The progress principle has become a recommended mainstay of policymaking at the level of the firm. But implementing policies regarding progress functions is an ill-defined task because the dynamics underlying firms' progress functions are still poorly understood. In essence, the progress principle as formulated by early pioneers as well as later researchers states that a firm can expect continuous improvement in its input-output productivity ratios as a consequence of a growing stock of knowledge (Arrow, 1962; Hirsch, 1952; Wright, 1936). Use of the progress principle in formulating corporate strategy was advocated by Andress (1954), Hirschmann (1964), the Boston Consulting Group (1970), and others. Its market implications cause it to be seen as an especially powerful tool for managers in competitive environments (Abell & Hamond, 1979; Hofer & Schendel, 1978). More recent work further explores the competitive advantages that firms can gain from the effects of experience via lower costs and via policies on pricing and output expansion (Bass, 1980; Conley, 1970; Dolan & Jeuland, 1981; Enis, 1980; Howell, 1980; Patel & Younger, 1978; Rapp, 1973; Robinson & Lakhani, 1975).

The progress principle is most commonly represented by progress functions. Progress functions differ from learning curves and experience curves in type of improvement and unit of analysis. Learning curves are used most commonly to describe labor learning at the level of an individual employee or a production process, such as an assembly line. Progress functions also may describe changes in materials inputs, process or product technologies, or managerial technologies—from the level of a process to the level of a firm. Because they aggregate effects, progress functions also may reflect improvements not necessarily resulting from increasing knowledge. For instance, they may reflect the effects of revising production methods to accommodate higher expected output levels. The term progress functions (or curves) is separate from experience curves; the latter, though sometimes used at the level of a firm, often are used to describe progress at an industry level. Experience curves also often use price as a proxy to capture progress effects (Boston Consulting Group, 1970), whereas progress functions are expressed in unit costs. This paper uses the term “experience” occasionally, but in the sense that experience is a means for firms gaining knowledge whereas progress is a result of firms gaining knowledge.

Because of their apparent similarity, progress functions are easily confused with other, frequently used
curves in economics and production management, such as long run cost curves and average cost curves (Gold, 1981; Henderson & Quandt, 1980). But the philosophy of dynamic, continuous change underlying progress functions differs sharply from the concepts underlying static cost curves. Emphasized here is the point that firms progress functions show continuing, dynamic cost reductions stemming from their capturing growing knowledge of different forms.

Firms that seek to use the progress principle face implementation issues, two of which are discussed in this paper:

1. What policy viewpoint on the progress principle is suggested by the 50-year history of studies on the concept?
2. What organizational issues arise in managing cost dynamics in the progress curve effect?

As Abell and Hammond note: “Experience does not cause [cost] reductions but rather provides an opportunity that alert managements can exploit. Consequently strategies resulting from market planning should explicitly address how cost reductions are to be achieved” (1979, p. 113).

Such advice is not easily followed. The framework widely proposed for applying the progress principle provides managers with only a single policy variable that can be manipulated, namely, cumulative volume. Predictions of progress using firms’ progress functions have proved unreliable. And underlying causes of cost improvements generally are obscure and poorly understood. These shortcomings render the progress principle of limited use in strategic planning until its underlying dynamics are better understood.

Shortcomings and Potential

Between 1920 and 1980 over 100 studies of progress functions were carried out in a variety of manufacturing-firm settings. These studies highlight the dynamics of production systems and point to opportunities for inducing progress in many cost categories—including production, marketing, and distribution. In popular form, the progress principle states that cost input per unit declines at a uniform rate with cumulative production. An early observation of this principle occurred in the aircraft industry, for which it was noted that direct labor input per airframe declined at a uniform rate as cumulative output grew (Middleton, 1945; Wright, 1936). Since then, the phenomenon has been observed and studied in different work settings and has been widely recommended for managerial control purposes and strategy formulation (Abell & Hammond, 1979; Andress, 1954; Boston Consulting Group, 1970; Hirschmann, 1964; Hofer & Schendel, 1978; Yelle, 1979). The most common formulation of the progress function is the log-linear form:

\[ y = ax^{-b}, \]

where

- \( y \) = input cost for the \( x \)th unit
- \( x \) = cumulative number of units produced
- \( a \) = input cost for the first unit
- \( b \) = progress rate

In progress functions as described above, cumulative production volume is a proxy for experience and provides the only input (policy) variable. As a result, strategies using this functional form usually require that a producer acquire the largest market share relative to competition in order to obtain low-cost producer advantages. Such strategies necessitate increases in rate of production and usually, therefore, scale of operations—increases that are expected to achieve output economies. Faster accumulation of cumulative volume, via an increasing (accelerating) rate of output, also is believed to lead to increasing cost decline with time (Abell & Hammond, 1979; Boston Consulting Group, 1970).

