Part II. The Analysis of Productive Efficiency in Agricultural Marketing:
Models, Methods, and Progress
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B. C. F.
The Analysis of Productive Efficiency in Agricultural Marketing:
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Although the efficiency of the marketing system has been a matter of public interest for many years, attempts to improve it through economic research were quite limited until the passage of the Agricultural Marketing Act of 1946. This act provided an expression of official concern with efficiency, a set of broad goals, and, most importantly, money to support research. It stated, among other things, that "a sound, efficient, and privately operated system for distributing and marketing agricultural products is essential to a prosperous agriculture and is indispensable to the maintenance of full employment and to the welfare, prosperity, and health of the Nation." To aid in achieving such a system, it further declared, "it is the intent of Congress to provide for . . . continuous research to improve the marketing, handling, storage, processing, transportation and distribution of agricultural products" [3].

Measured in terms of dollars spent and reports issued, it would appear that the congressional intent has indeed been carried out. In the period since World War II the United States Department of Agriculture and the state experiment stations (with federal help) have allocated between $4 million and $8 million per year to projects dealing with efficiency in various parts of the marketing system for agricultural products.¹ The results of these expenditures are described in some seven hundred research reports and journal articles concerned with productive efficiency and a substantial number of similar publications dealing with related studies of interregional competition and pricing efficiency.²

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In this paper I describe and evaluate the contributions of the many studies of productive efficiency to the field of agricultural market analysis and to the improvement of marketing operations. More specifically, I attempt to set forth and tie together the emerging elements of theory which seem especially relevant to the study of marketing efficiency, to review and evaluate the empirical methodology that has been developed, to summarize (within broad limits) some of the major results and findings of the empirical studies, and finally to offer some suggestions about future directions and development in this type of research.

The subject matter in this review is restricted primarily to the area of productive efficiency in the expectation that efficiency of the pricing and exchange system in the competitive or structural sense will be covered in other reviews. Limitation of the scope in this manner seemed necessary because of the large amount of research activity and the extensive body of literature pertaining to the subject. Since pricing and productive efficiency may sometimes be interrelated, the boundaries imposed should be regarded as matters of convenience, not as clear delineations.

On the Meaning of Efficiency

Economists, in writing about efficiency, have been quick to point out that it is a deceptively complex concept. Waugh [95], for example, made this observation: "An unsophisticated student might make two false assumptions: first, that it is easy to define (and to measure) the efficiency of agricultural marketing; and second, that almost everyone is in favor of efficiency. Actually, the concept of efficiency is very difficult when applied to a complex problem such as the marketing of farm products. And actually the public may prefer to keep some known inefficiencies, rather than to adopt new methods — especially if the prospective improvements in efficiency might reduce employment, decrease price competition, or lead to greater concentration of economic power." The definition and dimensions of efficiency vary at different levels within the market economy and become increasingly complex as we move from the firm to an industry or group and finally to the total system.

The individual marketing firm (or any other firm) is said to be technically efficient if its production function yields the greatest output for any set of inputs, given its particular location and environment. If some other production function is used, the ratio of output obtained with this function to output obtained with the best function, given the input combinations, is a measure of the degree of technical efficiency (see Farrell [210] and Timmer [246]). Neoclassical economic theory has traditionally assumed that firms operate with technically efficient production functions; since this is not always true in the real world, the determination of technical efficiency is quite important.
THE ANALYSIS OF PRODUCTIVE EFFICIENCY

for applied economists. Leibenstein [49] refers to actual productive performance relative to the production frontier as "X-efficiency." As reasons for deviations from the frontier he includes incomplete knowledge of available techniques, motivation, learning, and psychological factors. Cyert and March [21] have developed the concept of "organizational slack" as another factor accounting for such deviations.

Firms that are technically efficient still may be inefficient in a pricing sense if they fail to combine inputs so that marginal revenue products are equal to factor prices (or marginal factor costs). Firm pricing efficiency, or preferably allocative efficiency, is measured relative to the efficient production function as the ratio of cost with optimal input proportions to cost with the input proportions actually used (Bressler and King [14], Farrell [210], and Timmer [246]). The product of the index of technical efficiency and the index of allocative efficiency is a measure of economic efficiency of the firm. A firm that is efficient both technically and allocatively has an economic efficiency index of 1.0. Note that a plant may be both technically and economically efficient for its scale but inefficient with respect to its optimum scale. Optimum scale may also vary with relative factor prices (see Seitz [236]).

The total marketing system or an industry subsystem may be said to be efficient if (a) all firms are economically efficient as noted above, (b) the industry is organized to utilize capacity and to take full advantage of scale and location economies, and (c) the industry operates under exchange mechanisms that generate prices which conform to a competitive standard such as the perfect market. The degree to which (a) and (b) are achieved together is commonly referred to as productive efficiency, and the degree to which (c) is achieved is referred to as pricing efficiency (Bressler and King [14]). Helberger [36] has coined the term "O-efficiency" to describe the efficiency of alternative organizational configurations under (b) above and overlapping (c) as well. He includes the mix of conscious planning and unconscious market coordination as factors affecting O-efficiency. The prospects for accurate measurement of departures from O-efficiency, however, are described as "downright dismal."

The rigorous definitions of technical, allocative, and pricing efficiency derived from static neoclassical theory are strictly valid only in a timeless framework. Since real economic systems are characterized by uncertainty and continual changes in technology and environmental factors, measurement of efficiency at a single point in time may be illusory or misleading. What we need to know is the optimal utilization of resources and organization of industries over periods of time, given the facts of uncertainty and change. Efficiency thus should be measured as a function of time paths of system behavior rela-
tive to some optimal path. Progress on formulating such a dynamic framework appears to have been very limited to date.

Research supported by public funds must also consider the broader social implications of the results such as the external costs of new systems and production techniques and the way in which research benefits are distributed. Defining and measuring efficiency in this general context is very difficult. Members of a work group at the 1955 National Workshop on Agricultural Marketing, after struggling with the problem at length, decided that at all levels efficiency may be defined simply as the ratio of ends to resources. "What makes the strategic difference between the individual and the group is the differing content each might give to ends and resources" [87]. The ends relevant to the examination of efficiency of the economy may differ from those of total agriculture, or the agricultural marketing system, or an industry, or a firm. Further, as we move from the firm to more aggregative levels in the system, there is less and less agreement on which ends are relevant. Therefore, there is less and less agreement on what is truly efficient.

This uncomfortable state of affairs led Kohls [47] to call for workers in policy and workers in marketing to join forces. He further suggested that methods must be found by which the talents of other social scientists can be utilized. Although progress with respect to the last point appears to have been somewhat limited, the emergence of the "systems approach" seems likely to shift research approaches substantially in the direction desired by Kohls. The systems approach has been described by Churchman [18] as "a continuing debate between various attitudes of mind with respect to society." It focuses on the performance of total systems, with clear recognition that the optimization process may require some trade-off in efficiency among subsystems. This is consistent with Waugh's statement that some known inefficiencies may actually be preferred.

Economic research relating to productive efficiency may lead to improved marketing performance (1) by determining the relative efficiency of existing alternative production methods, scale of operations, and business practices, thereby aiding individual marketing firms to move to the most efficient production function for their environment (Leibenstein's X-efficiency), or to an improved position on a given production function, and (2) by formulating models of efficient organization within market areas or industries. The latter may serve as planning guides for industry groups and as aids to policy formulation for public agencies and legislative bodies.5

Efficiency may also be improved by developing new production techniques which lead to higher-level production functions. This is primarily an engineering or biological problem. Economists may be concerned, however, in
at least three ways: in the allocation of resources to technological research and development; in cost-benefit studies of new production techniques under varying factor costs and environmental conditions; and in evaluating the effects of new techniques on the economic organization and structure of the industry and the broader benefits to society. The study of the welfare effects of the tomato harvester by Schmitz and Seckler [71] provides an excellent example of an approach to the latter type of concern.

Formulation of a Theoretical Framework

It has been argued effectively that there need be no special economic theory of marketing (Mehren [56]). This would seem particularly true in the production of marketing services; the essential guides for empirical analyses relating to efficiency in agricultural marketing are or should be provided by the general body of microeconomic theory of the firm.

While accepting this view (see, for example, Boger [9]), marketing economists of the 1940s and 1950s discovered that the neoclassical theory, as formulated in the textbooks of that period, left much to be desired for their purposes. There were two major sources of difficulty. First, much of the conventional firm theory was aimed at developing a base for explaining resource allocation, market price, total output, and factor shares with rather less concern for the development of a base for empirical analysis. Second, and perhaps more importantly, the theory was expressed in a single dimension—rates of output and rates of input. Marketing operations, on the other hand, involved the added dimensions of time (length of operation), space, and form that, until recently, were accorded little attention in micro-theory texts.

Elaborations of the neoclassical theory during the past two decades have provided a more suitable framework for empirical studies of marketing efficiency. Many of these elaborations have been formulated without any particular reference to agricultural marketing (see Dano [22], Ferguson [29], Naylor and Vernon [63], and Shepard [76]) and may be considered a part of the current general core of microeconomic theory. No attempt will be made here to review such developments. There are, however, several types of modifications and extensions, growing substantially out of the work of agricultural economists, which are particularly relevant to marketing firm management and the study of marketing efficiency. They have involved (1) more precise and detailed specifications of production organization and methods of combining inputs, (2) incorporation of the length of operation as an added dimension of plant cost functions, (3) further elaboration of the nature of multiple service operations, (4) explicit development of the spatial dimensions of firm efficiency, and (5) formulation of models pertaining to total systems.
Production Systems in Marketing Firms

Agricultural systems transform raw materials such as seeds or feed and inputs of chemicals, water, and energy into products such as bales of cotton, tons of apples, or numbers of slaughter-weight steers. Marketing systems transform the products of agricultural production systems and inputs such as chemicals, water, and energy into intermediate products such as mixed feeds and into consumer products distributed geographically and temporally. Although resting on the same basic concepts of productive activity, the two systems differ in the conceptualization of the product, the time flow of inputs and outputs, and to some degree the interdependence of the separate plant processes.

In contrast to the more easily recognized and defined products of farm firms, the product of marketing firms is the service involved in transforming or transferring the basic farm products. The quantity of a service such as packaging fresh apples and arranging for their sale and shipment may be closely correlated with the physical volume of product handled. In many cases, however, the service is a complex bundle involving time, space, and form dimensions which may be difficult to measure. The output of a supermarket, for example, consists of the service associated with assembling six thousand or so items in a convenient location where they are readily available to consumers. The measurement of this product is considerably more difficult than is suggested by the usual presentation of neoclassical production theory. This still substantially unresolved problem in the analysis of sales-oriented firms will be discussed further in a later section.

Farm firm inputs are applied to fixed land or livestock units and outputs are obtained at intermittent intervals. Usually it is possible to vary the amount of farm inputs continuously since input and output rates are measured seasonally. Inputs of many marketing firms, on the other hand, are applied to time flows of raw farm products from which outputs emerge in continuous streams. An important result of this difference, at least for purposes of empirical analysis, is that labor cost functions which often would be continuous in farm firms may be discontinuous step functions in marketing firms. The discontinuities arise from the commonly used pricing system for labor which requires that workers be paid for time on the job rather than time actually worked. Although some farm labor is fixed per season, the inputs of hourly paid labor typically can be varied so that time on the job and time worked coincide. In marketing firms labor inputs must be purchased in whole units even though the rate of material flow might require fractional man-hours per unit of time — thus the step-type function. Continuous cost functions in empirical models of marketing firms, therefore, must be regarded
generally as approximations adopted for ease of manipulation, not as precise measures of cost-output relationships.

The more careful scrutiny of production systems required for effective studies of marketing efficiency made postwar agricultural economists increasingly aware of a fact engineers presumably took for granted — that most plant operations consist of many processes. Following Jantzen [45] and Kutish [48], French, Sammet, and Bressler [401] referred to these processes as stages. Most stages are organized sequentially about the flow of materials through the plant. A fruit-packing operation, for example, might be divided into stages such as receiving raw produce, dumping produce on conveyers, grading, packing, lidding, loading, receiving container materials, and assembling container materials. A meat-packing operation might involve processes such as receiving, slaughtering, dressing, cooling, and delivery. Nonsequential stages include overall management, record keeping, cleaning, maintenance, and storage operations. Activities within the latter stages may often occur at times that do not coincide exactly with the operations of flow-oriented stages and may relate to total output within some time period, such as a day, rather than to rates of flow.

Compatibility of product and material flow among sequential stages is maintained by adjusting input levels at each stage to the flow of output from the previous stage and by providing temporary storage between stages to smooth out irregularities in rates of outputs among processes. Such storage increases with the degree of irregularity of flow and, of course, adds to the cost of operation.

Processes often are organized in parallel fashion. This may occur in two ways — as a series of identical machines within a process or as a series of usually identical production lines across processes. A fruit-packing plant, for example, may have many identical packing stations within the grading stage. It may also have several production lines, each of which includes a nearly complete sequence of stages. Joel Dean [23] referred to this as "unit segmentation."

Plants with parallel organizations typically vary rates of output by varying the number of identical production units in use. In the common case where equipment units and labor are combined in fixed proportions, this produces a discontinuous stair-step type cost function that is linear in overall shape. Where it is possible to vary labor input per machine or production line by crowding workers or increasing the machine speed, the steps in the function will be less regular, and diminishing returns may occur with respect to the utilization of each machine. Optimum utilization requires that as output rates are increased each identical machine or production line is operated at the
same rate (see French, Sammet, and Bressler [401, pp. 551-553] and Dano [22, pp. 111-114]). The total function associated with varying the number of machines will be linear-homogenous in general shape.

If stages and production lines are appropriately defined to be independent except for the flow of materials between them, each may be thought of as having its own production function. Thus, we have many "plants" within a plant, and the single production function of neoclassical theory is actually an aggregation of many component production functions. While this does not invalidate the concepts and conclusions of the neoclassical formulations, it suggests some possible modifications with regard to determining optimum input combinations and approaches to efficient organization of marketing systems.

An obvious point is that factors are combined stage by stage or process by process. The stage then is the appropriate initial focal point for managerial input decisions and for the empirical measurement of cost functions.

In many cases factor proportions are fixed by the technology used, and the problem of determining optimum factor combinations becomes trivial in the short run and not directly meaningful in the long run. Consider a given plant in the short run with a specified production system producing a particular set of marketing services. Examination of the activities within and between stages will reveal in most instances that the opportunities for factor substitution are highly restricted. For example, chemicals and packaging materials are not substitutes for labor, and ordinarily labor energy cannot be substituted for electrical or mechanical energy used to operate machinery. Often the inputs become embodied in the product in such a way that changing the inputs defines a new product. Some substitution may be possible within classes of inputs—for example, among chemicals or, in rare cases, among types of labor—but such opportunities would appear to be rather limited.

The main factor substitution possibilities are between labor and machinery, which may require changes in the production technology. Under these circumstances we are not concerned with factor substitution as such but with the selection of the best production function. If we are suitably vague in defining inputs, including an amorphous view of capital, we can, of course, define a long-run production function which embodies the best parts of all possible short-run production functions. This is the neoclassical approach (see [29, p. 154] and [249]). Optimum input combinations are then determined by the usual mathematical manipulations of calculus. Such a functional concept may be useful in formulating models to explain the price system and broad categories of resource allocation, but it is of limited value to the empirical analyst or a plant manager. What is required is stage-by-stage examination of alternative production techniques and selection of the sets of techniques which minimize costs of producing any volume of marketing services,
Figure 1. Cost functions for alternative technologies at two plant stages, with operating time per demand or sale period held at a specific figure. Source: French, Sammet, and Bressler [401].
given the environment within which the firm must operate. Aggregation over stages then defines the optimum combination of factors.

The nature of the selection procedure is illustrated in figure 1. The hypothetical stage cost functions shown represent several alternative production techniques for two of the independent plant stages, defined in terms of specific combinations of equipment and variable inputs. If input substitution were possible, least-cost combinations of inputs would be implied. Each curve shows the total stage cost per seasonal period— including operating costs and returns above variable costs required to maintain and replace the durable factors— expressed in relation to the rate of output. The time of operation per seasonal period is held constant. The curve representing each production technique may be viewed as an “envelope” to the cost curves of plants of different size and employing different quantities of the same type of inputs (all using the same basic production technique). The intercept values represent the minimum inputs if production is to occur at all.

Another envelope may be drawn to the curve representing the different production techniques to obtain the long-run cost functions for each stage. In the example technique II in stage 1 is least costly if hourly volume is less than \( OX_1 \). Technique III is least costly if output is between \( OX_1 \) and \( OX_2 \); technique IV is least costly for rates of output between \( OX_2 \) and \( OX_3 \); and beyond \( OX_3 \) technique V is least costly. Note that technique I fails to be the most economical for any output and so is eliminated in determining the envelope.

A similar envelope is obtained for stage 2 and for each of the other plant stages. These functions may then be aggregated (including costs of a general nature) to determine the long-run cost or planning curve. If hours of operation per seasonal period are held at a different level, a different set of stage functions is obtained and, thus, a different long-run cost curve. In fact, there will be a whole family of planning functions, one for each length of operating period, which means that time of operation is itself a variable in the cost function. This point will be developed more fully in the next section.

As the number of alternative production techniques available at each stage increases, the magnitude of the possible discontinuities in the long-run cost function tends to decrease, although their total number may increase. There is a further relative decrease in the magnitude of the discontinuities (and again a further increase in the number) as the stage cost functions are aggregated into an overall cost curve. The long-run cost curve with variable techniques thus approaches a continuous function, and in a purely theoretical extreme it would be continuous, although this is quite unlikely for most types of plants.
Plant Costs and the Length of Operation

It is convenient to think of marketing firms as faced with two types of demand. One is the demand of consumers or other firms for the final physical product and the other is the demand of agricultural producers and shippers for marketing services such as packing, processing, and storage. Although consumer demands often remain fairly stable, the demand for marketing services may fluctuate substantially throughout the year, mainly because of seasonal changes in farm production and harvest rates. Marketing firms commonly adjust to these changing demands by varying both the length of operation within a particular time period and the rate of output. This adds a dimension to output that until recently has received little attention in economic models of the firm. Although the range of variability in the length of operation may be restricted by the perishability of the product and the flow pattern of the harvest, there are enough degrees of freedom to make this an important decision variable for many firms.

There are two types of length-of-operation decisions. Within short periods such as a day or a week, the firm must determine the combination of hours of operation and rate of output in the existing plant that will minimize the costs of producing any given total volume of marketing services. In formulating long-range plans, the firm must determine the optimum combination of plant size and seasonal length of operation for any expected seasonal volume of marketing service to be produced. The first type of decision has important implications for the shape of short-run cost functions and the second adds to the complexity of determining optimum plant scale. Both are important to the empirical analyst as well as firm managers.

Consider a firm producing a single marketing service within a production or marketing period of arbitrary length \( T \). During this period the plant is to be operated at some constant rate of output \( Q \) for a length of operation \( t \), \((t < T)\). The total quantity of service produced is thus

\[
S_T = Qt.
\]

Input requirements for each rate of output flow are prescribed as in the previous section or, more generally, are combined in optimum proportions as specified by neoclassical theory. For simplicity at the outset, the variable operating cost function in the rate dimension will be represented as a continuous approximation to the more realistic discontinuous function:

\[
C = f(Q),
\]

where \( C \) is the rate of total variable cost per unit of time and \( Q \) is the rate of output per unit of time.
Case I. No storage costs. Let us assume for the moment that (2) is indepen­dent of the length of operation — i.e., that fatigue is not a factor and that pay rates do not change — and that added storage costs are not incurred as output rates per unit of time exceed demand per unit of time. The cost per hour for any given rate of output then remains constant as the hours of operation are expanded up to $t = T$. The total variable cost incurred during the pe­riod $T$ is

\[(3) \text{TVC}_T = C_t = f(Q)t.\]

A general form of this relationship is illustrated in figure 2. Note that al­though cost increases nonlinearly in the rate dimension in this illustration, it increases linearly in the time dimension.

To determine the rate of output and the length of operation which mini­mize cost for any $S_T$, form the Lagrangian function

\[(4) L = f(Q)t + \lambda(S_T - Qt)\]

and set the partial derivatives with respect to $Q$, $t$ and $\lambda$ equal to zero:

\[(5) \frac{\partial L}{\partial Q} = t \frac{\partial f}{\partial Q} - \lambda t = 0\]

\[(6) \frac{\partial L}{\partial t} = f(Q) - \lambda Q = 0\]

\[(7) \frac{\partial L}{\partial \lambda} = S_T - Qt = 0\]

Solving (5), (6), and (7) gives the minimum cost rate of output, $Q^*$ and length of operation $t^*$, provided $S_T$ is such that $S_T < Q^*T$ (i.e., $t^* < T$) and subject to the usual second-order conditions. From (5) and (6) we obtain

\[(8) \lambda = \frac{\partial C}{\partial Q} = \frac{C}{Q^*},\]

which indicates that the optimum output rate $Q^*$ will be such that marginal cost in the rate dimension is equal to average variable cost. This, of course, is the rate at which average variable cost is a minimum.

