developing economies has been questioned. One must, of course, recognize that the applicability of CAM systems to an increasing array of industries is still being developed, along with assessments of resulting incremental benefits relative to the costs and risks involved. In industries where its applicability has been proved, however, CAM's diffusion to developing economies may well prove to be more rapid than has been true of past sophisticated technologies.

Instead of requiring each producer to develop the specific tooling and production methods needed to make a specified product, transmission of the instruction tapes for guiding identical machines can result in a rapid duplication of the products turned out on the original production line -- with minimal re-education of the technical personnel and minimal retraining of operators. This would help to reduce the barriers of inadequate labor skills and spcialized technical expertise which would otherwise tend to prevent or delay producers in a developing country from sub-contracting the production of parts for assembly elsewhere. Moreover, the diffusion of computer-aided manufacturing would help to reduce the proportion of the labor force needing high levels of skills in order to accelerate development of a country's industrial capabilities.

A related area of technological advances which tends to improve the competitiveness of small and medium-scale producers in developing as well as in developed industrial countries involves advances in measuring and control devices. These can substantially improve the ability of new producers to meet required quality standards at home or abroad, despite some differences in labor skills.

D. Decentralization of Manufacturing Operations

The preceding technological advances have made two major contributions to the domestic and even international decentralization of manufacturing operations: facilitating the realization of greater standardization; and also helping to increase the productive efficiency of small and medium-scale plants. In turn, these potentials have encouraged responsiveness to any special regional advantages in respect to the supply, quality and prices of needed inputs as well as attractive market prospects and favorable governmental relationships. Another motive for reliance on smaller and more widely separated production units has been the desire to minimize the impact of local disturbances or problems.

The term decentralization is not meant to be limited to the process whereby the already centralized manufacturing operations of a large firm is gradually subdivided into smaller units which are geographically dispersed. Rather it is also intended to encompass the increasing array of instances in which producers in developing areas search out domestic or foreign needs for certain components or finished products and proceed to produce them effectively enough to become a part of the international network of manufacturing operations whose capabilities are integrated by shifting trade patterns to provide the changing array of final products demanded by markets all over the world.

V, APPROACHES TO EVALUATING OPPORTUNITIES FOR INCREASING THE COMPETITIVENESS OF SMALLER SCALE OPERATIONS

Programs seeking to improve the cost competitiveness of smaller scale manufacturing plants should be based on careful diagnoses of the key opportunities and pressures likely to emerge over the next 3-5 years, rather on analyses of current conditions,because the latter may well change substantially by the time the newly planned facilities come on stream. Such a caution is suggested by the not uncommon temptation of decision-oriented industrial executives and government officials to substitute optimism in place of analysis and action in place of thought.

Such diagnoses should center around several interacting tasks, including:

1. selection of promising product and market targets;
2. evaluation of alternative technological innovations which would significantly enhance the productive efficiency of newly planned smaller scale local plants;
3. estimation of the potential production cost advantages and disadvantages of such plants relative to probable competitors in each market;
4. appraisal of the availability and cost of the capital required to provide such plants and the time required to achieve reasonable returns on such investments; and
5. analysis of other social by-products of such undertakings, including their effects on employment levels, skill development, support for other local industries and foreign trade balances.

Logical though it may sound, a comprehensive search covering all product and market targets is impractical. In seeking to narrow such efforts, attention might usefully be concentrated in three areas. The first encompasses conventional products and markets in which the competitiveness of long established producers has been progressively undermined by unchanging products, aging facilities and lagging technologies, or by increasing disadvantages in respect to the supply, quality and prices of needed materials, or the productivity and wage rates of labor. The second would cover domestic markets supplied by imports, but which enjoy favorable growth prospects and hence provide attractive opportunities for domestic firms to compete for increasing market shares on the basis of such factors as: greater sensitivity to local tastes; access to advantageous local inputs; more rapid responses to changing local conditions; and lower transport costs. And a third would relate to the development of export as well as domestic markets for products utilizing scarce or relatively cheap local resources whose sales potentials are expanding rapidly because of emerging technological developments.