These broad assertions have been examined by others. Lippman and Rumelt (1982) questioned the validity of the market share effect. And, as argued by Corey (1975), Hall (1980), Hammermesh, Anderson, and Harris (1978), and Woo and Cooper (1982), high performance via low-cost producer advantages does not necessarily correlate with high market share. But factors contributing to market share and to overall performance are not comprehensively addressed here. This discussion focuses on those firms emphasizing low-cost production and seeking dynamic cost efficiencies. For these firms, progress functions may be useful tools for analyzing aggregate dynamic effects not captured by static cost curves. But in their current forms progress functions also have serious limitations. In offering cumulative volume as the only policy input variable, they fail to match the complex, underlying dynamics of firms’ costs and imply that building cumulative volume is the only way to achieve progress. However, examination of progress-function studies reveals that sustained production often provides producers with opportunities to effect cost efficiencies that have little to do with cumulative volume. Although commonly used as a proxy for experience, cumulative volume should not be seen as defining the means to gain
In general, strategies using the progress principle involve anticipation of progress based on predictions of values of b (progress rates) in advance of experience. These rates then are assumed to be a given that can be achieved through alert managerial action. Therein lies a problem. Although evidence indicates that progress is widespread (Alchian, 1963), to date it has not been reduced to a stable, explainable, and predictable phenomenon. The progress curve is characterized by major variation. Over 200 empirical studies of progress curves suggest that, although the general notion of improvement with experience is strongly supported, in few instances has it been possible to estimate future progress rates with precision (Dutton & Thomas, 1982).

Figure 1 shows the frequency distribution of progress ratios obtained from a sample of over 100 studies. The studies include manufacturing processes in industries such as electronics, machine tools, EDP system components, papermaking, aircraft, steel, apparel, and automobiles (Alchian, 1963; Baloff, 1966a, 1971; Billon, 1966; Conway & Schultz, 1959; Hirsch, 1952, 1956; Searle & Goody, 1945). All are studies of firms’ progress functions estimating cost behavior (unit or average cost) with cumulative volume. Thus all measure changes in the input-output ratios of processes. No industry-level experience curve studies or studies showing price declines are included.

The variation in results shown in Figure 1 suggests that caution is needed in estimating future progress rates. More detailed breakdowns reveal that not only do recorded rates vary across industries, processes, and products, but they also differ for similar processes and products. Indeed, progress rates have varied widely for subsequent runs of the same product in the same plant (Alchian, 1963; Asher, 1956; Billon, 1966; Conway & Schultz, 1959; Hirsch, 1952, 1956; Nadler & Smith, 1963; Preston & Keachie, 1964).

Problems presented by the high variability and lack of stability in progress functions are rarely treated as major in the management literature. Industry experience curves, as well as firms’ progress functions, are commonly used to advocate managerial policies for firms to attain cost advantages. Industry experience curves often are misleading in showing average price trends correlating significantly with cumulative industry volume. Such trends may mask price variations and be distantly related to costs. In general, the empirical evidence offered in support of industry experience curves fails to address crucial issues such as: (1) Does cumulative experience alone explain a significant part of the observed price reductions? (2) How are long periods of nonprogress accounted for? (3) What do these curves say about industry cost patterns and trends?

More importantly for this discussion, industry experience curves say little about individual firms’ cost dynamics. In any given industry, firms’ progress functions, as well as progress rates, vary widely (Alchian, 1963; Billon, 1966; Nadler & Smith, 1963). This variation extends not only across firms at a given time, but also within firms over time. In military airframe production Alchian (1963) found that using industry-wide progress functions to anticipate firms’ future progress rates led to large errors. Firms’ past progress curves also proved unreliable in predicting their future progress rates. In both cases, the mean prediction errors fell in the 22 percent-25 percent range. Alchian’s conclusions about the problems associated with such predictions were supported by the later studies of Billon (1966), Conway and Schultz (1959), and Hirsch (1952, 1956).