As $S_T$ is increased, a point is reached where $t^* = T$ and further increases in $S_T$ can be accomplished only by expanding in the rate dimension. The length of operation becomes a constant in (3) and we return to the usual neoclassical model.

The equilibrium value of $S_T$ is determined by the conditions of demand facing the firm. Very often the demand for a marketing service during a spe­cified production and marketing period is predetermined by weather, cultur-
Figure 2. A cost surface for producing a single product by varying both rate and time of operation. Storage costs are assumed to be zero. Source: French, Sammet, and Bressler [401].
not, of course, permit production to go beyond the point where marginal cost is equated with price.

In the conceptually more general but probably less common case, the demand for a marketing service during \( T \) may vary with its price. Letting the quantity produced equal the quantity demanded and imposing (5), (6), and (7), the optimizing model for \( S_T \) may be expressed as

\[
NR_T = P_S S_T - f(Q)T = R(S_T) - \lambda^* S_T, \text{ if } S_T \leq Q^*T
\]

\[
NR_T = P_S S_T - f(Q)T = R(S_T) - f\left(\frac{S_T}{T}\right)T, \text{ if } S_T > Q^*T
\]

where \( NR_T \) is net revenue, \( P_S \) is the price of the service, \( R(S_T) \) is the total revenue function, and \( \lambda^* \) is the marginal cost when \( Q = Q^* \) (or equivalently, the minimum value of average variable cost) and the remaining terms are as defined above. If the initial solution of (9) yields \( S_T > Q^*T \), the optimum value is determined by (10), which is the neoclassical model.

Under the conditions specified above, it is clear that an efficient manager would, to the extent possible, adjust to changing demands for marketing services by varying the length of operation, with the output rates set to minimize the cost per unit of service per unit of time. An important consequence for theorists is that realized cost functions associated with changes in the length of operation tend to be linear over most of the range of actual output variation, even though the plant cost function conceivably may be nonlinear in the rate dimension. This will also hold for the more realistic case of discontinuous cost functions, both linear and nonlinear. Another consequence is that the often observed practice of equating price with average cost may also equate marginal cost and price, thus suggesting a closer correspondence between business practice and economic theory.

If fatigue were a significant factor, output rates might decline slightly as the length of operation increased, and cost would be a nonlinear function of time. In practice this seems very unlikely since worker inputs are usually set to keep up with machines and adequate rest periods are normally built into the input structure. Institutional restrictions such as minimum pay periods or overtime rates imposed by union contracts may limit the range of variation in length of operation and add discontinuities to the cost function in this dimension. These factors may become less restrictive, however, as the defined length of production period \( T \) increases.

Case II. Inventory considerations. If the length of operation is such that \( t \leq T \), it is likely that the rate of output will, during some periods, exceed the rate at which the transformed products flow to the next level in the marketing system. Thus, inventories will accumulate for a time before being reduced during the interval from \( t \) to \( T \) when the output flow is stopped. So far it has
been assumed that the variable storage costs associated with such inventory accumulation are negligible. This seems to be a reasonably accurate assumption for many marketing firm operations. In some cases, however, added cooling or handling costs may be incurred, so the previous analysis needs to be extended to encompass this possibility.

Production period storage costs — costs incurred within the time interval $T$, as distinct from costs of providing longer periods of storage services — are a function of the rate of output, the length of operation, and the rate of shipment or movement of product. The latter may be irregular, or may be continuous at a rate no greater than the rate of production, or may follow some other definite pattern. Each type of product movement generates a different pattern of inventory accumulation and, therefore, a different storage cost function. Generally, the function will be nonlinear.

The optimum combination of rate of output and length of operation is determined as specified previously in equations (4) to (7) with the storage cost function simply added to the production cost function. The net result is that the optimum rate of output is reduced slightly, compared with the case having no storage costs, and the length of operation is slightly increased (provided, of course, $t^* < T$). This is evident since, for given $S_T$, storage costs increase with increases in the rate of output and decrease with the length of operation. In the commonly encountered situation of linear and discontinuous cost functions and uniquely engineered plant capacities, the optimum output rate may occur at a “corner position” and thus remain unchanged with the addition of production period storage costs.

Case III. Dynamic extensions. Very often changes in the state of the production and marketing system from one production period to the next affect the firm’s cost function and restrict the possible range of output variation. For example, breakdowns may occur, labor supplies or other inputs may be limited, product inventories (other than normal storage operations) may be carried over, and biological or weather factors may affect worker performance. The values of these events (referred to as “state variables”) in the current period often are influenced by the state of the system and decisions made in previous periods. Thus, the optimization process must be developed with regard to a sequence of decisions, rather than independently for each period as in the previous analysis.

The simple static model developed above may be transformed into a dynamic framework by combining the production cost equation (3) with the production period storage cost equation and isolating the variables (previously treated as constants) which define the state of the system during each production period. Total variable cost in period $i$ of length $T$ becomes

\[ TVC_{Ti} = f(Q_i, t_i, Z_{1i}, Z_{2i}, \ldots, Z_{ni}), \]
where $Z_{1i}, Z_{2i}, \ldots, Z_{ni}$ represent variables which define the state of the system in each period and the other terms are as defined previously. Note that since $S_{Ti} = t_iQ_i$, $t_i$ may be replaced by $\frac{S_{Ti}}{Q_i}$.

The criterion function of the firm is the discounted sum of net returns over $K$ production periods of length $T$. The problem is to maximize this function subject to the difference equations which express the state variables in period $i$ as functions of values in previous periods. The problem might be specified as

$$
(12) \quad \text{Max } \sum_{i=1}^{K} \left[ P_s S_{Ti} - f(Q_i, S_{Ti}, Z_{1i}, \ldots, Z_{ni}) \right] B^i - 1,
$$

subject to

$$
Z_{1i} = h_1(Z_{1i} - 1, \ldots, Z_{ni} - 1, Q_i - 1, S_{Ti} - 1, u_{1i})
$$

$$
\cdot
$$

$$
\cdot
$$

$$
Z_{ni} = h_n(Z_{1i} - 1, \ldots, Z_{ni} - 1, Q_i - 1, S_{Ti} - 1, u_{ni})
$$

$$
S_{Ti} = r(i, v_i)
$$

$$
Z_{10} = b_{10}, Z_{20} = b_{20}, \ldots, Z_{n0} = b_{n0}.
$$

The term $B$ is a discount factor; $u$ and $v$ reflect uncontrollable factors; $b_{10} \ldots b_{n0}$ are initial values of the state variables, $Z_1 \ldots Z_n$, $Q_i$ is the decision variable; and $S_{Ti}$ is treated here as a state variable, although the model could easily be specified to include it as another decision variable.

The type of model illustrated by (12) is readily recognized as a control problem which involves choosing time paths for certain variables (in this case, $Q_i$), called control variables, from a given class of time paths called the control set (see, for example, [43, 16, 81]). The solution procedures required for dynamic control problems are beyond the scope of this paper. The formulation is suggestive, however, of the type of model extensions which ultimately may be required to deal more realistically and effectively with the production decisions of marketing firm managers.

The long-run cost curve is an envelope concept which, in neoclassical theory, specifies the minimum cost per unit of time in relation to rate of plant output per unit of time. However, for many agricultural marketing firms which do not operate throughout the year, the minimum cost associated with a particular rate of output differs, depending on whether the sea-
sonal length of operation (the sum of various production period hours of operation over the total operating season) is long or short. Moreover, production techniques that are labor intensive may be most efficient for plants with short seasons, while capital intensive techniques with higher fixed costs and lower unit variable costs may be selected by plants with longer seasons. Long-run cost functions thus involve considerations of both rate of output and seasonal length of operation.

For long-run planning purposes we need to know the scale of plant (measured in terms of expected rate of output) which gives the least cost for any seasonal volume of marketing service to be produced. The computational procedures involved vary with the degree of control over the seasonal length of operation. In the extreme case where the length is rigidly prescribed by harvest conditions or other factors, the planning curve is determined in accordance with the neoclassical model. Each seasonal volume of service is associated with a particular output rate or design capacity, and the cost function measured in terms of rates of output is directly convertible to a function of seasonal volume. However, there is a different planning curve for each possible length of season.

Frequently seasonal marketing firms are able to influence the length of seasonal operation by control of planting dates or by incurring added transportation or storage costs. The problem then is to find the minimum cost combination of both plant scale and length of seasonal operation for all possible seasonal volumes of service to be produced.

To illustrate the computational process, consider a simple long-run cost model of the general form

\[(13) \ TC_K = g(Q, t_K),\]

where \(TC_K\) is the total seasonal cost, \(Q\) is rate of output, and \(t_K\) is length of seasonal operation.\(^{17}\) The total cost involves two components — an envelope function wherein each point represents the cost for a specific plant operating at its designed capacity rate, or slightly to the left if short-run average cost functions are truly U-shaped; and transportation, storage, or other costs which may increase directly with increases in the seasonal length of operation. The long-run planning function is determined by first forming the Lagrangian function

\[(14) \ V = g(Q, t_K) + \mu (SK - Qt_K)\]

and setting the partial derivatives with respect to \(Q, t_K\) and \(\mu\) equal to zero:

\[(15) \ \frac{\partial V}{\partial Q} = \frac{\partial g}{\partial Q} - \mu t_K = 0\]
Solving (15), (16), and (17) for \( Q \) and \( t_K \) as functions of \( S_K \) and substituting in (13) gives

\[
(18) \quad T C_K = g(S_K),
\]

which is the long-run planning or economies of scale curve, assuming the appropriate second-order conditions which guarantee minimum cost values.

Since economies of scale involve an envelope concept representing least-cost operations, each plant depicted on the curve is assumed always to produce at a uniform rate. This is clearly the most efficient way. But many marketing firms faced with uncontrollable seasonal variations in demand for services cannot produce the same quantity of service during each time period. Given the need to adjust readily and efficiently, the firms might choose plant production techniques different from those they would choose if the same season volume of services could be produced at uniform rates. A planning curve such as (18), based on uniform operation, thus might be inappropriate for such firms.

To derive planning curves for plants faced with such variable demands it is necessary to specify the pattern of seasonal variation expected to prevail. Envelope functions with final forms similar to (18) then can be derived for all patterns of interest, although the added intraseasonal dimensions may produce a formidable computational task. For firms able to adjust to changes in intraseasonal demand by varying the short period length of operation (see previous discussion), the marginal cost remains constant over a wide range of output (values of \( S_T \)), and the planning curves for plants with variable outputs may differ little from plants with uniform outputs. Scale curves based on the latter thus may be practical substitutes. Where institutional factors restrict this type of adjustment process, the more involved development may be required (see, for example, Logan [52], Fitzpatrick and French [315], and Daellenbach and Fletcher [517]).

Uncontrollable variation in volume among seasons presents a similar problem in applying economies of scale analyses. The most efficient plant for a given uniform season volume may not be the most efficient for the same average but variable season volume. Again a family of scale curves can be developed in relation to mean season volume for each pattern of interseasonal variation of interest. In many cases the choice of plant scale and production technique may be essentially the same for uniform and flexible interseason opera-
tions, for the reasons suggested above. The main factor is the degree to which firms are free to adjust to changing demands by varying the length of seasonal operation (in total hours) rather than the rates of output.

Multiple-Service Plant Operations

Many firms engaged in agricultural processing or marketing operations produce more than one product or marketing service. Even if we think of the firm as producing a single type of service, such as packing fresh fruit for shipment to market, the service may differ qualitatively with the forms of packages used or the distribution of grades. Thus, multiple outputs are effectively the rule rather than the exception.

Neoclassical theory provides us with a mathematically elegant model of multiple-product production which is useful for conceptualizing the resource allocation and product mix decisions (see, for example, Henderson and Quandt [37, pp. 95-98], Ferguson [29, pp. 201-211], and Naylor and Vernon [63, pp. 123-128]) but which is quite inadequate as a framework for measuring production and cost functions in marketing firms. There are two major shortcomings in addition to the limitations of the single-product neo-classical model noted previously. First, because of the model's generality and the many variables involved, it is virtually impossible to estimate its parameters with the types of statistical data ordinarily available. Second, as a base for economic-engineering synthesis of production and cost functions, it offers few clues to the nature of the functions involved or the parameters to be determined. It assumes away or leaves unspecified a substantial part of the problem of interest to the empirical analyst and the firm manager.

Instead of one general multiple-product model, what is required is a set of models which will enable the researcher to infer from the type of multiple production some expected characteristics of the firm's production and cost functions. Bressler and King [14] classify multiple-product operations into five general cases: case 1, joint (marketing) services in fixed proportions; case 2, outputs with varying composition; case 3, independent services from a single plant; case 4, single services that may be applied to several physical commodities; and case 5, joint services with variable proportions. Since inferences with respect to these classifications may differ for short-run and long-run production, we shall first examine each case for a given plant and production technology and then see how the conclusions may be modified in long-run situations.

Bressler and King [14] argue that all of the multiple-production situations can be broken down into variants of the single-product model (also see Dano [22, p. 166]). Cases 1 and 2 are analytically equivalent to the single-product case. The joint products are simply redefined to be single products. In the sec-
ond case—typical of many biological growth situations—the composition of the product varies as the rates of input change but in a uniquely determined manner, so that production decisions are made in a single-product framework.

Case 3 includes situations in which one commodity may be processed during one part of the year and another at a different time or two or more products may be processed (or services may be produced) simultaneously but on separate production lines. In either situation, although there is some sharing of fixed factors such as the building and perhaps common costs such as sorting the basic raw product, the variable cost functions are independent. Thus, output decisions may be made separately for each product or service.

Case 4 (which appears to overlap somewhat with case 3) involves the application of a particular marketing service such as packing, transportation, or storage to different commodities or subgroups of commodities. Although the marketing firm may appear to be producing many different products, the production process involves only a single basic service. When a common capacity factor is fully utilized, the commodities to which the service may be applied become alternatives. Dano [22] refers to this type of situation appropriately as multiple products with alternative processes. The optimum commodity mix may be determined by programming methods. If the commodity mix of applications is given, the optimization problem is to schedule the output flow to minimize costs of transferring from one commodity to another, subject to the time sequence of demands. Although integer programming or other operations research techniques may be applicable in such cases (see Wagner [94] and Muth and Thompson [59]), the solution often may be fairly simple or even obvious. In any event the component cost functions involved are all single-product relationships.

Case 5 is distinguished from the others by the requirement that a change in the rate of output of one service affects the marginal costs of producing the other services. It is not possible to relate cost to the rate of output of each product independently of the rate of production of other commodities. Although this is often represented as the realistic or general case, Bressler and King [14] argue that on closer examination all such situations will be found to fall into one of the first four categories. They note that "proportions are not varied through a continuous function but by discrete changes in technology, changes in cultural practices, in breeds and varieties of crops and livestock in crop rotation, and so on. We have been unable to find a single case where, with a given set of technology and inputs, anything but a unique set of outputs would result."

In what at first glance might appear to be a contrary example, Reed and Sammet [479] point out that as the allocation of a given flow of raw material among grades or package forms is changed, the marginal costs of producing
the different product forms may be affected because of changes in flow rates in branch lines. This, however, violates the proposition that output rates of some products may be held constant while those of others are varied. It is actually a case of *alternative processes* wherein the component stage activities may be analyzed in terms of single-product equations.

Even if examples can be found of short-run production that is truly "joint with variable proportions," it seems clear that this occurs infrequently. The reduction of most multiple-product situations to single-product variants with respect to cost determination is obviously important to the empirical analyst for it enables him to deal with separable components in the measurement process. It does not eliminate the need for joint determination of the optimum output mix, particularly in the case of alternative products, but it allows the problem to be placed in a programming framework that is more readily solved with modern computer algorithms.

The long-run cost function for a multiple-product firm (which is not treated very extensively in the economic literature) is a multidimensional envelope to cost functions for plants designed to operate at all different output levels and combinations of levels for a given set of products (see Bressler [12]). Within this framework the single-product plant is a special case in which the design outputs of all commodities considered except one are set at zero.

Referring to the Bressler and King classifications of multiple-product situations, but now in a long-run context, it is clear that cases 1 and 2 may still be regarded analytically as variants of the single product model. Case 4 also appears to be amenable to formulation as essentially a single-product model (or a combination of single-product models). In case 3, however, the joint costs such as shared buildings and equipment, which remain constant for a given plant, become variable costs in a planning function. The selection of the best production technique and the level of the jointly shared cost thus may depend on the output rates for all the commodities involved. At least a portion of the productive activities in case 3, therefore, may shift to case 5 for purposes of long-run planning, although case 5 was rejected by Bressler and King as nonexistent in the short run.

Even the most simple of the truly interdependent multiple-product models is quite complex. Incorporating further considerations of uncertainty and the possible need for short-run flexibility and adaptability in the long-run planning model creates what is indeed a formidable problem for the empirical analyst. Two approaches have been tried. The first is to attempt to reduce multiple-product situations to single-product dimensions through some index of output (see Dean [23, pp. 296-313]; National Commission on Food Marketing [229, pp. 139-152]). In view of the uncertainties involved in long-run
planning, this may often be a practical and useful way of measuring of scale economies. However, it provides limited information regarding costs of alternative product mixes. The second approach is a stage-by-stage analysis, which permits a separation of activities into those which may be considered in a single-product framework and those which require truly joint consideration. The stage and component functions then may be recombined to model the total process of multiple production (for example, see Reed and Sammet [479]). These approaches are discussed in greater depth in the methodological sections of this paper.

Spatial Components of Marketing Cost

Supplies of raw agricultural products handled by a single plant typically are acquired from widely dispersed points. The assembled and transformed products, in turn, may be sent to widely scattered markets or customers. The theory of the marketing firm thus needs to include a framework for analyzing the efficiency of collection and delivery systems and the relation between plant volume and total assembly and distribution costs.¹⁹

THE COLLECTION OR DELIVERY COST FUNCTION

Let us consider first the costs associated with operating a single vehicle on a single route of given design. Following the general approach of Bressler [11], Judge and Baker [361], and Clarke [538], the total variable cost may be subdivided into components which can be analyzed separately with respect to the individual variable involved. The basic identity takes the form

\[ C_T = W_1(T_1 + T_2 + T_3 + T_4) + W_2D + W_3 \]

where

- \( C_T \) = total variable cost per trip,
- \( W_1 \) = hourly cost of the driver,
- \( T_1 \) = travel time,
- \( T_2 \) = time spent loading at farm collection points or unloading at customer delivery points,
- \( T_3 \) = time at plant,
- \( T_4 \) = miscellaneous and personal time,
- \( W_2 \) = operating cost of vehicle per mile,
- \( D \) = total distance traveled, and
- \( W_3 \) = cost of plant loading and unloading per trip.

An analysis of the component costs suggests the following set of relationships:
(20) \( T_1 = \frac{D}{S} \)

(21) \( S = f_1(N, V, X) \)

(22) \( T_2 = \sum_{i=1}^{N} f_2(V_{si}) \)

(23) \( T_3 = f_3(V) \)

(24) \( T_4 = k \)

(25) \( W_2 = f_4(S, V, X, N) \)

(26) \( W_3 = f_5(V) \)

where

- \( S \) = average speed,
- \( N \) = number of stops,
- \( V \) = total volume per trip,
- \( X \) = a composite of effects of road conditions, terrain, type of vehicle, and legal restrictions,
- \( V_{si} \) = volume per stop for stop \( i \), and
- \( k \) = a constant.

Substituting (20) to (26) in (19) gives an equation which, even after consolidating terms, is awkward to handle. However, it becomes much more manageable with a few simplifying assumptions. First, we might let the average speed, \( S \), be constant and independent of \( V \) and \( N \). Second, we might replace individual volumes per stop in (22) with the average volume, giving \( T_2 = N f_2(\bar{V}_S) \). Third, the average hourly operating cost of the vehicle might be regarded as unaffected by \( V \) and \( N \) within a given average environment. These assumptions, which seem likely to have relatively small effects in most cases, permit us to express the collection or delivery function as

(27) \( C_T = b_0 + B_1D + b_2N f_2(\bar{V}_S) + h(V) \)

where

- \( b_0 = W_1k \)
- \( b_1 = \frac{W_1}{S} + W_2 \)
- \( b_2 = W_1 \)
Equation (27) is, of course, restricted to the range such that

\[(28) \quad T_1 + T_2 + T_3 + T_4 = T \leq H\]

where \( H \) = daily hour limit or, alternatively, \( \frac{D}{S} + Nf_2(\bar{V}_S) + f_3(V) + k \leq H \). The total variable cost per season is the sum of costs per trip, to which may be added a value to cover costs associated with investment or ownership (such as taxes, license, time depreciation, interest, insurance, and garaging). In addition to its analytical uses this type of function may provide some guidance in establishing service charges for delivering commodities such as fluid milk, particularly with respect to the influence of volume per stop on cost \([537, 538, 542, 554]\). However, the allocation of indirect costs such as travel time and fixed investment costs is arbitrary. Such costs might, for example, be allocated on a customer basis by dividing by the total number of stops or on a volume per customer basis by dividing by season volume. The charge for the customer service component \((W_1T_2)\) would be the same in either case, but the allocation of other costs would differ.

