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Chapter VII

TECHNICAL CHANGE AND COSTS

It has been observed repeatedly that in the framework of economic theory the costs of a single enterprise with established plant and equipment are held to depend upon three factors. One, the impact of variations in the rate of operations on costs, was the subject matter of Chapters IV and V; a second, the effects of changes in factor prices on costs, was treated in Chapter VI. The present chapter is focused upon the third, the physical productivity of the factors employed by the firm and the technical effectiveness of their combination.

In our society, characterized as it is by spectacular and rapid innovations, "technological change" has become a byword. The widespread, and at times almost romantic, interest in technological developments is intensified by the highly important fact that for the first time an economy is "organized" to accept and encourage them. With a large volume of resources employed in research, technical changes can no longer be attributed to haphazard individual initiative. Perhaps the most popular theme in general discussions of technology has been the effect of innovations on the displacement of labor. This topic is not, however, directly of major concern to this study,[1] which seeks rather to observe the impact of innovations on the various elements of costs. This aspect of "technical change" has certainly also received considerable emphasis, especially in debates over "stagnation." It has been maintained that cost re-

[1] For a rather comprehensive summary of discussions concerning the effects of technological changes on the volume of employment, and for references to the main works, see Alexander Gourvitch, *Survey of Economic Theory on Technological Change and Employment* (National Research Project, Philadelphia, 1940).

ductions brought about by "technical change" offer a substantial medium through which idle resources may be reabsorbed.[2]

1. Matters of Definition

It is rather surprising that in most discussions of technology, even among economists, so little attention has been paid to what constitutes an innovation. At times "technical change" is identified with mechanization. This misconception is associated with the notion that innovations occur infrequently but in a spectacular fashion, with shattering effects. That the identification of technical change with mechanization reflects a narrow view is evident as soon as one considers instances of the effect of increased skill and training of wage earners on output, and the consequences of improved organization, techniques of management and coordination of factors. Empirical studies, moreover, easily disprove the contention that technical change is infrequent and spectacular. The Bureau of Labor Statistics study of a firm in the agricultural implement industry revealed that over 600 changes were made in an operating tractor model within a period of two years.[3]

In this discussion the terms "technical change" or "innovation" will be used to imply *any change in input-output relations which is not to be attributed directly to changes in factor prices or variations in the rate or scale of production of the enterprise in question.*[4] "Any change in input-

[2] Sumner H. Slichter, "Business Looks Ahead," *Atlantic Monthly* (November 1939), p. 596.

[3] Temporary National Economic Committee, "Industrial Wage Rates, Labor Costs and Price Policies," *Monograph No. 5* (Washington, 1940), pp. 131-37, 141.

[4] This definition is in accordance with economic analysis; ordinary usage of the term is much more ambiguous. *The Handbook of Labor Statistics* (Bureau of Labor Statistics, *Bulletin No. 616,* 1936, pp. 709 *et seq.*) defines "technological change" to "include all change . . . which results in higher productivity per manhour." This latter term is held to mean "work done in a given time." The *Handbook* recognizes, however, that this use of "productivity" must be distinguished from the "'effi-

output" relations is intended to cover variations in amount of output from the same input factors, in quantity of input factors producing the same output, in the combination of factors employed, or in the quality of input factors or product under conditions of given "plant." An innovation may arise from a change in the effectiveness of a single factor or from the way in which the various factors are combined. It is very important to observe that this definition excludes changes that might have arisen from variations in the two other determinants of costs in the system of economic theory. However, as will be indicated later in this chapter, substitution among factors as a result of price changes and variation in the rate of utilization give rise to very serious problems when one attempts to measure the rate of technical change. An increase in output per unit of labor input may be caused not by any change in the technical effectiveness of wage earners, or by any variation in the intensity of their effort, but simply by a substitution of other factors for human services as a result of wage increases. For instance, raw material of better quality, which requires a smaller amount of finishing or takes less time to process, may be purchased at a higher price.