In general, the empirical findings caution against simplistic uses of either industry experience curves or a firm’s own progress curves. Predicting future progress rates from past historical patterns has proved unreliable. Unexpected variability results in costly errors in production planning, and it may be a significant factor in the smaller than expected ultimate profits (Kiechel, 1981; Porter, 1980) found by firms using the concept. Evidence also indicates that the path of progress is subject to control and that certain kinds of progress effects can be induced (Conway & Schultz, 1959; Levy, 1965; Young, 1966). For policymakers these findings are highly suggestive, but they do not illuminate which factors in the underlying process are subject to control; nor do they show how the process can be influenced. Progress curves are aggregate empirical descriptions of a process, and they mask its underlying dynamics.

The mean and modal tendencies of the frequency distribution in Figure 1 suggest a basis for the widely publicized 80 percent progress curve (Andress, 1954; Hartley, 1965; Hirschmann, 1964). But believing that firms achieve cost leadership by accumulating volume faster along this (or another) given...
slopes is fallacious. A firm acting on this belief would be vulnerable to competitors achieving steeper slopes and lower costs for the same—or even less—cumulative volume. Observed variability in slopes could arise from a number of sources, several of which can be controlled. Not all managers accept a restricted range for progress slopes. This may be the reason why several firms in Hall’s (1980) sample achieved lowest cost positions without the benefit of high relative market shares, and why some of Woo and Cooper’s (1982) low market share firms were successful in low growth markets with standardized, slow changing, but frequently purchased, high value added industrial products.

Thus, paradoxically, the existence of high variability presents opportunities for managers willing to explore joint marketing and manufacturing possibilities for attractive market opportunities and potentially steep cost declines. Steepness of cost decline frequency is controllable via creative managerial efforts. Such influences may themselves involve investments, and consequently they need to be considered as part of the expenditure stream associated with a strategy. An understanding of causal relationships can lead production and marketing managers to discover and fill niche opportunities difficult for competitors to pursue. Hence its complex dynamics can make the progress curve a more effective competitive tool.

What also needs to be recognized, however, is that even with rational recognition of cost dynamics underlying progress, managers still may be faced with reaching decisions under conditions of uncertainty. These conditions arise from stochastic elements in the external environment such as technological change in capital goods or in the internal environment from specific firm characteristics (Sahal, 1979).

In the 50-year history of research on progress functions, various attempts have been made to explain the causal factors of progress functions. Traditionally separated by academic discipline barriers, this literature is not well integrated. Studies advocating the use of progress or experience curves, such as that of Abell and Hammond (1979), generally assume that a firm’s progress rate is a predetermined constant to be achieved by exploiting and controlling various sources of progress. Although sources of progress were explored by aircraft engineers in the years preceding and during World War II, empirical evidence validating many of these causes at the firm level is generally scarce. These causal factors also depend for their relevance and importance on macroeconomic conditions and on industry, firm, product, and process factors. Moreover, how these factors interact often is difficult to specify. The history of the development of the progress-function concept, from the 1920s to the present, reveals that although some causes have been validated under certain conditions, the existing evidence rarely warrants many of the common generalizations about progress effects.

This study uses the available progress-function studies as a lens to examine cost dynamics of the firm. Based on these studies, a framework is proposed to disentangle underlying causal factors of progress. The framework illuminates the underlying dynamics and suggests how causal factors and their behaviors may be viewed and controlled by managers. Advocated here is an approach that treats the progress rate as a given constant but as a dependent variable, one that is influenced by a number of potential policy variables.
Four Causal Categories

Actual studies of progress functions reveal four main categories of factors causing progress: (1) effects of technological change; (2) Horndal (labor learning) effects; (3) local industry and firm characteristics; and (4) scale effects. These causal factors (or combinations of them) explain observed progress in varying degrees (Dutton & Thomas, 1982).

Technological Progress in Capital Goods

In 1962 Arrow introduced technological change in capital goods into experience theory with the “learning-by-doing” concept. Arrow’s hypothesis stipulated that investment in a series of improving capital goods creates a changing production environment that contributes to the progress effect. In contrast to studies in which cumulative volume is treated as the sole measure of experience, Arrow emphasizes investment in capital goods as the primary vehicle of progress, with cumulative gross investment considered the main economic variable representing experience.