Because of the pervasive belief in the inherent economies of larger and more highly specialized plants, and because of the dominance of research on manufacturing methods by the larger industrial firms, most developmental efforts have been focussed on extending scale frontiers and learning how to utilize them more effectively. But, as was noted earlier, recent disappointments with resulting average utilization rates and production costs have re-directed performance improvement efforts towards identifying and harnessing the technological means of increasing the competitiveness of smaller scale operations through the development of more flexible processing methods and equipment. Such facilities can be located closer to regional market centers and better adapted to localized product specifications and input supplies. This represents the opening of a wide array of opportunities which are still in the process of exploration as they come to be recognized by producers in developing countries as well as by process and equipment manufacturers seeking new markets.

In appraising the potential advantages of proposed innovative processes and associated smaller scale operations, decision-makers need an analytical framework which facilitates tracing the probable effects of changes in production methods beyond productivity levels to costs and even profits.

Chart I presents part of a framework which has been found useful for these purposes in a wide array of industries. It covers the "network of productivity relationships". This emphasizes that attention must be given not only to the volume of each input required per unit of their joint product, but also to changes in the proportions in which the various inputs are combined.(41) Specifically, increases in output per man-hour are commonly attributable to utilizing machinery to replace part of the productive contributions formerly made by labor -- or to buying more highly processed materials and components which similarly reduce labor's role in remaining processing or fabrication ooerations. In either case, changes in any of the 6 links in the network requires tracing repercussions through the entire system to ensure its effective re-integration. For example, mechanizing some manual operations would tend to increase output per man-hour and to reduce capacity relative to fixed investment, in addition to possibly altering unit material requirements as a result of reduced scrap and reject rates -- thereby changing factor proportions as well.

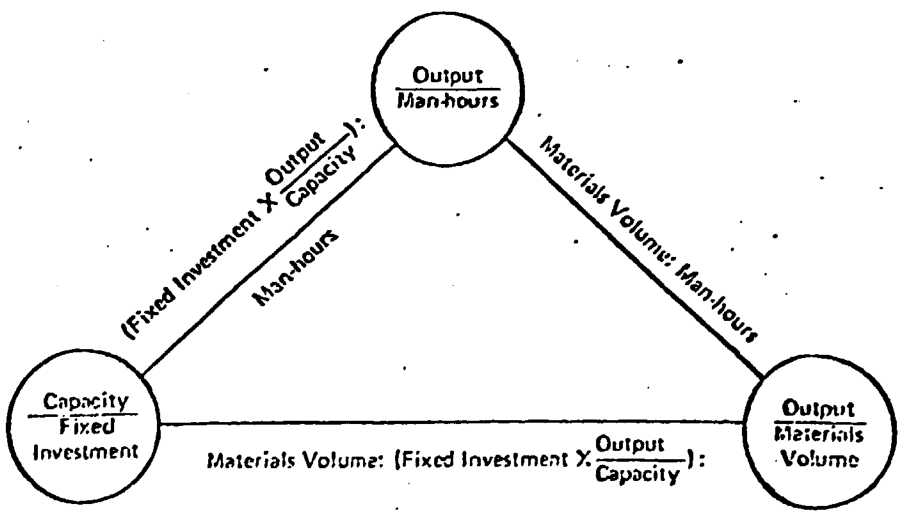
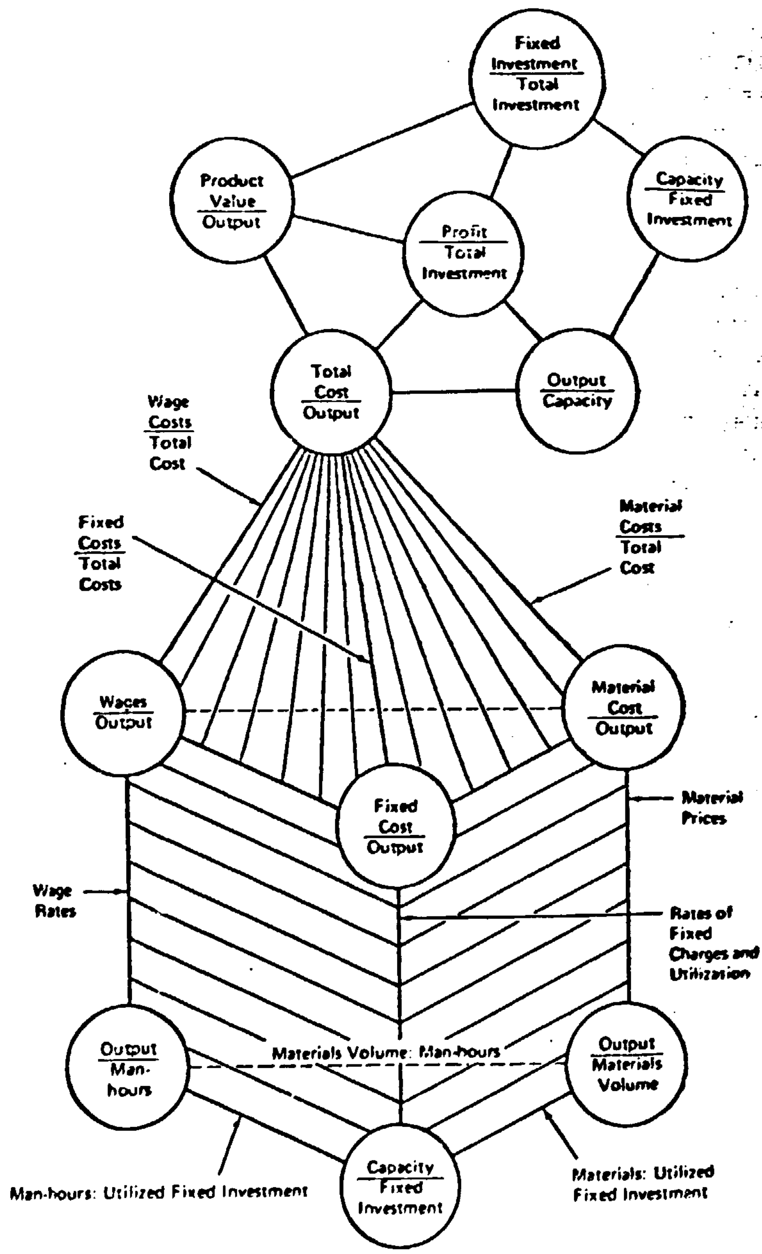