In any study of the single enterprise it is important to recognize that technical changes may originate in other sectors of the economy, particularly in earlier stages of the productive process, and yet vitally influence the input-output relations of the firm. Whether or not these transmitted technical changes will affect the factor prices paid by the firm depends on both the effect of the technical change on the costs of the supplying enterprise and the character of the market in which the firm purchases the factor. In any event a single enterprise at the end of the productive process may be but the point at which technical changes made in other enterprises emerge. A change in the

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ciency' of labor, or any other term which is narrowed down to express only the output due to the ability and willing cooperation of the workers themselves." See footnote 6, p. 53 above.

input-output relations of a publishing firm, for instance, may arise from changes in the making of pulp, the metal used in the type, the skill of typesetters, or the managerial techniques of transportation companies. Since the productive process is the result of a number of interdependent forces, a technical change introduced at one point may have marked ramifications throughout the system.

It is necessary, too, to draw a distinction between technical change and invention. A technical change implies some actual variation in the productive process, whereas an invention merely indicates the possibility of change. The invention must be put into operation in an enterprise before it can become a technical change. This is perhaps an unusually broad view of invention; ordinarily the discovery of a way in which to increase the skill of wage earners, for instance, would not be designated an invention. It cannot be inferred, of course, that every invention becomes a technical change. Indeed the fact that many inventions have not eventuated in technical changes is an indication of the new technical opportunities open to an enterprise. The extent of the gap between invention and utilization is a subject about which much might be learned.

Identification of technical change with mechanization sometimes implies a one-to-one correspondence between a patent and an invention. Even if this were true a patent could be no more than a phase of the invention, for "invention is a process, the granting of a patent being only an incident in the process."[5] But not every invention is patented; some may not meet the standards of the Patent Office in their interpretation of an invention; in other instances patent fees and litigation may be prohibitive compared to possible benefits; and in still other cases inventors may regard a patent as unnecessary. There can be little doubt that many technical changes (as defined) are never

[5] National Resources Committee, *Technological Trends and National Policy* (June 1937), p. 6. See also, *Hearings before the Temporary National Economic Committee,* Part 3, "Patents, Proposals for Change in Law and Procedure" (January 16-20, 1939).

patented at all; and many patents are, of course, never embodied in operating techniques.

Any definition of technical change is bound to raise the crucial question of the meaning of "fixed plant and equipment." The preceding chapters have been set in the context of the "short run": plant, equipment, and organization are assumed to be unchanged. (Chapter X discusses the way in which costs vary with the *size* and the *scale* of an enterprise.) However, since many technical changes, such as improvements in cutting tools, result in a change in "plant" as measured by technical capacity or the least-cost rate of output, the issue arises whether the impacts of such changes on costs are to be related to technical change or to variations in size of plant. It is clear that this problem is not involved in all technical changes. An improvement in the skill of wage earners or the quality of purchased materials and supplies would not be regarded as a possible change in "plant." Strictly speaking, it is impossible to assume "fixed" plant and, at the same time, to separate from accounting records the cost effects of technical changes in factors that constitute overhead (in the sense developed in Chapter IV) from variations in size of plant. Since interest in the effect of size of plant on cost is usually specified in rather large changes in output (relative to the industry in question), the influence of size of plant—with technique varying as size increases—will be neglected in this discussion when changes in potential capacity or the lowest-cost point are small. That is, plant is regarded as "fixed" unless the technical change causes output to vary "significantly."

It has been customary in economic thinking to classify technical changes as either labor saving or capital saving.[6] While this dichotomy is useful for general theoretical purposes, it does not lend itself very readily to empirical work, partly because the diverse types of agents that contribute to output are compressed into the two categories of capital and labor. Substitutions among various types of capital or

[6] See J. R. Hicks, *The Theory of Wages* (Macmillan, London, 1935), Ch. VI.

kinds of labor have no place in this scheme of classification. Since a great many technical changes undoubtedly are characterized by intra-capital and intra-labor substitution, a wider classification of factors would be necessary for empirical studies.

A further difficulty with this capital-labor saving category emerges from its reference to the effects of a technical change on the whole economic system. An innovation can be classified only after the initial effects in a single enterprise have worked themselves out through the entire economy. A technical change might at first be labor-saving, but finally come to be designated capital-saving when the total effects were appraised. Instances of technical change do not readily fall into these theoretical pigeonholes, first because an innovation is classified by its effects, and second because these effects are the total or net effect on the whole system. In view of these difficulties it would be useful for empirical investigation to distinguish between a classification of technical changes and an appraisal of the immediate or ultimate effects of the innovations.