Sheshinski (1967) presented strong empirical support in several industries for the learning-by-doing hypothesis, finding that cumulative investment in most cases fared better than cumulative output as a proxy for experience. Indirect confirmation of the importance of this cumulative investment effect in the progress-curve phenomenon is found in a number of other studies, both in airframe manufacture (Crawford & Strauss, 1947; Middleton, 1945; Wright, 1936) and in other industries such as shipping, steel, rayon, chemicals, and nuclear power (Baloff, 1966b; Hollander, 1965; Hufbauer, 1966; Joskow & Rozanski, 1979; Searle & Goody, 1945). These studies provide considerable evidence that cumulative investments and improvements in capital equipment explain a significant part of the variation in progress rates in similar processes and facilities. But apparently no attempts to isolate systematically the effects of serially-improving capital goods on the progress function exist.

The Horndal-Plant Effect

The Horndal iron works in Sweden had no new investment over a period of 15 years. However, productivity in terms of output per man hour rose about 2 percent per year (Lundberg, 1961). The Horndal-plant effect thus refers to progress brought about by direct and indirect labor learning for a given set of capital goods. Progress of this type can be attributed to adaptation efforts by labor and technical personnel and to other autonomous cost-reducing effects of sustained production of a good. Although this effect in many instances is closely allied to and interacts with economies of scale, the Horndal effect can and often does occur independently of rate and scale effects.

Many progress-function studies focus narrowly on direct-labor learning as the main cause of the Horndal effect. Such learning, in the strict sense, is improvement in the performance of fixed tasks. But it is only one of the several key factors in the Horndal effect. Improvements in direct-labor input often are due to indirect-labor behavior and learning. A frequent observation is that unless additional tooling and process changes are made by technical personnel, direct-labor input into tasks of fixed design tends to plateau after a certain period (Baloff, 1966a; Chassan, 1945; Conway & Schulz, 1959; Guibert, 1945). In many forms of machine-intensive manufacture direct-labor learning is relatively insignificant and progress is due to indirect-labor learning or technical adaptations by staff personnel or managers (Baloff, 1966b; Billon, 1966; Hirsch, 1952, 1956).

The significance of several causal factors in the Horndal effect has been empirically confirmed (Dutton & Thomas, 1982). The precise nature of the relationship between tooling and process design and rates of cost decline for a given set of capital goods is not yet fully understood. However, attempts have been made to analyze these relationships by Chassan (1945) and others. Product design changes also affect the shape of the progress curve. But the findings regarding their impact are mixed, no doubt heavily influenced by local system characteristics; steep improvement rates have been observed under conditions in which model and design changes (within models) occurred at regular intervals (Conway & Schulz, 1959), as well as when product design was unchanged for long periods of time (Baloff, 1971). Billon (1966) found in his studies of EDP system components and heavy printing machinery that frequent design changes created unpredictable changes in progress rates.

A number of other causal factors such as scheduling, inventory management, quality control, and wage incentives also result in the Horndal effect (Dutton & Thomas, 1982). Although their relationships are not fully understood, the importance of these fac-
tors in explaining a significant part of the observed variation in improvement rates can easily be overlooked.

**Local System Characteristics**

Even firms operating in highly similar markets with virtually identical capital goods and labor skills can vary widely in organizational structure, preferred customers, product mixes, and other operating system characteristics (Child, 1974; Starbuck & Dutton, 1973). The findings of progress studies to date argue for great variety—even uniqueness—in improvement rates for individual firms, plants, and processes. The organizations on which studies have focused are American industrial firms engaged in manufacturing. Often their preeminent concern is with cost effectiveness of operations, and they naturally focus on a particular set of operating factors. The findings indicate that the progress curve is affected by local operating system characteristics such as the degree of mechanization, the ratio of assembly to machining, the length of cycle times, and whether the process is continuous or batch. The only conclusive findings regarding their impact were provided by Hirsch (1952, 1956) in his studies of the manufacture of machine tools. Rates of improvement were found to be significantly different for assembly and machining labor. Thus prediction of improvement rates ought to be tied to local system characteristics. But to date few studies exist about how system characteristics affect experience and what changes may be needed to achieve targets.

**Effects of Scale**

Economies of scale are reductions in average costs attributable to increases in scale, and they can stem from a number of sources. Current progress theory does not distinguish between scale and nonscale effects because progress curves aggregate these effects. Scale is included here as a causal factor because sometimes much of what is attributed to experience is due to scale. For that reason causes of cost reductions often are misassigned. The two effects also are closely related, in that scale can contribute to progress effects, but how this occurs is not yet fully understood. Total unit cost reductions because of increases in production rate can be attributed not only to absorption of indivisible (fixed) costs but also to economies from Horndal-type adaptations that are facilitated by rate increases. Currently, however, findings regarding the effects of the rate of output on the progress curve remain mixed and contradictory. Impressive improvement rates were observed in aircraft production during World War II. During this time huge increases in output took place and new techniques for mass production were introduced. Engineering economies of mass production and extensive tooling for large volumes yielded significant improvements (Carr, 1946; Crawford & Strauss, 1947; Middleton, 1945). Studies of other industries following World War II, for which large volume increases were absent, produced mixed results with respect to the role of scale factors.