The discussion so far has ignored the problem of efficient route organization. To achieve minimum cost, travel patterns must be specified to minimize the total route mileage. This may be particularly challenging when the plant volume requires the operation of several routes. There is no general theory of optimum route organization. However, the operations research literature dealing with the “traveling salesman problem” provides several solution algorithms (see Bellmore and Neuhauser [7], Schruben and Clifton [276], and Hallberg and Kriebel [266]). Because of still unsolved difficulties in handling the more complex routing problems, solutions in practice have typically been of a trial-and-error nature (see Boutwell and Simmons [535]).

The achievement of optimum route efficiency is further complicated by the need to select the most efficient equipment for each set of distance and volume requirements. In simple cases equations such as (27) and (28) may be formed for each type of vehicle and the least-cost method readily determined for all conditions. More generally, however, the choice of equipment may interact with the route organization, with many combinations of equipment possible. Formal models for this type of problem are not well developed. For a related approach applicable to single-point pickup, see Henry and Burbee [565].

ASSEMBLY AND DISTRIBUTION COST FUNCTIONS

Assembly or distribution cost functions show how the total acquisition or distribution costs vary with the level of plant output.\(^{20}\) The functions are
unique to each plant location, the specific character depending on the distribution of supply sources (or customers) available to the plant and the density of production at each source. Some generalization about the likely overall form is possible, however, by introducing some simplifying abstractions. The model, which follows approaches used by Olson [718], Henry and Seagraves [567], Williamson [733], and French [265], will be in terms of assembly, but it can be reversed to apply to distribution activities as well.

Consider a plant located at the center of a circular supply plane with production spread nearly continuously throughout the area and the density of supply roughly constant throughout the plane. Assume for the moment a single stop for each load. Imposing these conditions on (27) and expressing on a cost per season basis gives

$C_S = Q(a_0 + a_1D)$

where

$C_S =$ total variable assembly cost per season,

$Q =$ total volume per season, and

$D =$ average one-way travel distance.

If the plant is visualized as located at the origin of a set of polar coordinates, then (see [265])

$D = \frac{2}{3} wr$

where

$r =$ radius of circular supply area, and

$w =$ a factor for converting from air distance to road distance.

Since the volume assembled ($Q$) is equal to average density multiplied by the area of the supply plane, the radius can be expressed as

$r = \sqrt{\frac{Q}{\pi P}}$

where

$P =$ density of supply per unit of area.

Substituting in (29) gives

$C_S = Q(a_0 + \frac{2}{3} a_1 w \frac{Q^{1/2}}{\pi^{1/2} P^{1/2}})$.

Dividing (32) by $Q$ gives an average unit assembly cost function which increases at a decreasing rate as the volume assembled increases.
Cost functions with similar shapes are obtained for rectangular supply areas with roads running along section lines [265] and for models based on route assembly where each load is picked up at several stops [535].

Since (32) includes only variable costs, it is applicable only to short-run cost models. Whether an assembly cost function can be regarded as fully meaningful in this context is perhaps open to question since the area of the plant supply plane is likely to be fixed in the short run. Changes in short-run output are more likely to be associated with changes in average density of supply.

A restricted long-run assembly cost function (for a particular vehicle type) is obtained by adding the cost of ownership or rental of transport equipment to (32). This imposes discontinuities at points where additional vehicles must be added, but it leaves the general shape of the function unchanged. A more general long-run assembly cost function would, of course, involve changes in transport method for greater distances. The rate of increase in assembly cost thus would be slightly less than suggested by (32) for larger volumes assembled. Similar considerations apply to the distribution of final products, particularly for commodities such as milk sold in local markets.

Although actual assembly or distribution cost functions will be modified by geographic configurations and real market factors, the general result regarding shape is quite significant. For the theorist, it suggests a factor which may be important in limiting plant size, even in cases where internal plant diseconomies of scale are absent. For the empirical analyst, it indicates the need to include assembly and distribution costs in the long-run planning curve. And for management, it is clearly an important factor influencing the location of the plant, the source of supplies, and the prices to be paid for raw products.

Total Systems Analysis

The economic theory or set of theories needed for guidance in studies of marketing systems for industries or areas may be separated into two parts—theory relating to systems design and theories of competitive equilibrium and behavior, both extended into spatial and vertical dimensions. The first component of theory focuses on the strict goals of minimum cost organization. The second provides a basis for considering the interaction between system organization and competitive behavior. The latter is essential in evaluating the desirability of alternative organizational structures and in formulating plans for implementing research findings.

DESIGN THEORY

An engineer-economist setting out to design an efficient marketing system might view the system as a single plant on a grand scale. The stage and flow concepts discussed earlier can be extended readily to this larger system. Fresh
fruit, for example, may pass through marketing stages such as transportation to a packing plant, packing, storage, shipment to central warehouses, transportation to retail stores, and final sales to consumers. Just as plant organizations are defined in terms of both methods and scale of production lines, the organization of a marketing system can be defined in terms of plant production methods and scale of plant. The design of a total system is somewhat more complex, however, because of the dispersion of raw product sources and markets and the consequent need to specify the location of each plant at each stage in the system.

The design problem facing the engineer-economist is to select the shipping patterns, plant techniques, plant scales, location, and number of plants at each stage to minimize some function of total cost. The cost of concern here is for the total system, but it could be the costs of processing firms, raw material owners, transport facility owners, consumers, or some other component [717]. The models constructed to solve this type of problem differ with respect to the assumptions about the continuity or discontinuity of space.\textsuperscript{22}

For the continuous case, we draw on the classical location models as presented by Losch [53] and Beckman [6] and extended first to agricultural marketing systems by Bressler and colleagues [11] at Connecticut and later by Williamson [733] and Olson [718]. The discontinuous case is formulated in a programming framework as applied particularly by Stollsteimer [726], King and Logan [707, 711], and others. It is difficult to separate the theory and its application in these cases, and so further discussion will be reserved for the methodological sections elsewhere in this paper.

Since the output at one level of a marketing system becomes an input at the next level, the system designer must also be concerned with the vertical coordination of activities. For a given system, the problem is to determine the best flow patterns of materials and sequences of activities. For the longer run, the problem is to select combinations of plant capacities among levels that will be "harmonious\textsuperscript{23} and to develop vertical arrangements that are optimum with respect to both their cost and risk.

The theory of vertical integration of processes within plants as developed by Dano [22, pp. 149-162] would appear as applicable to a given marketing system, as to a plant. However, Dano's model is static and deterministic whereas many coordination problems arise because of uncontrollable weather and biological factors and the wide range of individual producing units. Theoretical frameworks which would encompass these added dimensions of uncertainty and dynamics are not well defined. Several types of operations research models appear promising in empirical application. Niles [64] has developed a simulation model for producer-processor coordination in the sugar beet industry, and Belden and Schrader [626] have formulated a linear programming model of an integrated turkey production and marketing system.
Queuing theory, scheduling theory, and dynamic programming may also prove useful in this type of analysis.

Conceptual frameworks for analyzing the long-run economies of vertical arrangements have been formulated by Mighell and Jones [57], Baligh and Richartz [4], and Logan [51]. The Mighell-Jones study is a landmark work. It was perhaps the first thorough and rigorous development of both the economic and institutional base for vertical coordination in agricultural production and marketing activities. The work by Baligh and Richartz deals more generally and in greater theoretical depth with economic factors determining the vertical organization of marketing systems. Logan extends the analytical framework in a firm growth context, with emphasis on firm utility functions and risk factors.

COMPETITIVE BEHAVIOR

Whether the efficient system designed by an engineer-economist is achievable, or even desirable, depends on the decision-making framework and the competitive environment within which it will operate. Although a least-cost system design may appear consistent with the norms of perfect competition (and its extension to the perfect market concept [77]), the centralized decision structure required for achievement and the spatial monopolies associated with exclusive territories may in fact lead to pricing systems that are far less than perfect (Bressler and King [14, pp. 153-155]). Our theoretical framework for the analysis of regional or industry market organization, therefore, must include competitive as well as pure cost considerations.

Consideration of competitive behavior brings us into the realm of Helmberger's O-efficiency [36] (see the earlier discussion of efficiency concepts). The problem is to select from among the various possible organizational configurations of an economy the particular configuration which maximizes some welfare criteria. Since these configurations involve space, time, form, and vertical dimensions as well as competitive interactions, the problem is exceedingly complex. Although there have been some efforts to incorporate imperfect competition into quantitative spatial models (Williamson [733], Bobst and Waananen [687], Kloth and Blakley [708], and DeHaven [696]), most relevant theory provides only broad concepts rather than models that may be applied directly to empirical analysis of marketing systems. Helmberger [36] describes the general theory available as "informal and very weak." Additional theoretical modeling seems clearly needed in this area.

Estimation of Plant Cost Relationships

The discussion so far has been aimed at developing theoretical concepts which have been accorded limited space in standard neoclassical works and which
The Analysis of Productive Efficiency

seem essential to the study of efficiency in agricultural marketing. We turn now to a consideration of the empirical methodology and the scope of research concerned with cost and efficiency in the individual firm. Subsequent sections will deal with studies of efficient organization for industries, markets, and market areas.

Approaches to estimating plant cost and efficiency relationships may be grouped into three broad categories: (1) descriptive analysis of accounting data, which mainly involves combining point estimates of average costs into various classes for comparative purposes, (2) statistical analysis of accounting data, which attempts to estimate functional relationships by econometric methods, and (3) the economic-engineering approach, which "synthesizes" production and cost relationships from engineering data or other estimates of the components of the production function. Classifying all studies into these single categories, as will be done for convenience in the discussion that follows, often may be somewhat arbitrary since two or more approaches are frequently combined. A study which relies mainly on descriptive analysis may, for example, include some statistical analysis—and vice versa. There is also considerable variation in the degree of sophistication in statistical studies and, consequently, in their degree of departure from descriptive analysis. Economic-engineering studies may also rely on statistical estimation based on accounting data for some components. Moreover, many descriptive comparisons of costs rely mainly on data generated by quasi-engineering types of measurements.

Studies using any of these approaches share the common objective of providing guides to management that will in some way aid in improving efficiency. There are, however, some separable objectives which are achievable only through the use of particular approaches. These objectives, and the approach or approaches for each, are as follows:

1. Describe average cost experience to provide standards of comparison among firms; approach (1).
2. Describe and compare costs in firms following different business practices or operating in different ways; approaches (1) and (2).
3. Measure short-run cost functions to provide managerial tools for decision making; approaches (2) and (3).
4. Compare the efficiency of alternative production methods or techniques under different operating circumstances; approach (3).
5. Develop improved production techniques; approach (3).
6. Evaluate the effects of plant scale on cost; approaches (1), (2), and (3).
7. Test theoretical hypotheses; approaches (2) and (3).
8. Measure and compare relative total efficiency among firms and at different times; approaches (2) and (3).
9. Provide basic estimates of relationships for use in area or industry studies; approaches (2) and (3).

The fact that more than one approach is listed as consistent with a particular objective does not mean that the approaches are equally effective in achieving the objective. Differences in effectiveness will be discussed in subsequent sections.

Descriptive Analysis of Accounting Data

The computational procedures involved in this approach are straightforward and simple. Typically, average accounting cost records for a particular time period are obtained from a sample of plants. The degree of breakdown in these costs is variable, ranging from broad categories such as labor, materials, insurance, and taxes to more detailed records by department or plant stage. The cost data supplied by the plants sometimes may be supplemented by direct observations or interviews. Occasionally the investigator may attempt some standardization of the methods of reporting and allocating costs within and among plants.

The sample plants usually are classified according to factors such as size, location, type of containers used, degree of mechanization, or some other operating practice. Averages of the average costs are computed for each grouping and for each cost component. Frequently, the range in cost is given also and sometimes the data are presented for each plant in the sample. An effort is made to explain variations in cost among plants in accordance with the variations in class averages (such as by volume) and by other factors thought to affect costs based largely on the general observations and experience of the researcher.

The descriptive approach was the first method used to study marketing firm efficiency. It was virtually the only approach used in the few marketing firm cost studies made before 1940 (for examples, see [5, 27, 78, 80, and 83]). It is still widely used today.

The reference section of this article lists about a hundred research reports, published since 1949, which have followed essentially this approach, although perhaps not all would agree on their placement in this category. Very likely there are others that have escaped the attention of the author. Table 1 shows how these studies have been distributed in time and among major types of agricultural marketing activities. The nearly even split before and after 1960 suggests that the approach has remained popular. Moreover, measures of this type are frequently included in studies of a more analytical nature that are discussed elsewhere in this paper.

There appear to be four main reasons for the popularity of this approach.
Table 1. Descriptive Studies of Plant Cost Records: Distribution by Time, Commodity, and Function, 1949-71

<table>
<thead>
<tr>
<th>Commodity Group and Function</th>
<th>Published before 1960&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Published 1960 and later&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh fruit and vegetable packing</td>
<td>[97, 99, 119, 127, 150, 152, 170, 180, 186, 187, 191, 193]</td>
<td>[124, 190]</td>
</tr>
<tr>
<td>Dairy production processing</td>
<td>[98, 104, 110, 132, 144, 155, 183]</td>
<td>[103, 125, 138, 148, 161, 176]</td>
</tr>
<tr>
<td>Milk collection and delivery</td>
<td>[105, 147, 157, 158, 159]</td>
<td>[149]</td>
</tr>
<tr>
<td>Poultry and egg packing and processing</td>
<td>[101, 120, 122, 128, 162]</td>
<td>[142, 171, 172, 175, 184, 194]</td>
</tr>
<tr>
<td>Egg collection</td>
<td>[146]</td>
<td>[123, 139]</td>
</tr>
<tr>
<td>Cotton ginning</td>
<td>[131, 136, 168, 178, 179, 192]</td>
<td>[115, 116, 117, 118, 151]</td>
</tr>
<tr>
<td>Livestock auctions</td>
<td>[135, 153, 156, 188]</td>
<td>[102, 134]</td>
</tr>
<tr>
<td>Other&lt;sup&gt;b&lt;/sup&gt;</td>
<td>[92, 100, 107, 121, 130, 140, 173, 177]</td>
<td>[96, 111, 112, 113, 114, 126, 137, 141, 145, 163, 165, 166, 167, 181, 182, 195]</td>
</tr>
</tbody>
</table>

<sup>a</sup>Numbers in brackets refer to publications listed in the reference section.

<sup>b</sup>Fruit and vegetable processing, sugar processing, crawfish peeling, cattle feeding, grocery manufacturing, retail food store operations, slaughter plants, wholesale operations.

First, it is relatively cheap compared to economic-engineering analysis or to statistical studies. Second, it is easily understood by plant managers. Third, since the costs are "real," they provide a means for managers to relate their own cost experience to the experience of others. Thus, they suggest potential gains from improvement and may point to the direction of search for means of achieving such improvement. Finally, they may provide a record of cost experience useful to agencies and groups interested in broader questions pertaining to levels of marketing costs and margins—for example, the National Commission on Food Marketing in 1966.

There are, however, significant limitations to the approach. First, unless the record-keeping system is highly standardized among plants, the costs com-
pared may vary widely—especially among component costs—simply because of differences in accounting classification or allocation systems and the time of purchase of durable inputs. Second, in addition to differences in accounting systems, plant costs are affected by so many factors—managerial efficiency, scale, production methods, input prices, degree of plant utilization, environmental conditions, and random variations in plant performance—that the types of cross classification or groupings typically possible usually do not permit clear separations of the influence of individual factors. Finally, this type of study gives us only snapshots of past experience. It provides no quantitative measures of parameters and few general clues regarding the types of functional relationships suggested by our micro-theory framework.

Statistical Analysis of Accounting Data

Statistical analysis uses much the same data as descriptive analysis. It is distinguished from the latter by its attempts to develop quantitative estimates of production and cost functions or to test theoretical hypotheses about them.

The primary focus here will be on cost functions. Although production function studies have encompassed many types of economic activity including agriculture (see Walters [249]), there have been few applications to agricultural marketing firms (exceptions are found in Kelley et al. [220, 221]). In view of this and the extensive body of literature dealing with econometric estimation of production functions (see Walters [249], Brown [15], and Nadiri [60]), it seems best to limit the discussion to aspects of methodology most directly relevant to the evaluation of agricultural marketing firm studies. It should be noted, however, that many of the points to be made pertaining to cost functions also apply to the measurement of production functions.

The first applications of statistical approaches to cost measurement appeared in the late 1930s and 1940s in studies of nonagricultural firms by Dean [205, 206, 207], Dean and James [208], Yntema [254], Wylie and Ezekiel [253], and others. The methodology developed in these studies was extended and applied to a wide variety of production activities during the 1950s and 1960s. Many of the studies are reviewed or referenced in Walters [249] and Johnston [219]. Few applications to agricultural marketing firms are mentioned by these authors—in part because many were published later, but probably also owing to unfamiliarity with the work in this area. In any case, the statistical approach has been used in studies of agricultural marketing or related activities such as livestock auctions [200, 204, 225, 227, 228, 251, 252], grain elevator and milling operations [199, 220, 221, 232, 239, 245, 255, 256], cattle feedlots [209, 216, 218], retail food store operations [212, 229], dairy products processing [215, 222, 223, 224, 233], meat packing [214, 231, 235], and farm supply stores [217].
Nearly all of the studies cited in the preceding paragraph have been concerned with estimates of long-run cost functions from cross-section data. Only three [215, 217, 235] have involved the analysis of time series data, and even these have used cross-section data also. However, this very likely understates the actual and potential importance of time series analysis because it is commonly used to estimate some components of cost variation in economic-engineering studies to be discussed later in this paper and is widely used (often combined with cross-section data) in studies of other types of production activity.

If we can judge from the relatively small number of reports published, the statistical approach has been considerably less popular in studies of marketing firm efficiency than straight descriptive analysis of the economic-engineering approach. Offhand, this may seem surprising since research costs of statistical analysis are not especially high and the state of statistical science is generally well advanced. The explanation appears to be in the difficult specific methodological issues encountered, the limited uses of purely statistical analysis, and the availability of an alternative approach (economic-engineering) which, although more costly, may be more satisfactory for many purposes.

The analyst who sets out to measure plant cost functions by statistical techniques typically has available a set of observations on total cost and output from a sample of plants for a single accounting period such as a year. Less commonly, he may have data for several years, or he may have costs and outputs for each plant for time series of shorter accounting periods such as a week or a month. Attempts to derive theoretical cost curves from such data are jeopardized by possible distortions or biases owing to the character and treatment of the data or inappropriate specification and measurement in relation to the true model of cost behavior.29

DATA PROBLEMS

Statistical studies using accounting records face all of the data limitations of descriptive studies. The data defects may be of greater importance, however, because of the potential for biasing quantitative functional estimates. The five problems most commonly encountered are identified in the following list. (For further discussion, see Dean [23, pp. 303-324], Malmgren [226], Johnston [219, pp. 26-30], and Sammet [69, pp. 113-119].)

1. Measures of durable input costs, in the form of depreciation figures, may vary among plants owing to differences in accounting systems, the acquisition dates of the factors, and depreciation rules that do not accurately reflect the real input cost. Where data can be obtained from plants using uniform accounting systems, the degree of distortion may be reduced but clearly not eliminated.
2. Accounting values are averages for a period of time and may conceal variations in rates of output and plant utilization within accounting periods. Data on plant hours and rate variations for each period may be required for a more meaningful analysis. Using data for shorter accounting periods may also be desirable, although that can lead to another difficulty—the matching of outputs with the periods for which the associated costs are reported. In general, detailed records which permit analysis by plant components may be preferred, although in some cross-section studies disaggregated comparisons have proved unreliable because of variations among plants in the way costs are allocated to components or departments (see Thuroczy and Schlegel [245]).