Figure 1: The Network of Productivity Relationships among Direct Input Factors

(41) Incidentally, fixed investment is compared with the productive capacity which it provides rather than with actual output because the latter is affected by variations in the degree of idleness due to fluctuations in sales.

In order to explore the prospective effects of such changes in productivity relationships on unit production costs, attentions must be turned to accompanying changes in the prices of these input factors, as shown in Chart 2. Contrary to the common assumptions of technical specialists, such prices tend to interact with their qualitative capabilities or perceived contributions to output. For example, decreases in man-hours per unit of output are commonly interpreted by labor as evidences of increases in their productivity and, hence, as justification for higher wage rates.



Source: Reprinted with permission from *Omega, International Journal of Management Science* 1 (February 1973). ©Pergamon Press, 1973.

Chart -2. Productivity Network, Cost Structure, and Managerial Control Ratios

Higher quality or more highly fabricated materials and components also tend to command higher prices. Thus, the unit cost of each input is determined by the pr of change in its price as well as in the quantity required per unit of output. And the effect of resulting changes in each unit cost on total unit cost also depends on their respective cost proportions. These vary widely among industries, averaging in U.S. manufacturing industries about 56-60 per cent of product value for purchased materials and supplies, 15-20 per cent for direct wages, and 4-5 percent for salaries, leaving the rest to cover other costs and profits.

Thus, a 10 per cent increase in output per man-hour, if accompanied by an increase in hourly wage rates of only 5 per cent (an unusually favorable response according to extensive studies), would reduce unit wage costs by 5 per cent. But if such wages account for 20 per cent of costs -- as indicated above -- total unit costs would tend to decline by only 1. Even this sharply diminished benefit may be unavailable, however, for one must now ask how the gain in output per man-hour was achieved. If it involved the purchase of higher-priced materials or the introduction of more capital goods, their effects on their respective unit costs would have to be weighted by their respective cost proportions to determine result changes in total unit costs. Thus, the cost effects of technological innovations often deviate from expectations based only on anticipated changes in physical productivity relationships.