A grasp of cost dynamics with respect to scale and progress is facilitated by distinguishing two factors of cost reduction (Alchian, 1959; Hirschleifer, 1962):

1. cost reductions due to increased knowledge resulting from increased cumulative output; and
2. cost reductions due to change in expected volume of production.

The former is akin to the progress curve, because it stipulates that as production continues, knowledge and experience increase and result in economies. Technological improvements in capital goods and the Horndal effect contribute to both these sources of cost reductions. But the latter type of cost reduction is due to varying techniques of production as a function of expected volume. Techniques of production vary in order to exploit economies, mainly in absorbing indivisible costs. These economies can be realized only if production is scheduled in advance. A number of studies show instances in which cost reductions attributed to experience are likely to have resulted from this latter factor (Conway & Schultz, 1959; Wright, 1936). Because of their aggregate nature, progress functions can confound the effects of improvements that do and those that do not result from growing knowledge, as well as mask their dynamics.

**Managing the Rate of Progress**

What is evident from an examination of progress curve studies is that the $b$ parameter (the rate of improvement) is neither fixed nor automatic. In many instances improvement rate is an outcome of managerial policy decisions. More precisely, this parameter seems to depend partly on production decisions, partly on marketing decisions, and partly on joint decisions. Once it is realized and accepted that the rate of improvement is not a given, the question immediately shifts to the issue of how the rate of improvement may be managed.
Progress may stem from exogenous or endogenous sources and may be due to induced or autonomous learning (Levy, 1965). Induced learning requires investment, induction, or resources made available that are not present in the current operating situation. Autonomous learning involves automatic improvements that result from sustained production over long periods. Progress induced in the short run may appear autonomous in the long run, and induced learning at the level of the individual employee or operation may seem autonomous when aggregated over many operations. The distinction among these forms of progress must be made in the context of the time horizon and processes over which policy control is to be exerted. It can be argued that autonomous learning can be influenced by system characteristics, but the purpose here is to distinguish the relative degrees of accessibility to determinants of managerial influence. System characteristics that influence “autonomous” learning to some extent may be inherent, but they also may be cultural and not easily transferred, such as establishing Japanese work cultures in American factories—thus the distinctions: (1) that induced learning is affected by proximate causes and autonomous learning is due to distant causes, and (2) that autonomous learning is more systematic and predictable given a set of system characteristics.

Progress due to exogenous learning usually results from information and benefits acquired from external sources such as suppliers, customers, competitors, and government (Rosenberg, 1982, Sahal, 1977; Von Hippel, 1976). Endogenous learning is attributable to employee learning within a firm as manifested by technical changes, direct-labor learning, and smoothing production flows. These distinctions are illuminated in Table 1 by means of some examples.

This 2 × 2 scheme (Table 1) modifies Levy’s (1965) scheme wherein distinctions are made between induced learning, exogenous learning, and autonomous learning. It distinguishes among sources of progress in each of the four causal categories and suggests where progress may be influenced directly and where control may be more subtle. This scheme also differs from Levy (1965) in that Levy treats random and exogenous learning as one and the same—as consisting of improvements that can result when firms unexpectedly acquire information from their environments. But both endogenous and exogenous forms of progress can be subject to random influence (Dutton & Thomas, 1982; Sahal, 1979). By contrast, progress from exogenous sources can be considered deterministic when a firm takes deliberate advantage of improved capital equipment or sources of material supply.

Although in these instances not well controlled for mixing of effects across cells (such absence of controls is typical of progress-function studies), the 2 × 2 scheme of Table 1 suggests distinct, separate origins of dynamic (and not static) cost changes. The need for research to discover separate types of learning influences for each cell is suggested by frequent but unvalidated assertions about the reliability and origins of firms’ progress-functions such as:

One of the most reliable relationships in industrial economics is that as manufacturers move along the learning curve, unit costs fall steadily and dramatically. Lifetime production volume, rather than proximity to raw materials or markets has come to be seen as the true comparative advantage of the industrial world (Kinkead, 1980, p. 54).