3. Factor prices, including variable factors, may vary among plants owing to locational and institutional rigidities and over time owing to price level changes. Efforts to correct for price differences by using standardized values or adjusting by some price index have been criticized since the procedure takes no account of factor substitution as prices vary. There is not complete agreement, however, on the nature of the potential bias that may result from such adjustments (Johnston [219, pp. 170-176]). Walters argues that the degree of bias is likely to be small compared to the original price distortion [249, p. 42].

4. Time series of long duration may reflect variations in the physical plant structure and production technique. This may not be bad for some types of comparative purposes, but clearly the researcher must have some measure of the nature of any change of this kind.

5. Cost values for multiple-product plants may involve arbitrary and variable systems of allocating costs among products. Because of the difficulties in measuring output in multiple-service firms, plant scale is sometimes represented by an input such as number of workers or physical assets (for example, see [229]). Stigler argues that "there is no defense except convenience for measuring output by one input" [79]. More commonly, total sales is used as an output measure. If the output mix and component prices remain fairly stable over time and among plants, this may be a satisfactory approximation. Otherwise, it may be a rather misleading index. Where the number of products or services is small, output may be measured in multiple dimensions, but this generates identification problems which often cannot be resolved satisfactorily with the types and sizes of sample data available. The problem of measuring scale for integrated operations still seems open (for further discussion, see Smith [242]).

SPECIFICATION AND MEASUREMENT PROBLEMS

Most of the marketing firm cost studies cited earlier have failed in some way to account fully for the underlying process which generates the historical
records of cost and output. Consequently, what is estimated often turns out to be some descriptive function rather than the basic cost functions suggested by the theoretical framework appropriate to the production of marketing services.

Cost functions from time series data. In studies using time series data to estimate short-run cost functions, the major specification problem relates to the separation of rate of output and length of operation dimensions. If output varies from one accounting period to another by variations in the length of operation, the cost-volume relationship will be linear (see the earlier discussion of the theoretical framework). On the other hand, if length of operation remains constant and rates of output vary, the function may be nonlinear, although as we noted earlier there may often be reasons to expect approximate (discontinuous) linearity in the rate dimension as well. In any case, simply relating total cost to total volume per accounting period confuses the effects of the two dimensions and typically imparts a linear bias to the cost estimates. Much of the historical controversy over the shape of marginal and average cost curves appears traceable to this kind of confusion. The solution to the problem, other than to use an engineering approach, is to obtain accounting data in sufficient detail to separate cost components and outputs associated with changes in rates, length of operation, or discrete time periods such as a day or a week and so to formulate the statistical model in a manner consistent with the theoretical considerations discussed earlier.

Average regressions from cross-section data. In cases where cross-section data have been available it has been (and apparently still is) common practice to compute average seasonal costs for each plant, to plot this against volume per season, and to fit an average regression line which is represented to be a measure of some type of long-run cost function (for example, see [200, 204, 212, 223, 228, 233, and 251]). The shortcomings of this procedure have been recognized for so long that its persistence is surprising. The authors of the well-known study on cost behavior published by the National Bureau of Economic Research in 1943 [19] noted: "Not only may each plant be producing at some other level on its short-run average cost curve than the tangency point with the envelope, but with changes in price in any period it is certain to be out of long-run equilibrium. The fact that many establishments have grown piecemeal, and hence may have larger costs for a particular scale than a firm planned for that scale, will also distort the statistical relationship out of all resemblance to its analytical counterpart." In 1944 Erdman [28] made a similar point with regard to some of the early cost studies of agricultural marketing firms, and Bressler [13] in 1945 noted that such average regression lines "combine and confuse cost changes that result from more complete utilization of a plant of a given scale with the cost changes that accompany changes in scale."
A related type of criticism, commonly referred to as the "regression fallacy," was later developed by Stigler [79] and Friedman [32]. Stigler gives an example of three firms which on the average produce the same output per year but with random fluctuations around the average. Because of large fixed costs, in a particular year the plants with lower than average volume show higher average accounting costs while those with larger than average volume show lower average costs. "This fall in average cost with output would seem to show that there are definite economies of large-scale production, and yet actually the result is due only to the facts that all costs are not variable in the short-run and that output is subject to chance fluctuations." (Also see Johnston [219, pp. 188-192].)

In yet another criticism Friedman [32] has argued that in a competitive industry all firms would have the same average costs if specialized differences were properly capitalized. Variations in outputs from one firm to another would be due either to mistakes or the existence of specialized resources controlled by the firm. Cross-section data would thus reveal nothing about economies of scale. Walters [249] and Johnston [219] have noted that this objection would not apply in an imperfectly competitive world. Johnston particularly stresses the influence of the size of the market (local demand). The local demand and the assembly and distribution costs appear to be the main factors which permit the existence of agricultural marketing firms of widely differing scale. Since there has been substantial controversy among economists regarding the extent and nature of economies of scale, it would seem that imperfect information could also account for some real cross-section variation in plant size.

Although average regressions of the type described are highly suspect and clearly cannot be regarded as estimates of theoretical economies of scale curves, we still must ask whether they have any other value. Two points have been advanced which tend to support the notion that some meaningful interpretations may be possible. First, Johnston considers an example in which plant sizes vary, but the output of each plant is subject to "transient" variations around some normal level. The degree of distortion in the average regressions turns out to be small in this case, and Johnston concludes that "the statistical results confirm the hypothesis of economies of scale, although the extent of the economies may have sometimes been exaggerated." This is not too comforting, however, since an average regression which is able to confirm the existence of economies of scale may still miss badly on the level and the shape of the long-run cost function.

A more substantial point is developed by Walters [248] for the case where product demand, and therefore output, is variable. He formulates the concept of an expected cost curve based on costs of operating at a range of out-
put rates and then argues that "the results of empirical studies should normally be interpreted as estimates of an expected cost function." Just how they should be interpreted in cases where differences in management efficiency, historical growth factors, or data distortions are also important is not clear.

Attempts to avoid the regression fallacy have taken several forms. Most commonly a measure of capacity has been incorporated as a variable in the statistical analysis (for examples, see [225, 229, and 232]). A family of short-run cost functions may be obtained from the cross-section function by holding the capacity variable constant at various levels. Another approach is to classify plants by size, fit cross-section cost-volume relationships for each group (perhaps including a capacity variable within groups if the range is large), and then to draw an envelope function to obtain the scale curve [216, 256]. Two other approaches have been used in cases where both time series and cross-section data are available. One is to combine the two series into a single analysis of covariance model, allowing separately for individual plant and time effects (for example, see [217]). The other alternative is to develop short-run cost functions from time series for each plant and then to construct an envelope function (perhaps graphically) to the short-run cost curves [251].

Note that each of the methods of adjusting for the regression fallacy still produces an average regression but the things averaged may differ. The first two cases average differences due to management efficiency, environmental factors, and accounting variations. The analysis of covariance approach corrects for management and other differences in level of cost among plants and averages slopes of cost functions among firms. This may produce a peculiar hybrid type of function that is difficult to interpret (see Johnson [217, p. 184]). The last method develops short-run time series cost functions for each firm, with the envelope to these functions coming the closest of the four to approximating the theoretical concept of a long-run cost curve.

Frontier functions. For the case where only cross-section data are available, Bressler [13] has suggested that instead of fitting average functions the long-run cost function might be estimated as an envelope function to the bottom of the cost-volume scatter diagram. He noted that "such a curve would be more defensible as an approach to economies of scale than the average regression, for at least it may approach the true curve." Although application of the envelope approach to the analysis of cross-section cost data has been very limited, it has received considerable attention with respect to production functions. First brought into prominence by Farrell [210] and Farrell and Fieldhouse [211] as a basis for measuring productive efficiency, the frontier production function concept has been elaborated and extended by Bressler [203], Boles [201, 202], Seitz [236, 237, 238], Sitorus [241], Aigner and Chu [196], and Timmer [246, 247].
The basic approach to obtaining a frontier function is to constrain errors to one sign, fitting either least lines or least squares with linear or quadratic programming techniques. Timmer [246] identifies three variants of the approach: (1) The Farrell and Fieldhouse approach, with further programming elaborations by Boles, transforms all observations on plant outputs and inputs to a unit activity basis (inputs per unit of output) and derives an efficient unit isoquant in input-output space. A measure of scale is required if the plants are of different size. The iterative procedure used to estimate the efficient unit isoquant does not require the specification of a functional form. (2) Aigner and Chu specify a particular form of production function (in this case Cobb-Douglas) and fit this function with the error term constrained to be negative. (3) Timmer [247] formulates a “chance constrained” model which may build on either the Farrell or the Aigner and Chu approaches. In this case the frontier is estimated in a probabilistic fashion by constraining some percentage of the observations (say, 3 percent) to fall outside the frontier surface. The objective is to eliminate extreme observations which might be the result of data errors. This may require considerable judgment on the part of the researcher, particularly if the sample of observations is small.

Only one application of the frontier approach to agricultural marketing firms was uncovered. In this study O'Connor and Hammonds [230] used the Farrell approach to measure efficiency in meat-handling systems. They concluded that it was inferior to an alternative UOP (unit output price) profit model developed by Lau and Yotopoulos. However, in view of the progress suggested in other applications, the general approach appears to merit further exploration. But it is still subject to many of the data and specification problems of the more conventional methods.

Form of the cost function. Another perplexing problem facing the cost and efficiency analyst — one which may apply to production functions as well as to cost functions and to both frontier and average functions — is the specification of the form of the function to be fitted to the data. That it is indeed a problem has been amply demonstrated by Stollsteimer, Bressler, and Boles [244]. Taking the cross-section data used by Phillips [232] to estimate cost functions for mixed feed mills, they showed that it was possible to develop a wide variety of cost relationships, most based on seemingly quite plausible assumptions about cost behavior and each yielding highly respectable measures of correlation and reliability. A measure of capacity was used in all cases so that the regression fallacy was not an issue.

Stollsteimer, Bressler, and Boles [244] note how such different results could be obtained from one set of basic data and still yield correlation coefficients and t-ratios which suggest high degrees of reliability:
In part, this situation can be explained by the fact that changes in equation form were accompanied by compensating changes in the regression coefficients of the independent variables. . . . The changes in estimated slopes of the regression surface which accompanied changes in equation form apparently take place in such a way that each of the alternative models fit the observed cost-volume points quite well. However, when these alternative slopes are projected to the long-run situation, the alternative models yield quite different results.

Their conclusions are devastating:

Our general conclusion must be that the analysis of such cross-section data may result in high correlations and apparently significant regression coefficients, without providing the basis for confidence in the results as even rough approximations of the basic cost relations involved. . . . To be specific with respect to this study of feed mills costs, we are at a loss when faced with the problem of selecting among the several alternative formulations—although we would reject some and limit the range of applicability of others on logical grounds as noted earlier. We do not know whether long-run average cost levels are relatively high or low or if they are characterized by minor declines as scale is increased or by pronounced economies of scale extending over wide ranges in capacity. In a similar way, we find it impossible to forecast the effects of volume on costs for a plant of particular capacity. We would find it difficult or impossible to advise plant owners and managers as to the probable cost consequences of building larger or smaller plants or of combining the volumes for two or three plants in a single operation. Faced with this great diversity of empirical findings, we may well wonder if cost functions derived from cross-section data are fact or fantasy.

Although these dismal findings apply directly only to the cross-section models described above, the general conclusions and criticisms appear applicable to much of the cross-section analysis published to date. Some of the objections may be reduced through more careful data selection and by obtaining more detailed information about each plant, but this may require direct observation which soon moves us away from pure statistical cross-section analysis to the economic-engineering approach.

THE SURVIVOR TECHNIQUE

To complete our discussion of statistical approaches we need to consider briefly an alternative method of measuring scale economies called the "survivor technique." Originated in its modern form by Stigler [243], it has
been applied to many manufacturing industries by Saving [234], Weiss [250], Shepherd [240], and the staff of the Federal Trade Commission [213]. Some forty food industries have been included in varying degree (see especially [213]).

The survivor technique is conceptually appealing and mechanically simple. It is based on the hypothesis that plant sizes which are efficient will survive and plant sizes which are inefficient will decline. The distribution of value added by plant size class (usually measured in terms of numbers of employees) is computed for two or more census years and the changes in relative shares are compared. Data other than census figures could be used, of course, if available. Plants in size classes which show increases in shares are presumed to be “optimal.” The smallest group which shows an increase in its relative share is classed as the “minimum efficient size.”

The survivor technique avoids many of the problems encountered with cross-section analysis while retaining the advantage of being based on actual market results. Although no functional relationships are derived, the estimates of minimum efficient size, and the optimum size range if reliable and meaningful, could serve managers and policy makers about as well as functional estimates for some purposes. Unfortunately, the technique has many shortcomings.

A major problem is the fact that plants may survive for many reasons other than their internal efficiency (see Bain [198]). Furthermore, efficient scale may be influenced by environmental conditions pertaining to the extent of the market, sources of raw materials, and length of operation which usually are not revealed by the data used. The use of employment as a measure of size introduces the possibility of further bias caused by innovations that substitute capital for labor. Other problems relate to the method of measuring survival (by relative shares of sales, absolute growth, or number of plants) and to the data itself, particularly the changes in classifications between census years.

These limitations cast considerable doubt on the validity of the estimates obtained and the usefulness of this technique as a tool for agricultural marketing analysts. It may have some value when used with other approaches and when screened against other evidence, such as static size distribution and an analysis of the influences at work on plant sizes (Shepherd [240]). But Shepherd concludes that “the results fall short of the early promise of the survivor technique: the failures are many, the proven successes few.”

The Economic-Engineering Approach

The alternative to descriptive and statistical analysis of plant accounting data is to synthesize cost functions from engineering, biological, or other de-
tailed specifications of input-output relationships. This approach has come to be referred to most commonly as economic-engineering analysis. It has also been called the building block approach, the engineering approach, or the synthetic approach.

The technique, as applied to agricultural marketing firms, was originated in the early 1940s by R. G. Bressler, Jr., and his associates at the University of Connecticut. The excellent series of research bulletins produced by this group, under the overall title *Efficiency in Milk Marketing in Connecticut*, provided a foundation which was eagerly embraced by many agricultural economists newly involved in efficiency studies following the enactment of the Agricultural Marketing Act of 1946.

The synthetic method of model building was further refined and elaborated in the early 1950s, with the work at the University of California (to which Bressler had transferred his services) in particular serving as a prototype for many studies to follow. The California approach is described in detail in French, Sammet, and Bressler [401], Clarke [537], Boles [311], and Sammet [69]. Other early contributors to the development of the economic-engineering research methodology included Brewster [485], C. French [318], and Homme [267]. In a somewhat parallel development Chenery [258, 259] and Ferguson [262] pioneered the use of engineering data to estimate production and cost functions in nonagricultural firms. Subsequent applications in industry appear to have been less extensive than in agricultural marketing operations. For examples, see the trucking study by Smith [277] and the mathematical programming models of Isard [268] and Manne [270].

**SCOPE OF RESEARCH**

The economic-engineering approach, as defined here, encompasses studies ranging from simple descriptive comparisons of labor time requirements, through industrial engineering-oriented studies of methods improvement, to detailed estimates of short-run and long-run cost functions. All of these studies share the common feature of concern with micro-components of plant production functions. Some idea of the extent of this type of research may be obtained from table 2. The bracketed numbers in the table refer to 345 plant efficiency studies published since 1950. They are grouped by time period, by commodity or function, and according to the character or objectives of the study. The table excludes studies pertaining to farm supply operations such as bulk fertilizer handling and blending.

The 107 economies of scale studies listed in the table have been separated into two groups based on differences in approach. The studies classed as "economies of scale only" are developed from model plants in which costs of alternative production techniques receive only implicit consideration. The
### Table 2. Economic-Engineering Analysis of Plant Efficiency in Agricultural Marketing: A Classification of Studies, 1950-75

<table>
<thead>
<tr>
<th>Commodity and Function</th>
<th>Economies of Scale Only</th>
<th>Economies of Scale and Methods of Efficiency</th>
<th>Methods of Efficiency</th>
<th>Descriptive Cost Models</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cattle feeding</td>
<td>[284, 285, 286, 287, 288, 289, 290, 294]</td>
<td>[282, 283, 293]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cotton assembly and ginning</td>
<td>[295, 298, 299, 300, 301, 302, 303, 304]</td>
<td>[297]</td>
<td></td>
<td>[296]</td>
</tr>
<tr>
<td>Dairy products processing</td>
<td>[306, 308, 311, 314, 316, 317, 325, 330, 350]</td>
<td>[307, 331, 345]</td>
<td>[312, 318, 319, 320, 321, 322, 323, 324, 339, 342, 346]</td>
<td>[313, 334, 337, 349]</td>
</tr>
<tr>
<td>Egg packing assembly, and distribution</td>
<td>[353, 356, 360, 363, 364, 365]</td>
<td>[352, 355, 359]</td>
<td>[357, 369]</td>
<td></td>
</tr>
<tr>
<td>Fruit and vegetable processing</td>
<td>[480]</td>
<td>[473, 476]</td>
<td>[467, 478]</td>
<td>[465, 468, 469, 472, 474, 475, 479]</td>
</tr>
<tr>
<td>Elevator and milling operations</td>
<td>[488, 494, 502]</td>
<td>[481, 483, 489, 490, 495, 501, 505, 506, 512]</td>
<td>[485, 486]</td>
<td>[482, 487, 491]</td>
</tr>
<tr>
<td>Commodity and Function</td>
<td>Economies of Scale Only</td>
<td>Economies of Scale and Methods of Efficiency</td>
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<tr>
<td>Meat packing and assembly</td>
<td>[516, 518, 527]</td>
<td>[522, 524]</td>
<td></td>
<td>[517, 523, 525, 526]</td>
</tr>
<tr>
<td>Milk collection and delivery</td>
<td></td>
<td>[531, 532, 541, 546, 547, 549]</td>
<td></td>
<td>[535, 540, 542, 544, 548, 550, 551, 552, 553, 554]</td>
</tr>
<tr>
<td>Poultry processing and assembly</td>
<td>[555, 557, 561, 562, 570, 573]</td>
<td>[558, 565, 574, 575]</td>
<td>[560, 564, 576]</td>
<td>[563, 569]</td>
</tr>
<tr>
<td>Wholesale and retail food store operations</td>
<td>[599]</td>
<td></td>
<td></td>
<td>[559, 566, 567, 568, 571, 572]</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>[612, 616, 620]</td>
<td>[619, 621]</td>
<td>[610, 622]</td>
<td>[609, 614, 615, 617, 624]</td>
</tr>
</tbody>
</table>

*Numbers in brackets refer to publications listed in the reference section.

second group of studies synthesize total long-run cost functions from efficient component functions with best production techniques determined as outlined earlier in the theory section. These studies will be considered more fully later in the discussion.

The 152 studies classed under "methods efficiency" typically deal with single components of marketing firm activities such as a stage or a group of activities within a plant. The major focus is on developing improved production techniques or comparing the efficiency of alternative existing techniques. Although the effects of scale on choice of technique may be considered in some cases, the reports are not listed as economies of scale studies since they do not pertain to total plant operations.

The 86 reports classed as "descriptive cost models" include mostly comparative analyses based on time or work sampling studies or measures of cost functions for a single plant. Many of these studies are similar to descriptive analysis of accounting data, except that some of the data have been obtained by quasi-engineering measurements of labor time requirements rather than from accounting records.

The studies are separated into two publication time periods to see if there has been any significant change in research output or emphasis. Assuming that table 2 includes high and equal proportions of studies published before and after 1960, three things are revealed. First, the total number of studies published during the 1960s and early 1970s is almost the same as that during the 1950s, but the commodity distribution has shifted considerably. Operations such as meat packing, cattle feeding, and cotton ginning, which received little attention from synthesizers in the 1950s were brought more fully into the fold in the 1960s. Finally, there has been a shift toward greater emphasis on complete plant studies, rather than individual plant processes, as indicated by the increase in studies dealing with economies of scale and the decrease in studies concerned only with methods improvement.

THE ECONOMIC-ENGINEERING TECHNIQUE

If the reader were to select at random one of the studies listed in table 2 with the expectation that a review of the contents would provide a good guide to economic-engineering methodology, the chances are good that he would be sadly disappointed or, worse yet, would be misled and misinformed. Although the list includes many excellent studies, the reports have varied widely in the depth, rigor, and skill with which they have been developed and in the character and objectives of the analysis. The economic-engineering technique thus is better described in terms of what seems to have evolved as standard good practice, given particular study objectives, than in terms of methods that have actually been followed. Our focus is on studies combining
process or stage analyses into functional estimates which may reveal the nature of short-run cost functions, the comparative costs of alternative production methods under a range of conditions, and economies of scale.