It is suggested that types of technical change be classified according to the character of the substitution involved among factors *in a single enterprise*. Although the detail in factor classification will vary with special interests, the division will certainly be finer than simply "labor" and "capital." The following breakdown of productive factors provides an example of classification of substitutions whereby innovations in industry could be grouped more readily: (1) unskilled labor, (2) skilled labor, (3) supervisory labor and management, (4) clerical workers, (5) salesmen, (6) purchased materials, (7) fuel, (8) plant, (9) equipment and tools, (10) containers, (11) variable or circulating capital. Substitutions probably could be made between any two of these factors, so that in this example 55 types of technical change are possible. If changes in proportions involving more than two factors are considered, these types are multiplied many times. Only detailed empirical study could reveal which of these substitutions were most typical. Such an inquiry would not be simple because the designation of a technical change, as defined in this section, is in itself difficult. One would have to make certain first that the observed substitution was not due exclusively to changes in the rate of output or to variations in factor prices. The problems involved in eliminating the influence of these two determinants of cost will be considered in the next section. For an empirical study of typical patterns of substitution, however, it is not necessary to measure precisely the magnitude of technical change. What is required is to recognize that there has occurred a substitution which is not to be attributed entirely to factor price changes or to changes in the rate of output. Such a task, though far from easy, is not impossible, for similar output levels can be found and factor prices may have moved against the change or may have remained relatively constant.

A few specific cases will illustrate the usefulness of the concept of technical change that has been developed in this section, and in particular the diversified types of substitutions that actually take place. It has been impossible, on the basis of the information available, to ascertain that these substitutions did not arise in part from changes in factor prices and rates of output, but the presumption is that they were not controlling influences.[7] (a) The great increase in the use of instruments to maintain constant temperatures or pressures in blast furnaces and in similar operations seemingly represents a substitution of instruments for fuel. (b) The replacement of the bundle system by the line in the making of cotton garments is a more complex innovation, involving the substitution of skilled labor and some equipment for circulating capital. It is unnecessary under the line system to have as large an inventory of goods in process. (c) In iron ore mining the use of special dynamites instead of black powder appears to be an instance of the substitution of purchased material for

[7] These examples are taken from the studies of the National Research Project.

skilled labor, since with the dynamites a smaller number of holes must be drilled per ton of ore mined. (d) The adoption of induced drying fans in the manufacture of bricks provides an interesting substitution of equipment for circulating capital. This equipment reduces considerably the amount of time required to manufacture bricks, since it is no longer necessary to wait for sun and atmosphere to dry them. (e) The substitution of rotary for churn or cable drilling in petroleum oil well drilling involves both a shift from one type of skilled labor to another and a replacement of one kind of equipment by another.

2. *Measures of Technical Change*

An increasing number of studies in recent years have purported to measure the rate of variation in "technological change."[8] Without an exception these statistical investigations have taken the change in "output" per manhour, or per employee, as a measure of the rate of "technical

[8] The following studies may be mentioned: Spurgeon Bell, *Productivity, Wages and National Income* (Brookings Institution, 1940); National Research Project, *Production, Employment, and Productivity in 59 Manufacturing Industries* (Philadelphia, 1939); Witt Bowden, "Wages, Hours and Productivity of Industrial Labor, 1909 to 1939," *Monthly Labor Review* (September 1940, Reprint Serial No. R1150); Bureau of Labor Statistics, *Productivity and Unit Labor Cost in Selected Manufacturing Industries, 1919–40* (Washington, 1942); Mordecai Ezekiel, "Productivity, Wage Rates, and Employment," *American Economic Review*, XXX (September 1940), pp. 507-23; John Dean Gaffey, *The Productivity of Labor in the Rubber Tire Manufacturing Industry* (Columbia University Press, 1940); Nahum I. Stone, Alfred Cohen and Saul Nelson, "Productivity of Labor in the Cotton-Garment Industry," Bureau of Labor Statistics *Bulletin No. 662* (1939); W. D. Evans, "Mechanization and Productivity of Labor in the Cigar Manufacturing Industry," Bureau of Labor Statistics *Bulletin No. 660* (1939); Boris Stern, "Productivity of Labor in the Glass Industry," Bureau of Labor Statistics *Bulletin No. 441* (1927). Other studies by the Bureau of Labor Statistics have been made in the boot and shoe, plumbing and heating supply, woolen and worsted, cement, lumber, cotton textile, and clay products industries. See also, *Technology on the Farm*, A Special Report by an Interbureau Committee and the Bureau of Agricultural Economics of the United States Department of Agriculture (1940).