The experience effect whereby costs fall with cumulative production is measurable and predictable; it has been observed in a wide range of products including automobiles, semiconductors, petrochemicals, long-distance telephone calls, synthetic fibres, airline transportation, the cost of administering life insurance, and crushed limestone, to mention a few (Abell & Hammond, 1979, p. 106).

Although in many instances the evidence for an industry or firm-level progress effect is so strong as to be obvious by inspection, this conclusion is irrelevant to managing individual firms’ progress. To predict progress from past data, progress functions must be stable, that is, subject to the same known sources of variation over time and space. But the current evidence is otherwise. On the other hand, to induce progress from variability, managers need documented evidence for specific sources of progress variation accessible to the firm’s influence.

Interactions Among Firms’ Subunits

Exploiting the progress principle thus requires grasping opportunities latent in the cost dynamics of firms. These opportunities are realized through informational and decision processes. But relations between organizational behavior and firms’ progress functions are largely unexplored. By implication the incentive plan originated by Joseph Scanlon, the steelworkers’ union organizer, recognized the potential for inducing progress-function effects by directing feedback at firms’ organizational variables (Frost, Wakeley, & Ruh, 1974; Lesieur, 1958; Mc-
Table 1
Some Examples of Four Learning Types via Which Firms May Capture Progress Effects

<table>
<thead>
<tr>
<th>Autonomous Learning</th>
<th>Induced Learning</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Exogenous origins</strong></td>
<td>1. Learning of capital goods' suppliers induced by the users' experience with the equipment (Joskow &amp; Rozanski, 1979; Von Hippel, 1976);</td>
</tr>
<tr>
<td>1. General growth in scientific and technical knowledge that flows freely into the firm (Nelson &amp; Langlois, 1983);</td>
<td>2. Investment in improved capital goods in order to hasten the rate of progress (Hollander, 1965; Searle &amp; Goody, 1945);</td>
</tr>
<tr>
<td><strong>Endogenous origins</strong></td>
<td>1. Increased tooling (Chassen, 1945; Conway &amp; Schultz, 1959; Wright, 1936);</td>
</tr>
<tr>
<td>1. Direct-labor learning due to the “practice-makes-perfect” principle or wage-incentive plans (Conway &amp; Schultz, 1959; Lundberg, 1961);</td>
<td>2. Manufacturing process changes (Crawford &amp; Strauss, 1947; Middleton, 1945);</td>
</tr>
</tbody>
</table>


Because most causal factors of progress functions cut across organizational subunit lines, intraorganizational relations may influence progress effects. Some opportunities can be acted on separately by functional units of the firm. But, more often, strong interaction terms are present among firms’ subunits in finding and acting on cost-reduction dynamics. Two subunits typically having high potential for joint involvement in managing the cost dynamics of progress are marketing and production. Progress-function and other studies reveal the potential for such joint decisions in each of the four main causal categories. Capacity planning, sales forecasting, production scheduling, quality assurance, and new product introduction are typical areas in which interface is needed on a routine basis between marketing and production managers (Hayes & Wheelwright, 1979; Lawrence & Lorsch, 1967; McCann & Galbraith, 1981; Shapiro, 1977; Skinner, 1979; Walton & Dutton, 1969). Emphasized here is joint policy control in gaining progress benefits, because the nature of progress dynamics is such that marketing and manufacturing cannot be handled independently and induce high rates of cost improvement.

A producer can induce progress by reinvesting such that the effects of the capital goods supplier’s experience (via the improved products) are garnered. The extent and timing of investment may be key determinants of improvement. Effective management of this variable probably is affected by industry concentration, levels of competition, and other industry characteristics. Close interface on these investment decisions is called for between marketing and manufacturing, because decisions on reinvestment in capital goods depend on capital costs, disposal values, and expected net earnings from new equipment. And these earnings, in turn, depend on the productivity of equipment and future sales of products.

Studies of capital goods investment decisions have not recognized the serial-capital goods effect of Arrow (1962) and hence do not explore its potential for business strategy. In systems in which capital spending is a dominant policy variable, the association of increased market share and subsequently greater cumulative volume with experience could lead managers to overlook and misjudge sources of experience. To date, the relationships among the age of capital goods employed, the degree of improvement in newly available capital goods, and progress effects has not been formally studied. However, studies of productivity in industries such as rayon, chemicals, and nuclear power (Hollander, 1965; Hufbauer, 1966; Joskow & Rozanski, 1979) shed light on the dynamics of technological improvement via capital goods (Leiberman, 1982).
Hollander's study (1965) of Dupont's rayon manufacture found:

1. Technological change was closely linked with investment in plant and equipment and replacement was more important than investment in new facilities.