The nature of economic-engineering analysis perhaps can be described most clearly in terms of a series of procedural steps.\textsuperscript{37}

1. \textit{System description.} The economic-engineering method requires much greater familiarity with technical aspects of production than does the typical analysis of accounting data. The researcher thus must become familiar, through plant visits and consultations, with the production systems and organization of activities within and among the firms of concern. To begin his analysis he must be able to delineate the various plant stages and to specify fully the nature and sequence of operations to be performed within the plant or the system being studied. Typically, process flow charts and detailed job descriptions are developed to aid in visualizing the system structure.

2. \textit{Specification of alternative production techniques.} Unless the research is concerned only with the development of a short-run cost function for a single plant, the researcher must consider the variations in production technique that might be employed at each stage of the plant operation. For example, a fruit-packing plant might have a choice of three different types of equipment to use in the grading stage, two alternatives for box filling, and so on. In addition, there are alternative choices in building construction, layout, and in-plant transportation which may not relate to any particular "in-line" stage. For collection or delivery systems there are alternative choices of vehicle and methods of loading and unloading. Information on these alternatives is obtained by consultation with managers, engineers, and manufacturers and by visits to a cross section of plants using various production techniques. The sample of plants selected for economic-engineering analysis thus is purposive rather than random.

3. \textit{Estimation of the production function.} The total plant production function is obtained by combining the production functions for the various operating stages or components. The "building blocks" for the stage production functions are the building and equipment capacities and the associated input-output relationships for labor, chemicals, energy, and materials.

   Equipment capacities may be determined by measurements in plants selected for detailed study or from manufacturers' and/or engineers' specifications. Building space requirements are determined by space requirements for equipment, work space, storage, and traffic movement. Typically, these requirements are determined by observations in sample plants. Alternative building designs and constructions are developed by consultation with building contractors or construction engineers.

   The specification of equipment, layout (or route organization and distance
for collection and delivery systems), and building space generally prescribes the types of jobs to be performed, although some variation in crew organization and work procedures may be possible. Labor performance standards for various tasks may be developed from any of several sources. Most commonly they are derived from work measurement data obtained by time, production, or work sampling studies in a sample of plants which utilize the various production techniques to be considered. More rarely, standard work tables may be used. A source requiring somewhat less time and expense is the technique of crew survey based on informal observation of crew organization and interviews with plant personnel [69]. If detailed payroll records are available, they may sometimes be used as a means of estimating labor requirements, but normally they are better used as a means of checking the engineering estimates (see [69, 401]).

Input-output relationships for chemicals and energy may be determined by engineering formulas and studies of various machine and process requirements (see Chenery [258] and Smith [278]). For agricultural marketing firms, they are frequently estimated by simple specifications of requirements per hour of machine operation or directly in cost terms from plant record data [69].

Given the basic input-output standards plus appropriate allowances for rest periods, delays, breakdowns, and the like, the production function for each stage is obtained by a simple tabular arrangement. Average output rates are specified and the corresponding input rates determined from the performance standards and technical specifications. Note that most “in-line” stages (with grading an important exception) involve only a single output or “through-put” variable. At one end of the plant this may consist of units of raw material or animals to be processed. In other parts of the plant the stage outputs consist of various partially processed or finally processed products.

Production functions must also be specified for “off-line” activities such as record keeping, receiving raw materials, supervision, custodial inputs, plant preparation, off-season activities, and the like. Some of these inputs are related to the hours or days of operation for a particular plant, not to specific outputs. Others tend to be fixed per season if the plant operates at all, but are zero otherwise. Added together, these component production functions form a multidimensional total plant production function, and ultimately a total cost function, that would be impossible to estimate by ordinary statistical analysis of total aggregated accounting data. Plant record data may, however, serve a very important and often neglected purpose — that of establishing the credibility and character of the estimated component production functions. The synthesized functions may reflect standardized conditions not found in any particular plant, and comparison with actual input-output observations can provide a type of “ball park” check plus an indication of the level of performance being modeled.
4. Synthesis of cost functions. Once the production functions have been specified, the cost functions are determined by applying factor prices. Short-run cost functions are obtained by specification of a set of production techniques and their capacities (thus defining a particular plant) and computing variable operating costs for a range of output rates up to or in excess of the design capacity limits. Time and partial product dimensions can be eliminated or varied by specifying operating conditions such as length of season and ratios of each stage product to the final product or products.

To develop long-run cost functions, consideration must be given to all alternative stage production techniques and to the measurement of prices of durable inputs. The usual procedure for the latter is to specify an expected life of the equipment, divide this into the installed cost, and add an amount to cover the cost of borrowed capital, taxes, insurance, and, in some cases, a portion of average maintenance costs.

The long-run cost function may be derived by either of two approaches. The most common practice has been to construct several model plants of varying capacities, perhaps for alternative lengths of season, and then to fit envelope functions either explicitly or implicitly (see references in table 2 under "scale only"). With plants designed to have specific engineered capacities, this involves fitting the function to the lower measure of cost associated with design capacity. The model plant approach is most appropriate in cases where production techniques are fairly standardized or where the researcher is confident of being able to select a priori the best methods for each of his model plants. Otherwise there is some risk of obtaining biased estimates of the true scale curve because of overlooked technical possibilities.

In cases in which several alternative production techniques are available at several stages, the possible number of model plants may be very large. Consequently, the most efficient procedure may be to estimate long-run cost functions by stages (or to determine by stages the best technique for each output range and length of season) and then to combine these cost functions into a total long-run cost function. Variants of this procedure are used in the studies classed under "economies of scale and methods efficiency" in table 2. Very often a smoothed function is fitted to the synthesized cost-volume and length of run observations so that the cost function may be represented in more convenient equation form.

CRITIQUE OF THE ECONOMIC-ENGINEERING APPROACH

Table 2 shows that studies using the economic-engineering approach have outnumbered studies based exclusively on accounting records almost three to one. This suggests some important comparative advantages. The economic-engineering approach avoids many of the problems encountered in strictly
statistical studies. Moreover, it can be applied in cases wherein accounting record data are not available, and it can more readily handle cost functions with multiple products and the added dimensions of length of operation. And it is usually the only approach possible when the objective is to compare methods or develop improved methods of operation.

A major limitation of the economic-engineering approach is its high research cost. The amount of technical detail required to synthesize cost functions can be very expensive compared with the analysis of accounting data. Moreover, as the size and complexity of the operation increases, so does the possibility that the model builder will omit some aspect of cost (Black [257]). In principle, however, large and complex operations can be synthesized as well as smaller ones if the researcher is willing and able to devote the time and care necessary to obtain and organize the massive technical data. Although the economic-engineering approach has not been applied to the study of super plants such as in automobile manufacturing, it has been used successfully in some fairly large food processing operations (see [473, 479, and 524]). But in view of the expense involved, the objectives and expected benefits should be weighed very carefully against the research cost in each individual study.

One means of reducing the costs of synthesizing cost functions is by systematic tabulation of accumulated information on physical input-output relationships. Such data can be used in other studies involving similar operations. Although often cited as an advantage of the synthetic approach, recent publications by a southern marketing committee (Project SM-30) represent the first coordinated efforts along these lines (see [431, 474, and 475]). More recently, Sammet [272] has suggested a basis for evaluating the transferability of such microeconomic data over time.

Another still undeveloped possibility for reducing research costs is the use of a more aggregative approach combining economic-engineering, accounting, and statistics. Input standards and cost components might be analyzed in terms of broad aggregates while still avoiding many of the problems associated with accounting data only.

The economic-engineering approach has been criticized for the general lack of findings pertaining to diseconomies of scale. This has been attributed to the use of constant input coefficients (especially for labor) and the inability to measure or account for coordination problems as plant scale increases. Furthermore, although the engineering approach may handle technical aspects of production processes with considerable accuracy, estimates pertaining to management, sales, and service activities are apt to be very crude [213, p. 95]. Walters has suggested that in some cases the separate plant processes may intersect with one another and so may not be additively separable [249]. These
points are difficult to dispute as generalizations. In practice, however, the magnitude of distortion may be fairly small, particularly in view of the many other problems encountered with the statistical approach.

A related point made by Black [257] and others is that "the estimates derived from synthesis are cut adrift from the standard measures of reliability." Although perhaps attributing a bit too much to measures of reliability in standard statistical analyses, given the nature of the data problems outlined earlier, this is a valid criticism of many synthetic studies. Synthetic estimates clearly need to be checked against alternative sources of information, particularly actual plant performance data.

On balance the economic-engineering approach appears to offer more in terms of analytical power (at a higher cost) than either the descriptive approach or the statistical approach. However, the optimal choice of method depends on the objectives of the study and the funds and data available. An amalgamation of all three approaches may be appropriate in some cases.

The Evidence on Economies of Scale

Of all the factors that may affect marketing efficiency, the relation of cost to scale has received by far the most attention. In view of the empirical and theoretical interest, an attempt has been made to tabulate the results of these studies in a way that reveals something about the relative magnitudes and extent of economies of scale. This proved to be a difficult task since many different commodities and units of measurement are involved. Moreover, even studies dealing with the same commodities and the same units of measurement may differ significantly in the time units used (per hour, per day, per week, per season) and the associated specifications of conditions. In some cases the conditions are not clearly stated at all.

In order to make sense out of all this for summary and comparative purposes, all cost-scale findings were expressed in relative terms. The largest plant considered in each study was given a scale value of 100 and the reported average unit cost for that scale was also given a value of 100. Costs were tabulated for plants ranging in scale from 10 to 80 percent of the scale of the largest plant. These costs were then expressed as a percentage of the cost in the largest plant.

The results of these tabulations for both the economic-engineering studies and the statistical analyses of cross-section data are given in table 3. Not all of the scale studies listed in table 2 are included. Omitted are several that proved especially difficult to interpret or which dealt with only a single plant process or component rather than the total plant operation. Most of the studies included presented cost-scale relationships for a variety of situations. The values given in table 3 pertain to what appear to be the conditions most commonly
Table 3. Economies of Scale in Agricultural Marketing Plants: A Summary of Findings in Selected Studies, 1950-74

<table>
<thead>
<tr>
<th>Source</th>
<th>Commodity and Function</th>
<th>Output Units</th>
<th>Volume Range</th>
<th>Relative Average Total Unit Cost*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>10% 20% 40% 60% 80% 100%</td>
<td>Plant Scale Values+</td>
</tr>
<tr>
<td>1. [285] King, 1962</td>
<td>Feed beef (commercial)</td>
<td>1,000 head</td>
<td>10-70 per year</td>
<td>- - 128 111 104 102 100</td>
</tr>
<tr>
<td>2. [294] Williams and McDowell, 1965</td>
<td>Feed beef (drylot)</td>
<td>1 million lbs. gained</td>
<td>.25-12.75 per 120 day period</td>
<td>116 111 104 103 101 100</td>
</tr>
<tr>
<td>3. [287] Malone and Rogers, 1965</td>
<td>Feed beef (“warm-up”)</td>
<td>1 head</td>
<td>300-2,400 per year</td>
<td>- - 107 104 101 101 100</td>
</tr>
<tr>
<td>4. [289] McCoy and Wakefield, 1966</td>
<td>Feed beef (farm)</td>
<td>1 head</td>
<td>50-1,150 per year</td>
<td>139 115 100 100 100 100 100</td>
</tr>
<tr>
<td>5. [283] Hunter and Madden, 1966</td>
<td>Feed beef (commercial)</td>
<td>1 head</td>
<td>135-15,300 per year</td>
<td>113 107 103 101 101 100 100</td>
</tr>
<tr>
<td>6. [288] McCoy and Hausman, 1967</td>
<td>Feed beef (commercial)</td>
<td>1,000 head</td>
<td>4-64 per year</td>
<td>114 109 102 101 100 100 100</td>
</tr>
<tr>
<td>7. [284] Irrer and Jones, 1971</td>
<td>Feed beef</td>
<td>1 head</td>
<td>200-2,000 per year</td>
<td>132 127 111 103 101 100 100</td>
</tr>
<tr>
<td>8. [298] Covey and Hudson, 1963</td>
<td>Gin cotton</td>
<td>1 bale</td>
<td>6,000-22,000 per season</td>
<td>- - 124 113 107 100 100</td>
</tr>
<tr>
<td>9. [299] Lafferty, 1964</td>
<td>Gin cotton</td>
<td>1 bale</td>
<td>16,000-65,000 per season</td>
<td>128 121 115 109 103 100 100</td>
</tr>
<tr>
<td>10. [302] Thompson and Ward, 1964</td>
<td>Gin cotton</td>
<td>1 bale</td>
<td>8-12 per hour</td>
<td>156 138 126 113 107 100 100</td>
</tr>
<tr>
<td>11. [301] Metcalf, 1965</td>
<td>Gin cotton</td>
<td>1 bale</td>
<td>2.4-9.6 per hour</td>
<td>146 131 122 110 106 100 100</td>
</tr>
<tr>
<td></td>
<td>Assemble, store, and ginb High density</td>
<td>1 bale</td>
<td>(25%) (33%) (50%) (67%) (75%)</td>
<td>(66%) (83%)</td>
</tr>
<tr>
<td></td>
<td>Medium density</td>
<td>1 bale</td>
<td>(25%) (33%) (50%) (67%) (75%)</td>
<td></td>
</tr>
</tbody>
</table>

Economic-Engineering Studies

Assemble and gin

High density

Medium density

Low density

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<table>
<thead>
<tr>
<th></th>
<th>Low density</th>
<th>High density</th>
<th>Medium density</th>
<th>Low density</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.</td>
<td>[295] Anderson, 1966</td>
<td>4,436-13,440 per season</td>
<td>128 (25%)</td>
<td>125 (33%)</td>
</tr>
<tr>
<td>13.</td>
<td>[304] Wilmot, Stedronsky, Looney, and Moore, 1967</td>
<td>4,620-18,480 per season</td>
<td>129 (25%)</td>
<td>124 (33%)</td>
</tr>
<tr>
<td>14.</td>
<td>[300] Looney and Wilmot, 1971</td>
<td>4,620-27,720 per season</td>
<td>129 (25%)</td>
<td>124 (33%)</td>
</tr>
<tr>
<td>15.</td>
<td>[325] Henry, Bressler, and Frick, 1948</td>
<td>228-4,560 per day</td>
<td>129 (25%)</td>
<td>124 (33%)</td>
</tr>
<tr>
<td>16.</td>
<td>[350] Walker, Preston, and Nelson, 1953</td>
<td>45-255 per day</td>
<td>129 (25%)</td>
<td>124 (33%)</td>
</tr>
<tr>
<td>17.</td>
<td>[316] Frazer, Nielsen, and Ladd, 1956</td>
<td>1,000 lbs. (input)</td>
<td>129 (25%)</td>
<td>124 (33%)</td>
</tr>
<tr>
<td>18.</td>
<td>[330] Kolmer, Homme, and Ladd, 1957</td>
<td>2-2.2 per season</td>
<td>129 (25%)</td>
<td>124 (33%)</td>
</tr>
<tr>
<td>19.</td>
<td>[314] Conner, Webster, and Owens, 1957</td>
<td>1-3.175 per season</td>
<td>129 (25%)</td>
<td>124 (33%)</td>
</tr>
<tr>
<td>20.</td>
<td>[311] Boles, 1958</td>
<td>1 million lbs. powder</td>
<td>129 (25%)</td>
<td>124 (33%)</td>
</tr>
<tr>
<td>21.</td>
<td>[343] Strain and Christensen, 1960</td>
<td>1 million lbs. powder</td>
<td>129 (25%)</td>
<td>124 (33%)</td>
</tr>
<tr>
<td>22.</td>
<td>[333] Miller and Graf, 1970</td>
<td>1,000 695-lb. cases</td>
<td>129 (25%)</td>
<td>124 (33%)</td>
</tr>
<tr>
<td>23.</td>
<td>[329] Knudtson and Koller, 1960</td>
<td>1,684, 100-26,945,600 per year</td>
<td>129 (25%)</td>
<td>124 (33%)</td>
</tr>
<tr>
<td>24.</td>
<td>[222] Knudtson, 1958</td>
<td>21.9-109.5 per season</td>
<td>129 (25%)</td>
<td>124 (33%)</td>
</tr>
<tr>
<td>25.</td>
<td>[307] Babb and Taylor, 1962</td>
<td>9-77 per year</td>
<td>129 (25%)</td>
<td>124 (33%)</td>
</tr>
<tr>
<td>26.</td>
<td>[351] Webster et al., 1963</td>
<td>6,000-10,000 per day</td>
<td>129 (25%)</td>
<td>124 (33%)</td>
</tr>
</tbody>
</table>
Table 3. Economies of Scale in Agricultural Marketing Plants: A Summary of Findings in Selected Studies, 1950-74 (Cont.)