But neither is reducing total unit costs the primary objective of private firms, as shown in the upper level of Chart 2. Changes in the rate of profits on total investment, its fundamental criterion of performance, are the product of changes in five <u>interacting</u> factors: product prices less total unit costs determ average profits per unit of output; and the other factors include the proportion total investment allocated to fixed investment, the productive capacity provided that fixed investment, and the rate of capacity utilization.(42) It must be recognized therefore, that technological advances may also improve product capabilities, which may permit the firm to increase prices or to expand market share,in addition to affecting total unit costs, capacity utilization and the productive capabilities of its capital facilities. (43)

Thus, Chart 2 underlines the point made earlier that management planning must consider:

1. prospective changes during the next 3-5 years in the availability and prices of needed inputs and their resulting pressures on costs;
2. potential effects of prospective technological innovations on productivity and costs, as well as on product attractiveness and resulting product prices and sales; and
3. accompanying efforts by competitors to improve products and cost effectivene

Our extensive research on the development and utilization of major technological innovations also offers three additional suggestions to management. To begin with, maintaining technological competitiveness requires a continuing program of upgrading rather than some single surge effort. It must also be recognized that learning to extract the fullest potential contributions of major technological advances to a plant often takes several years or longer. Hence, capital budgeting evaluations of such investment proposals must reach far beyond the criterion of "net present value", which is widespread in advanced industrial countries.

---

(42) $$\frac{\text{Profit}}{\text{Total Investment}} = \Bigg(\underbrace{\frac{\text{Product Value}}{\text{Output}}}_{\text{Average Product Prices}} - \underbrace{\frac{\text{Total Cost}}{\text{Output}}}_{\text{Total Unit Costs}}\Bigg)\underbrace{\left(\frac{\text{Output}}{\text{Capacity}}\right)}_{\text{Capacity Utilizatio}}\underbrace{\left(\frac{\text{Capacity}}{\text{Fixed Inv't}}\right)}_{\text{Productivity of Fixed Investment}}\underbrace{\left(\frac{\text{Fixed Inv't}}{\text{Total Inv't}}\right.}_{\text{Internal Allocatic of Inv't}}$$

(43) For fuller discussion, see [22 , Chapters 4,5 and 6] and so Eilon et.al. [12].

This method involves calculating the expected profits to be contributed by the innovation during its years of use and discounting such returns back to the present at, say, 20-30 per cent annually for comparison with the required investment. But this means that virtually every major innovation which cannot be purchased, installed, de-bugged and brought to a high level of utilization within less than 2-3 years is likely to be rejected in comparison with simply putting the investment into loan market funds. Successive rejections of such innovations, however, can only ensure a progressive decline in competitiveness as existing facilities fail to keep pace with the adoption by other producers of equipment which is not only more advanced but also better adapted to the inevitable changes in product designs and product-mix. Evidence of such deteriorative effects on competitiveness abound in a variety of major industries.

Accordingly, increasing consideration may have to be given instead to what I have called "a continuing horizons approach."(44) This involves evaluating proposals not only in terms of net present value, but also in terms of the probable results of current decisions to adopt or not adopt on operating results two, four and perhaps even six years from now. Such an approach also requires estimation not only of the future profitability offered by innovations, but also of the continued and increasing lag in competitiveness likely to result from rejecting prospective innovations -- especially if competitors should decide to adopt them. The point being emphasized is that, if rejecting technological advances which are unlikely to yield attractive net present values within 2-3 years ensures progressive declining competitiveness, and if the major advances needed to ensure continuing competitiveness require more than 2-3 years to come to profitable fruition, then reliance on longer time perspectives is

---

(44) See Gold [27].

essential if prospective innovations are to be evaluated within the context of ensuring continuing competitiveness, instead of concentrating solely on net present value.

VI CONCLUDING NOTES

Prevailing conceptions of scale economies continue to be based largely on past beliefs combined with a limited, and far from representative, array of empirical findings. Neither provides a persuasive basis for evaluating the future competitiveness of small and medium-scale in almost any industry -- even such traditional sectors of increasing scale as steel, electric power generation and chemicals. After all, manufacturing output has been dominated by small and medium-size plants even in advanced industrial countries. And the trend toward larger scale operations which flourished up to the last five years or so seems to be receding in the very industries in which it was most pronounced. Key factors in this reversal have included an accelerated rate of technological advances, major changes in the availability and cost of inputs, increasing market pressures for product differentiation, the rapid development of hitherto less industrialized countries and increasingly aggressive competition throughout world markets.