2. Investment in indirect technological changes (designed to "permit the production of higher output levels from substantially unchanged plant facilities") had greater impact on cost reduction than did investment in direct technological change (i.e., change designed to "permit the production of given output levels at lower total costs").

3. The cumulative effect of minor technological changes usually was much greater than that of major changes. Minor changes effected by technical and engineering personnel, often in cooperation with capital goods suppliers, accounted for most of the productivity gains.

Although these findings are partly industry specific, they are useful in revealing firms' cost dynamics. In a study of nuclear power plants, Jossow and Rozanski (1979) found the relative impact of major and minor changes to be somewhat different. Workers effected minor improvements by learning to use and maintain equipment more efficiently. But such progress reaches a stage of diminishing returns. Eventually a major improvement occurs when the system regenerates itself with improved capital goods. Such improvements result from capital goods' suppliers learning from their own as well as from purchasers' experience, and from general technological advances (Shen, 1981).

These findings suggest areas in which policy control can be exerted. Decisions of replacement versus new investment and the timing of such investment are closely allied with expected future sales. Production makes decisions on regular maintenance and replacement of equipment, but it needs to make joint decisions with marketing in order to garner learning effects inherent in newly available capital goods. Whether induced progress via improved capital goods should be direct or indirect (in the sense defined by Hollander) depends on expected earnings. If significantly greater progress can stem from indirect technological change, then, because it means output expansion, marketing needs to seek greater opportunities. Conversely, in periods of growth either by increasing market share or because of growth of primary demand for the product, opportunities for progress via indirect technological change and via scale economies seem numerous. In the absence of demand growth, and if there are unpredictable fluctuations in demand, direct changes may be the most profitable. Erratic demand patterns require technological change that allows the flexibility to produce a range of volumes efficiently. Of course, suitable policies for both production and marketing must lie within the framework of the firm's overall strategy. But recognition of areas in which the two can exert joint influence to induce progress is a starting point for using the progress-function concept.

If local firm and industry characteristics are such that the cumulation of minor technological changes has greater impact than a major change, then opportunities usually arise that production can exploit alone, independent of marketing. Problems arise in routine manufacturing operations that lead to interaction between capital goods suppliers and users and subsequently results in learning via technological improvements.

Progress stemming from factors in the Horndal (labor learning) effect can be divided into induced and autonomous. It can be further divided into policy areas that require production decisions alone and those that require joint decisions. Production makes decisions on personnel and shop management, but both production and marketing criteria influence scheduling decisions and inventory practices. These decisions can facilitate autonomous learning. Such learning results from routine production planning and the "practice makes perfect" principle. Production also can induce progress more directly. Indirect labor and technical personnel in production can directly induce progress via increased tooling and changes in process design (Dutton & Thomas, 1982).

An area in which marketing and production can jointly induce progress effects is product design. A change in product design may occur endogenously because of insights by technical personnel wherein a new design makes production easier and less costly. Marketing then needs to explore product acceptance issues and price differentials that may be obtained. This, in turn, will determine the investment that production ought to make in a new product design. On the other hand, a change in product design may stem from exogenous sources as when it is dictated by external market considerations. In this case, improvement would depend on the level of technical expertise and familiarity with the new
design. Again, close interface and joint decisions are needed to exploit existing opportunities. The two also can jointly influence progress effects in the area of product quality. Quality improvements can be seen largely as an internal production function. But the investment to be made in inducing benefits and progress depends on policies with regard to product positioning and price, policies largely in the marketers’ area.

Policy control over local system characteristics could affect progress either by direct inducement or by facilitating autonomous learning. Internal design variables, such as the degree of mechanization, the ratio of assembly to machining labor and the length of work-cycle times, can be controlled by production alone to influence progress. On the other hand, marketing directly influences policy decisions with regard to factors such as the firm’s preferred customers and its product mix, factors that can significantly affect scale economies and progress effects.

Local characteristics vary greatly in their accessibility to managerial influence. Organizational design and structure, plant design, work cultures, and so on usually are less accessible and more difficult to transform once established. Nevertheless, they are components of local systems that affect progress by contributing to (or detracting from) several forms of autonomous improvement. But here, too, opportunities arise to effect beneficial changes such as redesign of organizational structure to delineate areas of joint production and marketing policy control to induce progress.