<table>
<thead>
<tr>
<th>Source</th>
<th>Commodity and Function</th>
<th>Output Units</th>
<th>Volume Range</th>
<th>10%</th>
<th>20%</th>
<th>40%</th>
<th>60%</th>
<th>80%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>27. [329] O'Connell and Snyder, 1964</td>
<td>Process fluid milk products</td>
<td>1 unit&lt;sup&gt;d&lt;/sup&gt;</td>
<td>1,929,911-30,878,576 per year</td>
<td>162</td>
<td>135</td>
<td>113</td>
<td>105</td>
<td>103</td>
<td>100</td>
</tr>
<tr>
<td>28. [345] Taylor, Bartlett, and C. French, 1964</td>
<td>Manufacture ice cream</td>
<td>1,000 gals.</td>
<td>100-500 per year</td>
<td>251</td>
<td>152</td>
<td>122</td>
<td>113</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>29. [695] Cobia and Babb, 1964</td>
<td>Package fluid milk only</td>
<td>1 qt.</td>
<td>5,000-130,000 per day</td>
<td>129</td>
<td>119</td>
<td>110</td>
<td>106</td>
<td>103</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Package, distribute, and assemble</td>
<td>122</td>
<td>114</td>
<td>107</td>
<td>103</td>
<td>101</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30. [331] Lilwall and Hammond, 1970</td>
<td>Manufacture cheddar cheese</td>
<td>1,000 lbs.</td>
<td>50-1373.4 per day</td>
<td>162</td>
<td>127</td>
<td>109</td>
<td>105</td>
<td>101</td>
<td>100</td>
</tr>
<tr>
<td>31. [356] Gallimore and Stemberger, 1962</td>
<td>Hatch chicks</td>
<td>1 million chicks</td>
<td>1.022112-17.52192 per year</td>
<td>135</td>
<td>135</td>
<td>119</td>
<td>115</td>
<td>114</td>
<td>112</td>
</tr>
<tr>
<td></td>
<td></td>
<td>135</td>
<td>135</td>
<td>119</td>
<td>115</td>
<td>114</td>
<td>112</td>
<td></td>
<td></td>
</tr>
<tr>
<td>32. [364] Pedersen, 1965</td>
<td>Hatch turkeys</td>
<td>1 salable poult</td>
<td>319.738-6,394.752 per year</td>
<td>122</td>
<td>114</td>
<td>107</td>
<td>103</td>
<td>101</td>
<td>100</td>
</tr>
<tr>
<td>33. [363] Pedersen, 1967</td>
<td>Hatch chicks</td>
<td>1 million salable pullets</td>
<td>0.379-3.79 per year</td>
<td>123</td>
<td>112</td>
<td>107</td>
<td>103</td>
<td>101</td>
<td>100</td>
</tr>
<tr>
<td>34. [352] Bird, 1960</td>
<td>Pack eggs</td>
<td>1 30-doz. case</td>
<td>6-96 per hour</td>
<td>133</td>
<td>118</td>
<td>108</td>
<td>105</td>
<td>103</td>
<td>100</td>
</tr>
<tr>
<td>35. [365] Peeler and King, 1963</td>
<td>Pack eggs</td>
<td>1 30-doz. case</td>
<td>649-10,384 per week</td>
<td>117</td>
<td>109</td>
<td>103</td>
<td>101</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>36. [359] Jones, 1964</td>
<td>Pack eggs</td>
<td>1 30-doz. case</td>
<td>14,560-249,600 per year</td>
<td>121</td>
<td>114</td>
<td>106</td>
<td>103</td>
<td>101</td>
<td>100</td>
</tr>
<tr>
<td>37. [353] Byers and Callahan, 1965</td>
<td>Pack eggs</td>
<td>1 30-doz. case</td>
<td>100-4,000 per week</td>
<td>146</td>
<td>120</td>
<td>108</td>
<td>103</td>
<td>101</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Assemble pack&lt;sup&gt;e&lt;/sup&gt;</td>
<td>132</td>
<td>110</td>
<td>99</td>
<td>97</td>
<td>97</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No.</td>
<td>Authors</td>
<td>Operation</td>
<td>Quantity</td>
<td>Weight/Dimension</td>
<td>Seasonal Capacity</td>
<td>Rate</td>
<td>Capacity</td>
<td>Efficiency</td>
<td></td>
</tr>
<tr>
<td>-----</td>
<td>--------------------------</td>
<td>------------------------------------</td>
<td>----------</td>
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<td>----------</td>
<td>------------</td>
<td></td>
</tr>
<tr>
<td>38</td>
<td>Bird, 1956</td>
<td>Pack fresh potatoes</td>
<td>10-lb. sack</td>
<td>500-3,000 per hour</td>
<td>-</td>
<td>134</td>
<td>112</td>
<td>103</td>
<td>100</td>
</tr>
<tr>
<td>39</td>
<td>French, Sammet, and Bressler, 1956</td>
<td>Pack fresh pears</td>
<td>1,000 lbs.</td>
<td>2,000-20,000 per season</td>
<td>159</td>
<td>126</td>
<td>110</td>
<td>106</td>
<td>103</td>
</tr>
<tr>
<td>40</td>
<td>Thor, 1959</td>
<td>Pack fresh citrus</td>
<td>1 3/5-bu. box</td>
<td>120,000-850,000 per season</td>
<td>-</td>
<td>111</td>
<td>104</td>
<td>101</td>
<td>101</td>
</tr>
<tr>
<td>41</td>
<td>Stallings and Sammet, 1959</td>
<td>Pack fresh plums</td>
<td>100 28-lb. crates</td>
<td>.5-12.0 per hour</td>
<td>157</td>
<td>124</td>
<td>111</td>
<td>104</td>
<td>101</td>
</tr>
<tr>
<td>42</td>
<td>French and Gillette, 1959</td>
<td>Pack fresh apples</td>
<td>1 bu.</td>
<td>25-1,000 per hour</td>
<td>-</td>
<td>122</td>
<td>113</td>
<td>105</td>
<td>101</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Assemble and pack</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>High density</td>
<td></td>
<td></td>
<td></td>
<td>118</td>
<td>110</td>
<td>103</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium density</td>
<td></td>
<td></td>
<td></td>
<td>111</td>
<td>104</td>
<td>99</td>
<td>97</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low density</td>
<td></td>
<td></td>
<td></td>
<td>109</td>
<td>103</td>
<td>97</td>
<td>96</td>
</tr>
<tr>
<td>43</td>
<td>Mathia and King, 1963</td>
<td>Pack fresh sweet potatoes</td>
<td>1 bu.</td>
<td>20,000-80,000 storable capacity</td>
<td>-</td>
<td>102</td>
<td>101</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>44</td>
<td>Bohall, Farrish, and Podany, 1964</td>
<td>Pack green-ripe tomatoes</td>
<td>40-lb. carton</td>
<td>300-925 per hour</td>
<td>113</td>
<td>103</td>
<td>(32%)</td>
<td>(59%)</td>
<td>100</td>
</tr>
<tr>
<td>45</td>
<td>Carman, 1967</td>
<td>Pack fresh apples</td>
<td>1 bu.</td>
<td>100-500 per hour</td>
<td>-</td>
<td>122</td>
<td>106</td>
<td>103</td>
<td>101</td>
</tr>
<tr>
<td>46</td>
<td>Mathia, 1967</td>
<td>Store apples</td>
<td>1 carton</td>
<td>10,000-80,000 per season</td>
<td>110</td>
<td>105</td>
<td>(25%)</td>
<td>(100)</td>
<td>100</td>
</tr>
<tr>
<td>47</td>
<td>Mathia, 1969</td>
<td>Pack fresh blueberries</td>
<td>12-pt. flat</td>
<td>9,375-75,000 per season</td>
<td>138</td>
<td>120</td>
<td>108</td>
<td>103</td>
<td>100</td>
</tr>
<tr>
<td>48</td>
<td>Scott, 1959</td>
<td>Can passion fruit</td>
<td>1 lb. (input)</td>
<td>20,000-80,000 per day</td>
<td>111</td>
<td>104</td>
<td>(50%)</td>
<td>(100)</td>
<td>100</td>
</tr>
<tr>
<td>49</td>
<td>Dennis, 1958</td>
<td>Grade and freeze strawberries</td>
<td>1,000 lbs.</td>
<td>5-25 per hour</td>
<td>-</td>
<td>130</td>
<td>111</td>
<td>105</td>
<td>102</td>
</tr>
<tr>
<td>50</td>
<td>Reed, 1959</td>
<td>Assemble and process lima beans for freezing</td>
<td>1,000 lbs.</td>
<td>5-30 per hour</td>
<td>-</td>
<td>113</td>
<td>105</td>
<td>102</td>
<td>101</td>
</tr>
<tr>
<td>51</td>
<td>Davis and Hutchings, 1960</td>
<td>Process peas for freezing</td>
<td>1 lb.</td>
<td>5,000-30,000 per season</td>
<td>-</td>
<td>108</td>
<td>103</td>
<td>103</td>
<td>102</td>
</tr>
<tr>
<td>52</td>
<td>Reed and Sammet, 1963</td>
<td>Freeze spinach, other vegetables</td>
<td>1,000 lbs.</td>
<td>5-30 per hour</td>
<td>-</td>
<td>113</td>
<td>106</td>
<td>101</td>
<td>100</td>
</tr>
<tr>
<td>53</td>
<td>Goble, 1964</td>
<td>Grade and freeze strawberries</td>
<td>1 lb.</td>
<td>400,000-2,000,000 per season</td>
<td>-</td>
<td>111</td>
<td>105</td>
<td>102</td>
<td>100</td>
</tr>
<tr>
<td>54</td>
<td>Reed, 1967</td>
<td>Can sweet corn</td>
<td>1 case</td>
<td>20-40 tons per hour</td>
<td>-</td>
<td>108</td>
<td>103</td>
<td>103</td>
<td>100</td>
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<tr>
<td>Source</td>
<td>Commodity and Function</td>
<td>Output Units</td>
<td>Volume Range</td>
<td>10%</td>
<td>20%</td>
<td>40%</td>
<td>60%</td>
<td>80%</td>
<td>100%</td>
</tr>
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<td>------</td>
</tr>
<tr>
<td>55. [472] Law and Beeson, 1967</td>
<td>Flake sweet potatoes</td>
<td>1 lb. (input)</td>
<td>6,000-24,000 per hour</td>
<td>-</td>
<td>-</td>
<td>105</td>
<td>102</td>
<td>101</td>
<td>100</td>
</tr>
<tr>
<td>56. [473] Mathia, Pearson, and Ela, 1970</td>
<td>Can lima beans</td>
<td>1 case</td>
<td>100-1,500 per hour</td>
<td>121</td>
<td>(7%)</td>
<td>113</td>
<td>105</td>
<td>102</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Can leafy greens</td>
<td></td>
<td></td>
<td>134</td>
<td>(7%)</td>
<td>118</td>
<td>107</td>
<td>103</td>
<td>100</td>
</tr>
<tr>
<td>57. [476] Pearson, Mathia, and Ela, 1970</td>
<td>Can okra</td>
<td>1 case</td>
<td>100-800 per hour</td>
<td>194</td>
<td>(12%)</td>
<td>108</td>
<td></td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Can dry beans</td>
<td></td>
<td></td>
<td>131</td>
<td>(7%)</td>
<td>115</td>
<td>106</td>
<td>102</td>
<td>100</td>
</tr>
<tr>
<td>58. [485] Brewster, 1954</td>
<td>Process cottonseed oil</td>
<td>1 ton seed</td>
<td>10,600-105,600 per season</td>
<td>-</td>
<td>-</td>
<td>129</td>
<td>105</td>
<td>102</td>
<td>100</td>
</tr>
<tr>
<td>59. [494] Hall, 1955</td>
<td>Handle grain</td>
<td>1 bu.</td>
<td>250,000-1,500,000 per season</td>
<td>193</td>
<td>(17%)</td>
<td>172</td>
<td>145</td>
<td>130</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Store grain</td>
<td></td>
<td></td>
<td>223</td>
<td>(2%)</td>
<td>142</td>
<td>119</td>
<td>110</td>
<td>100</td>
</tr>
<tr>
<td>60. [512] Yager, 1963</td>
<td>Handle grain</td>
<td>1 bu.</td>
<td>235,000-1,053,000 per season</td>
<td>201</td>
<td>(22%)</td>
<td>181</td>
<td>119</td>
<td>126</td>
<td>103</td>
</tr>
<tr>
<td></td>
<td>Store grain</td>
<td></td>
<td></td>
<td>154</td>
<td>(26%)</td>
<td>112</td>
<td>117</td>
<td>126</td>
<td>101</td>
</tr>
<tr>
<td>61. [489] Burbee, Bardwell, and Brown, 1965</td>
<td>Mix broiler feed</td>
<td>1 ton</td>
<td>5,434-90,577 per season</td>
<td>185</td>
<td>(50%)</td>
<td>156</td>
<td>125</td>
<td>113</td>
<td>106</td>
</tr>
<tr>
<td></td>
<td>Mix and distribute\dagger</td>
<td></td>
<td></td>
<td></td>
<td>(50%)</td>
<td>117</td>
<td>126</td>
<td>101</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>High density</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Medium density</td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Low density</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>62. [483] Austin and Nelson, 1966</td>
<td>Mix commercial feed</td>
<td>1,000 tons</td>
<td>6-52 per year (approx.)</td>
<td>-</td>
<td>104</td>
<td>99</td>
<td>97</td>
<td>99</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>mix commercial feed</td>
<td></td>
<td></td>
<td></td>
<td>107</td>
<td>97</td>
<td>93</td>
<td>97</td>
<td>100</td>
</tr>
<tr>
<td>Source</td>
<td>Activity</td>
<td>Output Units</td>
<td>Output Volume/Time</td>
<td>Efficiency</td>
<td>Profit Margin</td>
<td>Notes</td>
<td></td>
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<tr>
<td>Vosloh, 1968</td>
<td>Mix commercial feed</td>
<td>1 ton</td>
<td>80-300 per day</td>
<td>--</td>
<td>133 117 108 100</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Van Ausdale and Oldenstadt, 1969</td>
<td>Handle grain</td>
<td>1,000 bu.</td>
<td>70-375 per season</td>
<td>--</td>
<td>257 164 123 109 100</td>
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<tr>
<td>Anderson and Helgeson, 1974</td>
<td>Store grain</td>
<td></td>
<td>50-260 per season</td>
<td>--</td>
<td>160 117 106 103 100</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Holder, Morrison, and Traylor, 1974</td>
<td>Mix commercial feeds</td>
<td>1,000 bu.</td>
<td>100-2,000 per year</td>
<td>375</td>
<td>-- -- -- -- 100</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Logan and King, 1962</td>
<td>Assemble and mix commercial feeds</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Logan, 1966</td>
<td>Mill rice</td>
<td>1,000 cwt.</td>
<td>500-7,000 per year</td>
<td>171 131 114 109 104 100</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Franzmann and Kuntz, 1966</td>
<td>Slaughter beef</td>
<td>1,000 head</td>
<td>15-250 per year</td>
<td>129 122 113 107 104 100</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cassell and West, 1967</td>
<td>Slaughter beef</td>
<td>1 head</td>
<td>20-120 per hour</td>
<td>--</td>
<td>133 116 108 101 100</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Franzmann and Kuntz, 1966</td>
<td>Slaughter beef</td>
<td>1,000 head</td>
<td>37-265 per year</td>
<td>--</td>
<td>104 100 98 99 100</td>
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<tr>
<td>Cassell and West, 1967</td>
<td>Slaughter hogs</td>
<td>1,000 head</td>
<td>.7-10.5 per week</td>
<td>150 139 124 114 107 100</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Holder, Morrison, and Traylor, 1974</td>
<td>Handle grain</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Schnake, Franzmann, and Hammons, 1968</td>
<td>Process meat</td>
<td>1 lb.</td>
<td>50,000-250,000 per week</td>
<td>-- 126 120 -- -- -- 100</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Bird, 1964</td>
<td>Freeze-dry chicken</td>
<td></td>
<td>2-16 per season</td>
<td>--</td>
<td>171 135 115 101 100</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Gibb and Riley, 1961</td>
<td>Livestock auction</td>
<td>1 head sold</td>
<td>10,000-110,000 per season</td>
<td>253 (9%) 167 (18%) 137 (32%) 123 (50%) (73%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Kuehn, 1971</td>
<td>Livestock auction</td>
<td>1 LMU</td>
<td>8,000-130,000 per season</td>
<td>176 (9%) 141 (18%) 114 (32%) 106 (50%) (73%)</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Baum, Faris, and Walkup, 1952</td>
<td>Process fryers</td>
<td>1,000 fryers</td>
<td>200-9,000 per day</td>
<td>123 112 107 103 101 100</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Abbott, 1954</td>
<td>Process turkeys</td>
<td>1 turkey</td>
<td>60-1,200 per day</td>
<td>140 (5%) 117 (25%) 102 (50%) 100</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Donald and Bishop, 1957</td>
<td>Process broilers</td>
<td>1,000 lbs.</td>
<td>25-400 per week</td>
<td>132 118 108 103 101 100</td>
<td></td>
<td></td>
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<tr>
<td>Rogers and Bardwell, 1959</td>
<td>Process broilers</td>
<td>1 broiler</td>
<td>150-10,000 per hour</td>
<td>138 124 110 105 102 100</td>
<td></td>
<td></td>
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<tr>
<td>Rogers, et al., 1958</td>
<td>Process broilers and other fowl</td>
<td>1 bird</td>
<td>150-5,000 per hour</td>
<td>145 128 116 107 103 100</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Source</td>
<td>Commodity and Function</td>
<td>Output Units</td>
<td>Volume Range</td>
<td>Relative Average Total Unit Cost*</td>
<td></td>
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</tr>
<tr>
<td>80. [562] Farrish and Seaver, 1959</td>
<td>Process broilers</td>
<td>1 broiler</td>
<td>15,000-75,000 per hour</td>
<td>10%  20%  40%  60%  80%  100%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>81. [566] Henry, Chappell, and Seagraves, 1960</td>
<td>Service, assemble, and process broilers</td>
<td>1 bird</td>
<td>1,800-9,600 per hour</td>
<td>10%  20%  40%  60%  80%  100%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>82. [574] Rogers and Rinear, 1963</td>
<td>Process tom turkeys</td>
<td>1 million lbs.</td>
<td>4-76 per year (approx.)</td>
<td>10%  20%  40%  60%  80%  100%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>83. [558] Burbee and Bardwell, 1964</td>
<td>Hatch chicks and process broilers</td>
<td>1 million broilers</td>
<td>1.19-19.76 per year</td>
<td>10%  20%  40%  60%  80%  100%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>84. [575] Rogers and Smith, 1966</td>
<td>Further processing of poultry: Cooked chicken parts</td>
<td>1 million lbs.</td>
<td>1-15 per year</td>
<td>10%  20%  40%  60%  80%  100%</td>
<td></td>
<td></td>
<td></td>
<td></td>
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**Statistical Studies**

<table>
<thead>
<tr>
<th>Source</th>
<th>Commodity and Function</th>
<th>Output Units</th>
<th>Volume Range</th>
<th>Relative Average Total Unit Cost*</th>
</tr>
</thead>
<tbody>
<tr>
<td>85. [233] Purcell and Penny, 1955</td>
<td>Process and package milk in paper cartons</td>
<td>1 qt.</td>
<td>1,000-34,000 per day</td>
<td>10%  20%  40%  60%  80%  100%</td>
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<tr>
<td>86. [222] Knudtson, 1958</td>
<td>Manufacture butter</td>
<td>1 million lbs.</td>
<td>9-77 per year</td>
<td>10%  20%  40%  60%  80%  100%</td>
</tr>
<tr>
<td>87. [215] Hanlon and Koller, 1969</td>
<td>Process butter and nonfat dry milk</td>
<td>1 million lbs.</td>
<td>140-470 per year (approx.)</td>
<td>10%  20%  40%  60%  80%  100%</td>
</tr>
<tr>
<td>88. [231] Parsons and Guise, 1971</td>
<td>Export Abattoir</td>
<td>1 cattle equiv.</td>
<td>18,000-155,000 per year</td>
<td>10%  20%  40%  60%  80%  100%</td>
</tr>
<tr>
<td>89. [561] Donald and Bishop, 1957</td>
<td>Process broilers</td>
<td>1 broiler</td>
<td>150-4,000 per hour</td>
<td>10%  20%  40%  60%  80%  100%</td>
</tr>
<tr>
<td>90. [216] Hopkin, 1958</td>
<td>Feed cattle</td>
<td>1 head</td>
<td>1,100-44,000 head capacity</td>
<td>10%  20%  40%  60%  80%  100%</td>
</tr>
<tr>
<td>Reference</td>
<td>Year</td>
<td>Type of Feed</td>
<td>Feed Quantity (input)</td>
<td>Feed Quantity (output)</td>
</tr>
<tr>
<td>-----------</td>
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<td>-----------------------</td>
<td>------------------------</td>
</tr>
<tr>
<td>Dietrich</td>
<td>1969</td>
<td>Feed cattle</td>
<td>1,000 head</td>
<td>107 100</td>
</tr>
<tr>
<td>Phillips</td>
<td>1956</td>
<td>Mix feeds</td>
<td>1,000 tons</td>
<td>164 100</td>
</tr>
<tr>
<td>Thuroczy</td>
<td>1959</td>
<td>Mill rice</td>
<td>1 cwt. (input)</td>
<td>128 100</td>
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<tr>
<td>Lindberg</td>
<td>1958</td>
<td>Livestock auction</td>
<td>1 animal unit</td>
<td>192 100</td>
</tr>
<tr>
<td>Wootan</td>
<td>1966</td>
<td>Livestock auction</td>
<td>1 animal unit</td>
<td>121 100</td>
</tr>
<tr>
<td>Broadbent</td>
<td>1971</td>
<td>Country hog market</td>
<td>1 hog-unit equivalent</td>
<td>239 100</td>
</tr>
<tr>
<td>Wilson</td>
<td>1971</td>
<td>Livestock auction</td>
<td>1 LMU</td>
<td>132 100</td>
</tr>
<tr>
<td>Farstad</td>
<td>1952</td>
<td>Retail meat</td>
<td>1,000 lbs. (input)</td>
<td>277 100</td>
</tr>
</tbody>
</table>

*Expressed as a percentage of the largest plant cost.
+Expressed as a percentage of the scale of the largest plant. It was not possible to tabulate values for exactly 10, 20, 40, 60 and 80 percent in all cases. The actual percentages for which values were tabulated are given in parentheses in the body of the table.

a300, 200, and 50 bales per square mile, respectively, available for ginning.
b100, 75, and 25 bales per square mile, respectively, available for ginning.
c300, 200, and 50 bales per square mile, respectively, available for ginning.
d1 unit equals 1 quart for all fluids except cream; 1 unit equals 1/4 quart of cream.
eAssembly costs reported for only one production density.
fIncludes picking, hauling, packing, and selling.
g30,000, 1,500, and 75 field crates (bushels) per square mile, respectively, available for packing.
hAssembly here refers only to linear field-to-plant transportation costs.
i1 case contains 24 No. 303 cans or equivalent.
j32.73, 6.55, and 1.31 tons of feed distributed per square mile, respectively.
k100, 50, and 12 hogs per square mile, respectively, available for slaughtering.
lRefers to sausages and other cured and smoked meats.
m1 LMU (livestock marketing unit) = 1 beef animal, 3 calves, 4 hogs, or 5 sheep.
nThis refers to processing exclusive of evisceration. All other processing studies reviewed included evisceration.
osti25,000, 5,000, and 1,000 birds per square mile, respectively, available for processing.
pAbattoir for export meats from Australia only.
qh1 cattle equivalent = 1 beef animal, 8.3 sheep, 8 pigs, or 3 calves.
r1 animal unit = 1 beef animal, 1 hog, or 6 sheep.
s1 animal unit = 1 beef animal, 1 hog, or 6 sheep.
t1 hog-unit equivalent = 1 beef animal, 4 hogs, 5 sheep, or 8 feeder pigs.
encountered. The relationships for other variants usually do not differ much in relative terms.

This type of relative comparison is very imperfect since the size of the largest plant which serves as the base measure varies considerably among studies, even for studies dealing with the same commodity. Therefore, we need to be very careful in interpreting these findings. Nevertheless, it seems possible to reach some tentative conclusions.

First, although substantial variability is observed, there appears to be some consistency in findings among studies dealing with particular types of commodities. For example, dairy processing plants and elevator and milling operations, which involve larger inputs of capital items relative to labor, show greater scale economies than plants for egg or fruit and vegetable packing.