In this tumultuous environment, it would be extremely hazardous to identify the industrial sectors in which the competitiveness of smaller scale plants would be likely to grow most rapidly. Excellent surveys of general possibilities are available,[45] of course, but practical decisions must be more precise than merely targeting the electronics or pharmaceutical or automated machinery industries. Indeed, it would be fundamentally unsound to imply that all countries face similar practical options

(45) For example, see UNIDO [51].

instead of recognizing that the success of each country's programs will depend above all on choosing the particular product and market niches which are most likely to maximize its specialized natural resource advantages, human capabilities and available capital. In fact, widespread concentration on the same product and market sectors is likely to ensure a high ratio of failures, especially in respect to gaining shares in international markets. On the other hand, there are numerous sectors within virtually every category of industries in which small and medium scale plants can achieve effective competitiveness. It should also be borne in mind, however, that the initial success of any such undertaking may erode over time unless it remains alert to needed responses to changing competition and opportunities.

Before concluding, it is important to recall attention to the important warning presented in the first section of this paper. Appropriate scale can indeed make significant contributions to the competitiveness of manufacturers in developing countries. But such contributions will seldom suffice. After all, reducing the cost of products facing declining market demand is unlikely to safeguard profitability. Nor will product improvements yield their full potential benefits if they are poorly marketed. In short, gains in the competitiveness of production costs through adjustments in scale or other means must be reinforced by the other essential determinants of economic success: effective planning, procurement, marketing, distribution and servicing as well as sound and adequate financial capabilities.

REFERENCES

[1] M.A. Adelman, "Concept and Statistical Measurement of Vertical Integration" in [49].

[2] R.S. Aries and R.D. Newton, Chemical Engineering Cost Estimates (New York: McGraw-Hill 1955).

[3] Charles Babbage, On the Economy of Machinery and Manufactures (London: Charles Knight, Third Edition Enlarged, 1833).

[4] J.S. Bain, "Price and Production Policies" in [13].

[5] ________, Barriers to New Competition (Cambridge, MA: Harvard University Press, 1956).

[6] H.C. Bauman, Fundamentals of Cost Engineering in the Chemical Industry (New York: Reinhold, 1964).

[7] M.C. Boylan, Economic Effects of Scale Increases in the Steel Industry: The Case of U.S. Blast Furnaces (New York: Praeger, 1975).

[8] __________, "Exploratory Evaluations of Major Technological Innovations: Blast Furnaces in [26a].

[9] H. Chenery, "Engineering Production Functions", Quarterly Journal of Economics, November 1949.

[10] Committee on Price Determination, Cost Behavior and Price Policy (New York: National Bureau of Economic Research, 1943).

[11] C.M. Crowe et.al., Chemical Plant Simulation (Englewood Cliffs, N.J.: Prentice-Hall, 1971).

[12] S. Eilon, B.Gold and J.Soesan, Applied Productivity Analysis for Industry (Oxford: Pergamon, 1976). Russian translation: Ekonomika, Moscow, 1980. Chinese translation: The Technical Economy and Modernization of Management Institute, Beijing, 1982.

[13] H.S. Ellis (ed.), A Survey of Contemproary Economics, Vol I(Homewood, IL: Richard Irwin, 1948).

[14] B. Gold, Foundations of Productivity Analysis (Pittsburgh, PA: University of Pittsburgh, 1955).

[15] _______, "New Perspectives on Cost Theory and Empirical Findings," Journal of Industrial Economics, April 1966. Reprinted in [16].

[16] _______, Explorations in Managerial Economics: Productivity, Costs, Technology, and Growth (London: Macmillan, 1971 New York: Basic Books, 1981) Japanese translation: Chikura Shobo, 1977.

[17] _______, "Evaluating Scale Economics: The Case of Japanese Blast Furnaces," Journal of Industrial Economics, September 1974. Reprinted in [22].

[18] _______, "Tracing Gaps Between Expectations and Results of Technological Innovations: The Case of Iron and Steel," Journal of Industrial Economics, September 1976. Reprinted in [22].

[19] _______, "Interactions Between Technological Innovations and Factor Prices," Revue d'Economie Industrielle, Spring 1978. Reprinted in [22].

[20] _______, "Some Shortcomings of Research on the Diffusion of Industrial Technology" [42]. Reprinted in [28a].

[21] _______, "Steel Technologies and Costs in the U.S. and Japan," Iron and Steel Engineer, April 1978. Reprinted in [22].

[22] _______, Productivity, Technology and Capital (Lexington, MA: D. C. Heath-Lexington Books, 1979, 1982).

[23] _______, "Changing Perspectives on Size, Scale and Returns: An Interpretive Survey," Journal of Economic Literature, March 1981.