The effects of scale and progress are so closely intertwined that separation of the two often is a difficult task. But scale economies (and their contribution to progress effects) represent an area in which numerous opportunities arise for inducing progress. Economies from varying techniques of production for different volumes of output can be realized only if volume is known in advance. In order to induce this aspect of progress, interface and cooperation between marketing and manufacturing is essential. Improved tooling that yields economies is a form of adaptation that is relatively short run in value; progress-inducing investment in improved capital goods is a long run adaptation. A firm that seeks to manage progress effects so as to gain competitive advantages confronts several issues:

1. Does the cumulative effect of regular short run adaptations or inducements yield significant progress relative to a long run inducement?
2. When does the cumulative progress due to short run inducements asymptote?
3. When and how does the system have to be regenerated in order that progress may continue?

Most systems display a pattern of several short run adaptations that are periodically “interrupted” by a significant long run adaptation. The causal factors of progress discussed here fall into one or the other of these categories based on industry, firm, techno-
logical, and market characteristics. Investments in improved capital goods, changes in organizational and plant designs, major scale changes in the ‘fixed’ factors of production (such as capital goods, absolute plant size, average direct labor employment), and most changes in product design are designed to effect long run improvements and position the firm to proceed down a progress curve that is different from the current one. On the other hand, most factors in the Horndal effect, scale effects that arise from routine operations and, minor technological improvements in equipment (Hollander, 1965), can be considered short run adaptations.

In the diverse literature on progress functions and their use, the causal factors underlying progress vary widely. In general, economists emphasize technological change in capital goods and scale economies as the primary causes of progress. Studies in the industrial engineering and management literature focus on factors in the Horndal effect and local system characteristics. The emphasis on dynamics also varies significantly. For instance, Levy (1965) incorporates the asymptotic property of the progress function and treats progress as consisting of essentially one-time adaptations to a predetermined target. Arrow (1962), on the other hand, emphasizes serially-improving capital goods and their continuous impact on progress. Studies of organizational effectiveness are not strictly progress-function studies, but their concerns include learning and progress. They are essentially static in nature, and learning is treated as a step function that changes the system from one steady-state to another (Miles, 1980; Nadler & Tushman, 1977).

Without an understanding of how different causal factors interact and influence firms’ cost dynamics, prescriptions for using the progress principle, have limited value. The literature lacks longitudinal studies that control for different factors, thus isolating relative effects. The state of the art does yield a framework for managerial use in exploring different bases of progress and in considering impacts of organization on progress effects. Inducing progress reduces to a problem of return on investment; a firm’s maximum spending to induce progress depends on the profits required from a given strategy, for which the costs of inducing progress are reflected in the strategy’s expenditure stream.

**Conclusions**

Traditional progress functions are limiting in implying that manipulation of costs is best attained by maximizing cumulative volume of output. Contrary to widespread assertion, the rate of improvement in a firm’s traditional progress function of the form \( y = ax^{-b} \) cannot be relied on as a constant based on past performance. Instead, it needs to be treated as a dependent variable influenced by a firm’s behavior regarding a set of causal factors. An examination of five decades of progress-function studies reveals four causal categories underlying firms’ progress ratios. Varying between origins internal or external to firms, these causal factors also differ in how they arise, by being induced or autonomously. Reexamining firms’ historical progress functions in this light illuminates factors that may be emphasized and controlled to meet firms’ future progress-rate goals. In highlighting the dynamics underlying progress, this approach also indicates factor combinations that may need to vary from past practice to achieve future progress goals.

Decisions regarding progress rates involve a priori investment considerations as well as ex post implementation issues.

Approaching firms’ progress functions in this fashion reveals the absence of studies linking dynamic cost progress with organizational behavior. Because of the interdependence among causes of progress and because these causes cut across firms’ hierarchical and subunit as well as organization-environment boundaries, a combining analysis of progress-function and organizational behavior variables constitutes a research opportunity. Relations among firms’ major subunits, such as between production and marketing, may significantly affect progress rates. Examining such interunit relations in terms of four causes of progress suggest a wide range of opportunities for research and application on progress functions and their uses.

**References**


Kiechel, W., III. The decline of the experience curve. *Fortune*, October 3, 1981, pp. 139-145.


John M. Dutton is Professor of Management in the Graduate School of Business Administration, New York University.

Annie Thomas is Assistant Professor of Management in the Graduate School of Business Administration, New York University.