Second, plants that are, for example, only 20 percent of the size of the largest plant considered have costs from 10 to 40 percent higher than the largest plants for high labor operations and from 30 to more than 100 percent higher for the capital intensive operations such as dairy processing. For high-labor operations, most of the in-plant scale economies have been achieved at a scale equal to 60 percent of the largest plant. The more capital-intensive operations still show significant gains at 80 percent of the largest plant scale.

If we restrict consideration to in-plant operations, only two of the studies listed (based on either economic-engineering or statistical analysis) show any diseconomies of scale within the size ranges considered. And even these cases (Franzmann and Kuntz [518] and Donald and Bishop [561]) seem open to question. However, if we include assembly or distribution costs, the picture changes a bit. The studies by French and Gillette [398], Henry et al. [566], Burbee and Bardwell [558], Byers and Callahan [353], Burbee et al. [489], and Cobia and Babb [695] all show the optimum scale shifting back to the range of 40 to 80 percent of the largest plant, depending on the level of supply density or the transportation system. Several other studies (Covey and Hudson [298], Metcalf [301], and Anderson [295]), all dealing with cotton, do not show the optimum scale shifting with the addition of assembly cost, but the magnitude of scale economies is reduced.

Because of differences in volume range and commodity coverage, it is difficult to make meaningful general comparisons between the results of statistical studies (last section of table 3) and the economic-engineering models. The two direct comparisons included in table 3 produced rather divergent results. The study by Knudtson [222] (table 3, items 24 and 86) concluded that the statistical analysis overstates the economies of scale. Whether this can be generalized seems doubtful since the type of data and sample could affect the statistical results. A study by Donald and Bishop (table 3, items 77 and 89) developed a synthetic function with continually decreasing costs and a statis-
tical cost function with decreasing and then increasing costs (item 89). However, the authors indicated little confidence in their statistical function because of nonstandardized procedures with respect to hours of operation, uniforms for workers, and packaging operations.

The widespread existence of economies of scale, with the largest plant almost always showing the least cost, is clearly an important force in shaping the future development of the marketing system. In dealing with the specific implications of these findings, however, it is important to recognize that scale is only one of several factors affecting the level of plant cost. The model scale curves are standardized for operating conditions and abstract from the real-world concern with uncertainty and change. Moreover, they all pertain only to plants, not firms, and thus reveal little about possible advantages or disadvantages for multiplant firms. Considering the significance of increasing assembly costs and the flatness of many scale curves in the medium to large range, it is easy to see how a scale disadvantage may often be offset by other cost and market factors. The evaluation of the potential impact of these scale findings thus requires consideration of specific location and growth patterns and the relation of existing plant size and cost distributions to the estimated scale curves. Most of the plant studies referred to in table 3 did not explore the broad economic implications of their findings in depth, if at all. In the next section we shall consider some studies that have.

Applications and Extensions of Plant Efficiency Research

As the methodology of plant efficiency research advanced beyond the formative stages and as empirical applications became more widespread, the plant studies began to provide essential inputs into several other types of studies. These include (1) firm optimizing studies, (2) feasibility studies, (3) studies of efficient organization of market regions or industries, and (4) studies of wholesale market organization.40

Firm Optimizing Studies

Whereas cost and efficiency research provides management with information to aid in the decision process, firm optimizing research focuses on improving the skills of management in making decisions. There are two aspects involved—one concerned with the organizational and behavioral structure of management and the other with developing quantitative tools by which optimizing solutions may be obtained.

Except for occasional conceptual articles (Kohls [634] and C. French [630]), agricultural marketing firm analysis relating to the first aspect has consisted mainly of educational activities and reports published by the Farm-
er Cooperative Service and the various state agricultural extension services. Although Leibenstein [49], in his article on X-efficiency, has suggested that motivational factors and improved managerial skills may be very important in shifting firms from an interior position to the frontier of their production possibilities, agricultural marketing firm research pertaining to this aspect has been very limited. Agricultural economists have tended to view the area as belonging to the general field of firm management (rather than as a specialized area for marketing firm analysis) or as a teaching related activity. It might be noted, however, that the measurement of managerial performance is still one of the weakest elements of firm efficiency analysis, particularly in economic-engineering studies.

Research on the second aspect has consisted mainly of case study illustrations of how operations research tools (especially linear programming) may be used to solve short-run decision problems. This type of study has been developed most extensively by James Snyder and Charles French and their colleagues at Purdue. Examples of their research and several similar types of studies by others are listed in the reference section (items [626] to [644]). The problem of determining optimum product mix has received the most attention. The procedures applied are based on generally standard operations research models.

Feasibility Studies

A time-honored approach to the development of rural areas has been to encourage the establishment of processing or marketing facilities in regions where they have not existed in the past or to expand facilities in existing areas. Successful developments of this sort may increase marketing and production opportunities for farm resources and provide more jobs and investment for the area. Feasibility studies have, as one objective, the evaluation of the likely degree of success of such ventures (Woodard [682]). Feasibility analysis may also be required when existing firms are contemplating changes in their operations such as mergers or consolidations, expansions of present facilities, adoption of new technologies, relocation, addition of new services or product lines, and expansion of market area (Schmermerhorn [673] and Hammond [658]).

Dalrymple, in a comment appended to the paper by Woodard [682], argued that "there is no clearly defined area of feasibility as such. Rather, it is a hybrid made up of a number of areas of work within agricultural economics alone." Although this is undoubtedly correct, it is possible to identify four components or phases that are common to most studies which deal with questions relating to feasibility: (1) analysis of final product demand, (2) analysis of processing, assembly, and distribution costs, (3) analysis of raw product ac-
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acquisition costs and (where appropriate) farm costs and returns, and (4) a final budgeting model which evaluates expected benefits (or losses) from the venture considered. Let us look at a highly simplified description of the analytical processes required.\footnote{42}

The demand phase brings together all available information on consumption and utilization trends, competition and production in other areas, commodity price levels and price elasticities, income elasticities, and institutional requirements for product marketing. This must be translated into a set of anticipated prices, f.o.b. plant, for the range of possible product volumes considered.

The second phase requires estimates of processing and assembly costs (ideally, estimates of long-run cost functions). In some cases the assembly cost component may be regarded as part of the grower cost. The processing or handling cost function is expanded to include several alternative rates of return on investment. Often consideration is given to several possible plant locations and several lengths of operating season. The estimated costs plus return on investment for various volumes and situations are then subtracted from the schedule of expected prices to obtain a "raw product fund" (see Dahle, Jones, and Nichols \cite{651}). This determines the maximum amount the processor can pay per unit of raw product for the various situations considered.

The third phase estimates the probable acquisition cost to the processing plant. If the commodity is already produced in the area but not processed, existing prices and opportunity costs for alternative crops may establish the minimum level of prices that must be paid. However, an assessment must be made of supplies available at these prices. If the commodity has not been produced in large quantities, production costs must be synthesized. This requires consultation with production specialists. The syntheses may involve simple budgeting studies or more complex linear programming analysis for model farms such as those by Hammond et al. \cite{660} and Stollsteimer, Coutu, and Dahle \cite{678}. The most difficult part is to estimate the total regional production available at various prices and return rates.

The last phase combines the first three to estimate expected returns to processing and production for the several situations and volume levels considered. A complete study might also include an evaluation of expected environmental and community effects.

Although long a matter of concern to extension specialists in agricultural marketing and to the technical assistance staff of the USDA Farmer Cooperative Service, feasibility analysis apparently did not attract much research attention until the 1960s. This probably was owing to the fact that these studies usually build on previous cost analyses and it was not until the late 1950s.
that there was an accumulation of research findings and familiarity with the economic-engineering approach which is at the heart of most such studies. A look at the reference section shows that at least thirty-eight reports on feasibility (items [645] to [682]) have been published since the early 1960s. Very likely there are others that have been overlooked. Twelve reports deal with vegetable processing, nine with livestock related operations, and the rest with a variety of products. Much of the leadership for this type of research has been provided by the economics group at North Carolina State University (see [658, 659, 660, 666, 676, and 678]).

Efficient Organization within Market Areas

Research dealing with with efficiency of marketing areas or marketing sub-industry organization has focused mainly on the determination of the optimum number, size, and location of marketing facilities. Two classes of models have emerged. One group treats space as continuous for purposes of defining optimal marketing areas for individual firms, and the other specifies finite numbers of markets, locations, and raw material sources.

THE CONTINUOUS SPACE APPROACH

Consider a region with approximately uniform average density of raw product supplies and/or spatial density of demand. Take a long-run average cost function, estimated as described earlier, and add to it average assembly and/or distribution cost functions, also estimated as described. Take the first derivative with respect to plant volume, set it equal to zero, and solve for the volume that minimizes the combined average plant, assembly, and distribution cost. Divide this volume into the total regional supply (or demand for distribution cost functions). The result is a crude approximation of the optimum number of plants for the region and the assembly or distribution area for each plant. Arbitrarily locate one plant. This then determines the locations of all other plants.

Note that in this case assembly or distribution cost functions based on circular supply areas would not be appropriate since the areas would have to overlap to blanket the entire region. With direct road patterns, hexagonal areas would be most efficient. For a hexagon circumscribed by a circle of radius $r$, the area is $2.598 r^2$ and the average one-way air travel distance is $.6685 r$ (see Beckmann [6, p. 471]). These values may be substituted in equations having the form of (30), (31), and (32) to obtain an assembly cost function based on hexagonal supply areas. Where roads form a square grid system, a square supply area is most efficient (see French [265] for the development of assembly cost functions in such a case). The difference in efficiency among these forms is very small, however.
This approach to optimum size and numbers of agricultural marketing plants was first used by Olson [718] in a study of milk assembly. Williamson [733] later elaborated the model into a more general spatial equilibrium framework for plant location, including both competitive and monopsonistic cases. He also showed how, under some fairly heroic assumptions, the model can be applied to cross-section data to obtain statistical estimates of the relation of optimum plant size to supply density. Variants of the Olson and Williamson models have been applied to grain elevator size and location by Von Oppen and Hill [729] and Araji and Walsh [684], to livestock markets by Miller and Henning [715], to optimum milk plant size by Cobia and Babb [694] and Babb [685], to cotton ginning and warehousing by Wilmot and Cable [734], and to petroleum distribution to farms by Haskell and Manuel [697]. The several other studies which have combined processing and assembly or distribution costs (see table 3) have dealt somewhat implicitly with optimum numbers (if not location) as well as size.

The major difficulty with the continuous space approach is, of course, that supply density typically is not uniform and supply areas are not regular and continuous in shape. Moreover, there often are limited numbers of realistic choices of efficient locations, and the plant cost functions may not be independent of these locations. Under these circumstances the continuous model may give very poor approximations to realistically efficient size and location solutions.

THE DISCRETE SPACE APPROACH

The alternative to the continuous approach is to group supply sources and market territories into finite numbers of point locations and to consider some predetermined set of feasible potential plant locations. As in the continuous case, we still need to know the transportation cost functions (or all point-to-point rates) and the long-run processing or handling cost function. One of the first models for solving this type of problem was developed by Stollsteimer [726] as a basis for determining the optimum number, size, and location of pear-packing plants in a fairly homogenous pear-producing region (also see Hoch [699], Mathia [713], Stollsteimer [725], and Stollsteimer, Courtney, and Sammet [723]). The problem may be stated algebraically. Minimize

$$\begin{align*}
\text{TC} &= \sum_{(J, J_k)} \sum_{j=1}^{J} P_{ij}X_{ij}J_k + \sum_{i=1}^{J} \sum_{j=1}^{J} C_{ij}X_{ij}J_k \\
&\text{subject to}
\end{align*}$$

with respect to plant numbers ($J \leq L$) and locations $J_k [k = 1, \ldots, \left(\binom{L}{J}\right)]$, subject to
The ease or difficulty of solving this problem is affected by the presence or absence of economies of scale, the form of the processing cost function, the effects of location on plant cost, and the number of sources and potential plant locations to be considered. In his original application of the model Stollsteimer introduced the strategic assumption (supported by empirical analysis) that the long-run total cost function for pear packing could be approximated by a linear equation with a positive intercept. The solution then was obtained in three stages.

First, the minimum assembly cost was computed for each possible number of plants. This was accomplished by considering all possible combinations of locations for each number of plants and selecting the particular pattern giving the least assembly cost. If processing or handling costs varied by location, they were simply added to the transportation costs in the first stage minimi-
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zation. Second, the total processing plant cost was expressed as a linear function of plant numbers. With constant long-run marginal cost, the slope component of processing cost is affected only by total volume and not by plant numbers, but the intercept component increases directly with plant numbers. The third step was to add the minimized assembly cost (a decreasing function of plant numbers) to the increasing processing cost function and to determine the number of plants which minimize combined total cost. The exact locations and plant volumes were obtained by reference to the first stage minimization process.

The basic Stollsteimer model has been extended to encompass multiple-product plants by Polopolus [722] and to handle discontinuous plant cost functions by Chern and Polopolus [692]. The latter permits some relaxation of the restrictive assumption regarding the form of the long-run plant cost function. Other modifications and extensions have included a procedure for testing the sensitivity of the model to changes in parameters (Ladd and Halvorson [709]) and a method of approximate optimization which may greatly reduce the very large amount of computer time required for cases in which the number of potential plant locations is large (Warrack and Fletcher [731]).


Although the Stollsteimer model may be used to determine optimum plant location, size, and numbers with respect to either assembly or distribution systems, it is not applicable to situations where both must be considered. One approach to this problem has been to use a transshipment model which is a modification of the basic linear programming transportation model (King [706]). The transshipment model, by classifying each production or consumption area as a possible shipment or transshipment point, gains considerable computational advantage. The first application to agricultural marketing was in a study of livestock slaughter plant location by King and Logan [707]. A "heuristic" technique was used to handle the problem of economies of scale. This involved first specifying a set of (low) costs for all locations, solving, then examining the result for consistency with the economies of scale curve, revising costs, solving again, and so on until no further significant cost reductions were achieved.

The transshipment model was further developed by Hurt and Tramel [704] to handle more than one level of processing, more than one plant at
each level, and more than one final product. Leath and Martin [710] extended the model to include inequality restraints, and Toft, Cassidy, and McCarthy [728] developed a procedure for testing the sensitivity of the model to change in cost elements of the model. Applications to the analysis of market area efficiency have included, in addition to the King-Logan study, a study of fluid milk plant location in Washington by Bobst and Waananen [687], milk manufacturing plant location in Louisiana and Mississippi by Alexander and Ashley [683], slaughter plant location in Queensland, Australia, by Cassidy, McCarthy, and Toft [691], meat freezing plant location in New Zealand by Brodie and McCarthy [688], a study of cotton processing facilities by Hudson and Jesse [703], and plant location for a honey packer by Holroyd and Lessley [701].

Other variants of linear and nonlinear programming procedures have also been used. The basic transportation model was used by Pherson and Firch [720] to determine optimum warehouse location for a multi-plant meat-packing firm, by Lytle and Hill [712] in a study of country elevators, and by Clay and Martin [693] in a study of retail farm machinery dealerships in Virginia. Carley [690] and Hopkin et al. [702] apparently also used the transportation model in studies of fluid milk plants in Georgia and feed-mixing plants in New England, although the procedures are not clearly specified in either report. Miller and King [716] further extended and compared several classes of programming models and computational procedures. These models were applied to the determination of minimum cost locations for peanut-grading plants [717].

Several techniques have been developed to accommodate the computational difficulties that arise with nonlinear long-run total processing cost functions. The Chern-Popopolus extension of the Stollsteimer model to handle discrete functions and the King-Logan heuristic procedure have been mentioned. Kloth and Blakley [708] used separable programming in a study of optimum dairy plant location in the United States. This procedure, which was further elaborated by Baritelle and Holland [686], approximates all nonlinear functions by piecewise-linear functions. Candler, Snyder, and Faught used concave programming to formulate a model to determine optimum rice mill location. The results are reported in Holder, Shaw, and Snyder [700]. Experience with these techniques to date suggests that the best choice of method may vary with the characteristics of the individual problem.

As we have moved from consideration of plant size and location in local assembly areas to the inclusion of wider distribution systems and then to larger geographic areas, the analytical models have overlapped increasingly with the more general models of interregional competition and spatial allocation. Eventually they merge. Any further consideration of location models
thus takes us beyond the scope of this paper. Readers interested in a review of spatial equilibrium and location models should see Weinschenck, Henrichsmeyer, and Aldinger [732] and Takayama and Judge [727].

AREA EFFICIENCY IN GENERAL

The studies just described focused almost exclusively on the design aspects of efficient area organization. From them we may learn, for example, that two plants located at points x and y would in the long run be more efficient than the present twelve for some projected levels of supply and/or demand. Although such information may be of general value in formulating both public and private goals, the results are apt to be rather sterile in the absence of some central planning authority. The models tell us what could be achieved if we could start from the beginning, but they typically provide few clues to how to get there from where we are, if indeed it would be desirable to do so.

We need models which would serve as guides in the establishment of public policies and incentive systems aimed at encouraging an orderly shift toward the optimum structure. The analytical problem is formidable. Consideration must be given to ownership and vertical coordination aspects, the forces of imperfect competition and local monopoly, uncertainty, and technological and environmental changes. The models would need to be extended into a dynamic framework which would encompass the adjustment process over time. This would provide a basis for comparing and evaluating alternative policies and programs aimed at achieving the efficiency goal. With the possible exception of a few milk marketing and interregional competition studies, the studies concerned with production efficiency on the one hand and pricing efficiency and market structure on the other have traveled largely separate paths. If research on area efficiency is to have any real applied value, we will need to merge these concepts into a single dynamic systems approach.

Central Market Studies

The evolutionary process by which city wholesale markets have developed has been far from perfect. The situation in the late 1930s was described by W. C. Crow [743]: "Antiquated, improperly designed and equipped markets, too many markets within a city, inadequate facilities for handling truck receipts, markets without rail connections, unregulated hours, lack of information on supplies, and unethical practices are among the most important problems in the wholesale fruit and vegetable markets of the large cities of the country. The solution of these problems offers one of the most fertile fields for reducing marketing costs with consequent benefits to growers, consumers, and produce dealers."

After World War II the United States Department of Agriculture, with
limited experiment station cooperation, initiated a series of studies of wholesale food distribution facilities that eventually covered nearly every major city in the United States. A number of examples of such studies are listed in the reference section (items [735] to [763]). The list is by no means exhaustive.

Studies of these markets have been of two types. One group has focused on descriptive aspects of market organization—the number and size of different types of firms, activities and services, costs and margins, and changes in the market structure. They provide background information. The more numerous group aims directly at improving the efficiency of the market. The approach has been described as “facility planning.” Although it is difficult to identify a set of principles of facility planning, some fairly standardized research procedures have emerged.

The basic orientation is that of the economic-engineering approach. A typical study begins with a systematic description of the current facilities, market organization, and costs. Inadequacies are identified, and plans are made for improving the system. This may involve simply altering existing facilities or, more commonly, developing plans for new facilities at alternative sites. Usually this includes rather detailed specifications and layouts. Costs and returns are estimated for the new system and methods of financing are considered. Finally, the potential benefits of the new system are evaluated.

Although the systems developed are not necessarily optimal, they ordinarily represent realistically achievable improvements and include within them the plans for getting there. In this sense they go a desirable step beyond most studies of area efficiency dealing with optimum size, numbers, and locations. A possible shortcoming, however, is the failure to include all costs in the analysis, particularly the procurement costs of retailers.

Evaluation of Progress and Achievement

The analytical system concerned with marketing efficiency has evolved through several phases. The end of World War II found us with an inadequate theoretical framework and an undeveloped empirical methodology; most empirical work was directed toward internal plant operations. Then followed a period of concern with developing approaches and concepts appropriate to more sophisticated analysis. Studies at that time continued to focus mainly on plants and production processes. In the late 1950s and early 1960s these studies were extended to encompass assembly and distribution activities. Then came the feasibility studies and area efficiency studies which have been the central focus of much recent work.

We now have available a very good static theoretical framework for mea-
suring costs and analyzing the efficiency of individual firms. It builds on realistic specifications of the way plants operate and incorporates the important dimensions of length of operation and space. It also suggests a means of dealing more effectively with multiple-product operations, although this aspect needs some further testing and elaboration, particularly with regard to economies of scale. Relatively little attention has been given to the operations of firms with several plants, but the problem of so extending static plant theory does not appear formidable. Our theory still does not provide a good framework for incorporating uncertainty, growth, technical change, and variability into cost models. In dealing with integrated operations and total market systems, we find a good framework for the design of efficient systems but a far less satisfactory framework for handling the related competitive structures.