[24] _______, "Improving Managerial Evaluations of Computer-Aided Manufacturing (Washington: National Research Council, December 1981). Also see the author's "Computer-Aided Manufacturing Sets New Rules for Production," Harvard Business Review, November-December 1982.

[25] _______, "Pressures for Restructuring the World Steel Industry: A Case Study of Challenges to Industrial Adaptations," Quarterly Review of Economics and Business, March 1982. Italian translation: L'Industria: Rivista di Economia e Politica Industriale (Bologna), July-September 1982.

[26] _______, "Robotics, Programmable Automation and International Competitiveness," Transactions in Engineering Management of the Institute of Electrical and Electronic Engineers, November 1982.

[27] _______, "Revising Capital Budget Methods to Improve the Competitiveness of Manufacturing Industries," Proceedings of the Conference on Manufacturing Productivity Solutions, 1982. (Dearborn, MI: Society of Manufacturing Engineers, 1983.

[28] _______, "Manufacturing Technology," in [36].

[28a] B.Gold, G.Rosegger and M.G. Boylan, Evaluating Technological Innovations: Methods, Expectations and Findings (Lexington, MA: D.C. Heath - Lexington Books, 1980).

[29] J. Hadar, Mathematical Theory of Economic Behavior (Reading, MA: Addison-Wesley, 1971).

[30] D. Huettner, Plant Size, Technological Change and Investment Requirements (New York: Praeger, 1974).

[31] M.D. Intriligator (ed.), Frontiers of Quantitative Economics (Amsterdam: North Holland, 1971).

[32] J.Johnston, Statistical Cost Functions (New York: McGraw-Hill, 1960).

[33] R.G. Lipsey and P.O. Steiner, Economics (New York: Harper & Row, Third Edition, 1972).

[34] E. Mansfield, Economics (New York: Norton, Second Edition, 1977).

[35] R.T. Masson and P.D. Qualls (eds.), Essays in Industrial Organization in Honor of Joe. S. Bain (Cambridge, MA: Ballinger, 1976).

[36] H.B. Maynard and R. W. Christian (eds.), Handbook of Business Administration (New York: McGraw-Hill, 1983).

[37] C.R. McConnell, Economics (New York: McGraw-Hill, Sixth Edition, 1975).

[38] E.M. Miller, "The Extent of Economies of Scale: The Effects of Firm Size on Labor Productivity and Wage Rates," Southern Economic Journal, January 1978.

[39] J.R. Moroney, "Economics of Scale in Manufacturing," in [52].

[40] M.S. Peters, Plant Design and Economics for Chemical Engineers (New York: McGraw-Hill, 1958).

[41] C.F. Pratten, Economies of Scale in Manufacturing Industry (Cambridge, MA: Cambridge University Press, 1971).

[42] M. Radnor, I.Feller and E. Rogers, The Diffusion of Innovations: An Assessment (Evanston, IL: Northwestern University, 1978).

[43] P.A. Samuelson, Economics (New York: McGraw-Hill, Ninth Edition, 1973).

[44] W.G. Shepherd, The Economics of Industrial Organization (Englewood Cliffs, N. J.: Prentice-Hall, 1979).

[45] Adam Smith, Wealth of Nations (London: Strahan and Cadell, Sixth Edition, 1791).

[46] Caleb A. Smith, "Survey of the Empirical Evidence on Economies of Scale", in [49].

[47] M.H. Spencer, Contemporary Economics (New York: Worth, 1971).

[48] G.J. Stigler, The Theory of Price (New York: Macmillan, Revised Edition, 1952).

[49] ___________, (ed.) Business Concentration and Price Policy (Princeton, N.J.: Princeton University Press, 1955).

[50] ___________, "The Economies of Scale", Journal of Law and Economics, October 1958.

[51] United Nations Industrial Development Organization, Appropriate Industrial Technology for Basic Industries: Monograph No. 13 on Appropriate Industrial Technology (New York: United Nations, 1981).

[52] D. Watson, Price Theory in Action (Boston, MA: Houghton Mifflin, 1969).

[53] A.A. Walters, "Production and Cost Functions: An Econometric Survey," Econometrica, January-April, 1963.

[54] L.W. Weiss, "Quantitative Studies of Industrial Organization", in [31].

[55] ___________, "Optimal Plant Size and the Extent of Suboptimal Capacity," in [35].