Methodological approaches to cost measurement have become well established, with economic-engineering emerging as clearly the most powerful, most effective, and most widely used method. It is also the most costly method. Inexpensive descriptive analysis of accounting data may be suitable if the objective is only to describe practices and reported cost experience. Problems may arise, however, when an attempt is made to generalize from descriptive data with regard to the effects of scale and other factors affecting costs. The authors of many of the hundred or so descriptive studies reviewed were unable to resist the temptation to do so, and the effectiveness of their work suffered accordingly. 48

Although statistical approaches to cost measurement have evolved well beyond the early naive models which fitted regressions to scatter diagrams of average annual cost and volume data, they are still subject to severe data and specification problems. So far, the results of pure statistical models have been unimpressive and generally uncertain. Statistical analysis may, however, be important for some components of economic-engineering models.

Methods of solving programming problems required to determine optimum numbers, sizes, and locations of facilities within marketing areas have developed rapidly in recent years. Although our capability in this area is now well advanced, we are likely to see further developments in the use of computers to deal with increasingly complex structures.

It is clear that we now have substantial capability for effective study of alternative production techniques, economies of scale, and organizational structures in agricultural marketing. How we are likely to apply this capability in the future is discussed in the remaining pages.

The several hundred studies included in this review vary widely in the depth of the analysis and in the skill and rigor with which the findings have been developed and reported. Many are excellent, but others leave much to be desired. The shortcomings most often observed (and this includes many
studies using the economic-engineering approach) have been (a) failure to ex­
plot the available data to the fullest, (b) a tendency to confuse and combine
the various dimensions and components of cost, and (3) inadequate or nonex­
istent measures or indications of reliability. The first and second deficiencies
arise when studies are developed without a carefully formulated theoretical
base. This means that the empirical analysis cannot bring out all of the cost
interrelationships involved and those measured may be of uncertain character.

Regarding reliability, it could perhaps be argued that many studies are
written for business managers who are concerned mainly with results and are
not interested in technical details. But even a lay reader might like to see
some evidence of the precision and representativeness of the estimates. Eco­
nomic-engineering studies do not automatically generate measures of relia­
bility, but it is possible to compare the final cost predictions against actual
observations (with due consideration for capacity utilization and technology)
and to evaluate the reasons for their differences. This is rarely done.

Another problem that became evident in the course of constructing the
summary of economies of scale findings is the frequent failure to provide ade­
quate explanation and detail. Often the reader has no way of being sure of
the specifications of the model, the exact conditions to which it applies, or
even what it really means. If professional economists have this problem, one
cannot help but wonder about the value of such reports to the average mar­
keting firm manager.

To evaluate the public benefits accruing from the analytical system de­
scribed in this paper we need to consider the general contributions to eco­
nomic knowledge, the direct effects on marketing costs and prices, and the
side effects on employment, income distribution, economic growth, and relat­
ed factors. Unfortunately, there are few quantitative measures of these effects.
About the best that we can do is to compile a list of favorable and unfavor­
able indicators and then attempt to form some conclusion on the benefit­
cost ratio.

On the favorable side, the sheer volume of published reports on marketing
efficiency is impressive. These studies have undoubtedly contributed to our
general understanding of the marketing system and marketing processes in
ways that are difficult to measure in monetary terms. The importance of cost
and efficiency studies in providing materials for the National Commission on
Food Marketing studies in 1966 is one example (see [61, 62, 163, 164, 165,
and 229]).

The theoretical and conceptual developments have contributed to many
course offerings in agricultural economics and also have much broader signifi­
cance. Unfortunately, the available evidence seems to suggest that this work is
not well known to general economists.
Studies pertaining to plant location, consolidation, feasibility, and operating methods have become major activities of the agricultural extension services and the USDA Farmer Cooperative Service. Efficiency models have contributed significantly to these programs. However, reports of such technical assistance often are not widely distributed, and so the extent of the contribution is difficult to document.

Many instances can be cited of research that has had a direct impact on the marketing system — for example, reduced labor costs from studies of handling apples in the northwest, milk delivery studies and their relation to volume pricing in California, scale and feasibility studies which have led to consolidations, and wholesale market studies which have brought about improvements in city markets. Most such improvements appear to have been of eventual benefit to consumers by leading to lower prices. In addition to such specific gains, Trellogan and Townshend-Zellner [82] have shown that productivity has increased in the total marketing system relative to the increased volume of services demanded of it. However, there is no way of determining how much of this was a result of economic research.

On the less favorable side, we still do not know the extent to which the research results have actually been used. We do know that not all of the research has been good research and that not all of it has been well presented. But even economic research that is good in a technical sense (which might describe the bulk of studies) may often be overlooked or ignored by private firms. The plain fact is that, except for a few isolated cases, we do not have much evidence one way or another. At this point we can only hope that the findings have had and will have positive benefits in excess of their cost.

It might be noted that the annual expenditures on marketing efficiency research have been very small relative to the total agricultural marketing bill (probably less than 2/100 of 1 percent of the total). Thus only relatively small improvements in marketing efficiency are required to cover the taxpayers' cost. My subjective judgment, based on the performance measures I have examined, is that the returns to the public have been at least positive. Whether the benefits have matched the legislators' optimistic perception of what originally seemed possible is another matter. Although we may agree with Leibenstein [49] that "improvement in X-efficiency is a significant source of increased output," the record suggests that economic efficiency research alone can provide only modest gains, particularly compared with the gains made possible by technological developments, and by its nature the impact is extremely difficult to evaluate.

The future of marketing efficiency analysis will be shaped to a large extent by our reactions to three issues or points of concern: (1) the potential impact of efficiency research on the structure of the economy, (2) needs and atti-
tudes toward research for public decision making versus private decision making, and (3) possible applications to previously neglected and new areas of research. It has been suggested that possibly the main thrust of developments in marketing efficiency analysis may be to challenge the idea that the market is a better coordinator and planner than a centralized system would be. The models and information generated could lead to a restructuring of the economy with more centralization, more concentration, and more government controls.

Reactions to this suggestion may vary with viewpoints on the trade-off between efficiency and control and the plausibility of the suggestion itself. If one accepts the proposition and is concerned about the undesirable effects of more centralized control, the answer is to curtail expenditures on this type of research. An alternative is to construct models that show the way to improved efficiency while retaining substantial individuality among decision units.

As originally conceived and developed, productive efficiency research was aimed almost entirely at the private decision-making sector. It was expected that competitive forces would reflect cost savings forward to consumers in the form of lower prices and/or back to producers in higher returns. While this still seems likely, rapidly advancing technology, industrialization of marketing and farming, and growth of firm size have made firm efficiency a less important issue in many minds than concentration, integration, quality of the environment, and “people” problems. With these changes in attitude there appears to be increasing reluctance to utilize public funds to support research pertaining to private sector efficiency.

Efficiency research for public decision-making purposes involves the development of larger systems models which may be used to evaluate market structure and performance, marketing control devices, and administered pricing programs. This will require closer ties between models of productive efficiency and models of pricing efficiency. We need to extend industry and area efficiency models to include vertical coordination, imperfect competition and local monopoly, uncertainty, and technological and environmental changes. In developing optimum system designs we must recognize what exists and include in the models plans for formulating realistic programs or policies to guide the shift toward the optimum structure. To compare and evaluate alternative policies and programs in a dynamic framework, we may need to incorporate concepts and procedures from control theory (which is concerned with optimal time paths for decision variables), and probably we will want to draw heavily on concepts in modern decision theory. Simulation may have an increasing role also.
More aggregative types of plant studies, as opposed to detailed economic-engineering studies, may suffice as inputs into the broader models. However, access to the essential cost and price data is a point of concern. Although marketing firm cooperation has been generally good (French [263]), large complex organizations may be understandably reluctant to participate in this type of study. Should this prove to be a serious obstacle, the public interest might require some type of legislative authorization to provide the needed access.

Although extension of marketing firm efficiency analysis to encompass public policy objectives may be desirable, the wisdom of completely abandoning methods improvement studies might be questioned, particularly if supported more by private interests. If Leibenstein [49] is correct in his assessment of the great potential for improving X-efficiency through motivation, better knowledge of technical opportunities, and learning activities, possibly we should be doing more, not less, in this area. Bloom [8], in a recent study of the food industry, states that there is urgent need for increased research effort with respect to the possibilities of improving productivity through implementation of system economies in food distribution. He suggests that some of the necessary research should be undertaken by trade associations, individual companies, and other private groups but that other projects are so complex and have so many interrelationships with other industries that they are beyond the scope of privately financed research efforts. "Quasi-governmental agencies" are suggested as the appropriate place for such projects.

Much of the work proposed by Bloom and Leibenstein seems to require private initiative and an extension or technical assistance more than a research approach. Thus we are still left with some uncertainty about the role of the publicly supported research economist. Dobson and Matthes [24] argue that benefits may accrue from firm-specific work by (1) providing experience that contributes to the improvement of teaching and other research programs, (2) contributing to regional development studies, (3) helping to maintain competitive environments by focusing on smaller firm efficiency, and (4) developing joint studies with several firms cooperating.

Future studies must build on past developments and there are still some neglected areas. For example, we now know a great deal about technical economies of scale, but very little has been done on multiplant operations and pecuniary economies in purchasing inputs. There have been few studies of retail service operations such as farm machinery dealerships, farm supply operations, and grocery stores. And we still have not gone very far in presenting scale economies in a framework that involves variability of output and includes dynamic considerations such as firm growth and expenditures for research and development.
The methods, models, and expertise associated with marketing efficiency analysis would appear to have much to contribute to other types of research. Rural development seems a particularly promising area. In addition to feasibility studies research on the efficiency of providing rural services such as health care is needed (for an example, see Doherty [25]). Methods of solid waste disposal also lend themselves to this type of analysis. Finally, Abbot [1], Currie [20], King [46], Folz [30], and others have noted the need for and potential benefits of studies aimed at improving the efficiency of marketing systems in developing countries.

In conclusion, it appears to me that this review may coincide with the end of an era. The analytical systems for research and our perceptions of problems have evolved in such a way that we increasingly focus on issues that cross traditional production, marketing, and pricing lines. The emergence of Commercial Agriculture Committees to replace separate Farm Management and Agricultural Marketing Committees and the recent reorganization of the USDA Economic Research Service along commodity and analytical lines are indicators of this change. Although we shall certainly continue to be concerned with efficiency in agricultural marketing, future reviewers are likely to have difficulty in identifying it as a distinct area of study.

Notes

1. It is impossible to determine exactly the amount of federal and state funds actually utilized for cost and efficiency research or to separate clearly the expenditures on productive efficiency from pricing efficiency, interregional competition, and related studies. The figures cited have been developed from data obtained from M. L. Upchurch when he was administrator of the USDA Economic Research Service and have been supplemented by rough estimates (see [31, p. 426]).

2. The definitions and distinctions among these types of efficiency are made clear elsewhere in this review.


4. Note that pricing efficiency as used in this context is not the same as pricing efficiency for the individual firm. To avoid confusion, it seems preferable to refer to firm pricing efficiency as allocative efficiency (Timmer, [246]), although allocation decisions are involved in both cases.

5. For additional discussion of these points, see [84, 85, 86, 87, 89, 90, 91, 260, and 264].

6. Reference is made to model formulations in books such as Hicks [38], Carlson [17], Samuelson [70], Schneider [72], and Henderson and Quandt [37].

7. For discussion relating to this point, see Machlup [54].

8. This may be strictly true only where each machine cost function is continuous. With discontinuous functions there may be small ranges in which output rates on one
machine could be slightly increased and another correspondingly decreased without affecting total costs.

9. A stage is independent of another stage if the activities included within the stage are "separable" from other stages. The choice of the amount and type of input at stage i can then be made independently of the choice at stage j. For further discussion, see French, Sammet, and Bressler [401, p. 574] and Sammet [69, p. 50]. The basic mathematical concepts of separability were first developed by Leontief [50].

10. If machine speeds can be varied, some minor short-run substitution of labor and machinery may be possible. For example, operating a forklift truck at higher speeds would increase the rate of machine input relative to labor input, provided that the labor time saved need not be paid for or can be put to other uses. The practical range of such substitution would appear, however, to be highly restricted.

11. The importance of the time dimension in short-run production theory was recognized in the early 1950s by Kutish [48] and French, Sammet, and Bressler [401]. It was discovered and elaborated somewhat later by several general economists (Alchian [2]), Hirschleifer [39], Dano [22], and Georgescu-Roegen [33, 34]), who apparently were unaware of the earlier literary development by Kutish or the more quantitative models developed by French, Sammet, and Bressler. In fact, Hirschleifer noted that his "rather extensive survey of the literature in both economic theory and business economics...failed to turn up any significant attention devoted to this topic." Apparently he did not examine the literature of agricultural economics.

12. For a discussion of managerial choice under institutional restrictions such as overtime pay rates, see Doll, Rhodes, and West [26].

13. For a graphic illustration, see French, Sammet, and Bressler [401, p. 566].

14. To illustrate, if shipment rates are constant and the total quantity produced during T is shipped or moved out during T (no inventory carry-over), the production period storage cost function will have the form

\[ TSC = \frac{wtT(Q - R)}{2} \]

where w is the storage cost per unit of product per unit of time, R is the rate of product movement, and the other terms are as defined previously (see Horowitz [41, pp. 245, 246]). Since \( S_T = tQ \), substituting for t gives a nonlinear function of Q. Since quantity produced \( (S_T) \) equals quantity shipped \( (RT) \), the cost function may be expressed with R eliminated as

\[ TSC = \frac{wtT}{2} Q(1 - \frac{t}{T}) = \frac{wQ}{2}(tT - t^2). \]

15. If the production period, T, is made smaller and smaller, \( S_{T_1} \) merges with \( Q_1 \) (or disappears) and (12) approaches a continuous time model which is called a functional. For a theoretical formulation of factory processes in terms of functionals (including recognition of the rate and length of operation dimensions), see Georgescu-Roegen [33, 34]. His discussion does not, however, deal explicitly with the optimization aspect of the control problem described.

16. For examples of solution approaches and additional references on control theory see [16, 43, 63 (chapter 11), 74 (chapter 3), 81]. Also see "Systems Analysis and Simulation: A Survey of Applications in Agricultural Economics" by S. R. Johnson and Gordon C. Rausser in A Survey of Agricultural Economics Literature: Volume 2, Quantitative Methods in Agricultural Economics, 1940s to 1970s (University of Minnesota Press, 1977).
17. Approaches to the derivation of such functions will be discussed in the methodology sections. For empirical examples, see French, Sammet, and Bressler [401 (pp. 633-700) and 478].

18. Pfouts [67] treats this cost as a continuous function of quantities of fixed factor transferred from the production of one commodity to another. In practice, such costs seem likely to vary discretely. For example, the entire plant may be adjusted to handle one commodity for another period. The switching cost then is fixed and independent of volume produced so the model still decomposes into a set of essentially single-product components with respect to cost variation.

19. The spatial dimension of productive activity is largely neglected in the standard works on neoclassical theory — perhaps reflecting the view that the basic concepts are readily applied to all types of economic activity. The extensive literature on transportation economics, which deals mainly with policy or institutional factors, includes some theoretical models for transport firms — see, for example, [65 and 66]. However, the theoretical concepts most applicable to agricultural marketing firms, as contrasted to specialized transportation firms, have been developed mainly by agricultural economists as part of their empirical studies.

20. Increased volumes of raw products may be acquired by extending the geographic supply area or by raising prices (or lowering service charges) to induce more production in nearby areas. Similarly, depending on location, increased volumes may be shipped to more distant markets at higher cost or sold in nearby markets at lower prices. The present discussion focuses on the geographic aspects. For consideration of the problem of increasing nearby production density versus expanding supply areas, see Henry and Seagraves [567].

21. Boutwell and Simmons [535] show that with route assembly the marginal and average costs of assembly may remain constant over a moderate distance from the plant. Increased volume is handled by adding routes of approximately equal distance instead of extending the length of haul of individual vehicles. Eventually, however, a radius is reached beyond which further extensions require some increase in travel per unit of product assembled.

22. For a general discussion of the differences in approach, see Weinschenck, Henrichsmeyer, and Aldinger [732, pp. 39-48].

23. The concept of harmonious combinations of capacities among stages was first developed by Jantzen [45] and later elaborated by Brems [10]. See also French, Sammet, and Bressler [401, p. 555]. It involves searching for a common denominator of all of the durable factors that may be employed at the various stages — a common denominator representing the output rates that minimize the average total unit cost of production.

24. This comment is not intended as a slight to the contributions of earlier writers on this subject such as Mueller and Collins [58] and Seaver [73]. However, the Mighell-Jones study went considerably beyond these in formulating theoretical structures.

25. For examples of general works on location theory, see [6, 35, 40, 44, and 53]. Beckman suggests that the powerful tools of linear programming have a “tendency to reduce location problems to a format where the geometry of space completely disappears and is replaced by an abstract framework of matrices.” He deplores “the exclusive or even predominant use of this approach.”

27. The shortcomings of accounting data are explored more fully in the section on statistical analysis.


29. The conceptual issues and major criticisms of statistical approaches to measuring cost and production functions have been reviewed at some length by Walters [249] and Johnston [219]. Readers interested in a full treatment are referred to these articles. The discussion here summarizes only the major points as they relate particularly to studies of marketing firms.

30. It is appropriate, however, to use a physical measure such as floor space, provided short-run cost functions are computed for each size (in relation to a measure of output); the long-run cost function then is derived as an envelope to the short-run curves. See Henderson and Quandt [37, p. 75] for a discussion of the theoretical basis for this approach.

31. Economies of scale with variable outputs were discussed in the earlier theoretical section on long-run cost functions.

32. Analysis of covariance has been used more extensively to attempt to estimate production functions, particularly for agricultural operations. The assumptions and interpretations involved in covariance analysis of production functions may differ somewhat from the application to cost functions.

33. Only two examples of cross-section cost envelopes could be found—one by Stollsteimer, Bressler, and Boles [244] and the other by Donald and Bishop [561]. Both were fitted graphically.

34. Methia and Hammond [55] used a modification of the Farrell approach to measure economic efficiency in a sample of apple-packing plants. However, their frontier function was developed from engineering data, not statistically from the observations.

35. Some might argue that while the survivor technique is clearly an empirical technique, it is not a statistical approach in the sense used above. Two other approaches can be identified in this general category: One approach is to obtain managers' opinions about optimum size [197]. The other approach has been called the "lowest labor cost method" [213]. The ratio of wage payment to value of shipments is computed from census data in a particular industry for plants grouped by employment size. The plants with the lowest labor cost as a percentage of sales are presumed to be the most efficient. Because of the seemingly obvious limitations of these approaches, they will not be elaborated further.

36. These reports are listed and partially summarized by Bressler [11].

37. For further discussion, see [69, 261, 267, 271, 273, 279, 280, 401].

38. For a description of work measurement methods and the use and application of standard data, see Sammet [69 (pp. 141-223), 269, 274, 275].

39. This may slightly overstate the relative importance of economic-engineering studies since some of the reports listed in table 2 are descriptive comparisons based on engineering measurements, such as time study, and thus are only a step removed from descriptive analyses of accounting data. Furthermore, tables 1 and 2 undoubtedly overlook some publications. Even so, the ratio is great.

40. Plant efficiency research has also provided an important input in many studies of interregional competition which are not considered in this paper. See "On Economic Optimization: A Nontechnical Survey" by Richard H. Day in A Survey of Agricultural Eco-

41. See Vincent [644] for a bibliography on managerial economics.

42. See Schermerhorn [673], Woodard [682], and Polopolus [721] for additional details.

43. See Dalrymple [652] for a list of related studies. Much of the feasibility work of the Farmer Cooperative Service has been reported only in documents prepared for internal use by the FCS and its clients.

44. Density can, of course, be specified as a continuous function of space. Measuring such a function is likely to be quite difficult.

45. The Bobst-Waanen study [687] makes a stride in this direction by introducing possible institutional or legal restrictions on market concentration. However, the means of achieving even the restricted optimum are not specified.

46. The study by Lyde and Hill [712] gives some consideration to the adjustment process by evaluating the short-run effects of alternative capital structures on the optimal number and type of country elevators.

47. The term “wholesale market” is used here to include groups of businesses which comprise the food distribution center for some city or area. It also includes some assembly markets such as the farmers’ market at Benton Harbor, Michigan.

48. This is not to suggest that a descriptive study cannot be analytical and rigorous. It can, but considerable care must be exercised in drawing quantitative inferences from the data of such studies.

49. For further discussion pertaining to the directions of needed future marketing research, including marketing efficiency and firm management research, see Shaffer [75] and the proceedings of the 1968 Nebraska seminar on better economic research [91].

50. For discussions and examples of environmental issues in agricultural marketing, see Rogers and Vertrees [68], Vertrees [93], and Hudson, Cole, and Smith [42].

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