change."[9] Professor Mills has suggested a measure of "physical output per unit of productive effort" as an indication of the change in "productivity."[10] In actual statistical work, however, he approximates this concept by output per manhour. Thus indexes of the change in "productivity" of industries or the total system have been calculated simply by dividing indexes of output or production by indexes of manhours or number of wage earners employed. The rather wide and indiscriminate use of these statistics in wage negotiations,[11] in popular discussions, and even in technical economic journals calls for a scrutiny of the meaning of such an index and its relation to the definition of technical change set forth in the preceding section.

It will be convenient to start such a critical appraisal by designating the situations under which an index of output per manhour may vary. First, a change in the rate of plant utilization may influence output per manhour, depending on the character of the input-output relations. Second, a change in relative factor prices may induce a substitution among labor services and other factors; for instance, a rise in the price of high quality raw materials may mean that a cheaper material requiring more labor is used. Third, since all skills of labor are equally weighted by the hours of employment, a change in relative wage rates may induce a substitution among different types of labor and a change in output per manhour. Fourth, a special difficulty arises when data for more than one firm are combined to present industry figures (and all indexes of "productivity" are of this character). The addition of less "efficient" firms at high levels of industrial output, coupled with their disappear-

[9] Numerous devices have been used to measure "output." For instance, Gaffey, *loc. cit.*, adopts number of tires, tire miles, and pounds of crude rubber as measures of "output" in a study of "productivity" in the rubber tire manufacturing industry.

[10] F. C. Mills, "Industrial Productivity and Prices," *Journal of the American Statistical Association*, XXXII (June 1937), pp. 247-62.

[11] For an instance of judicious use of such statistics, see: Steel Workers Organizing Committee, *Brief Before a Panel of the War Labor Board*, Cases No. 30, 31, 34, 35 (1942), pp. 55-80.

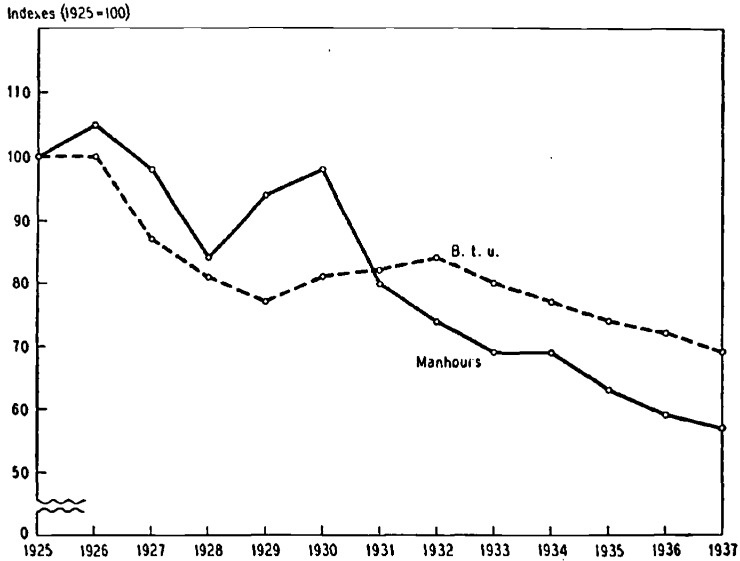
ance from business in periods of depression, introduces another factor which may induce changes in output per manhour or per wage earner. Fifth, variations in the size and scale of plant may result in an altered combination of factors and hence a change in output per manhour. Sixth, an index of output per manhour may vary because of technical changes, as defined above, resulting from the substitution of other factors for any type of labor included in the manhour data. This heading includes the impact of "undermaintenance" of equipment and other resources upon output.[12]

To designate as a change in "productivity" the variation in output per manhour arising from the first five of the above factors is certainly a mistake, or at best a peculiar conglomerate useful only for specialized purposes. For the system as a whole there may be some sense in indicating the way in which output per manhour has fluctuated. A study of the path of output per manhour may be useful in predicting the probable increase in output for small changes in increased manhours of application. Such data might be especially interesting for war economies, but certainly they could hardly be expected to give an accurate picture of the variation in technical change as defined here. In addition to including the effects of too many factors, indexes of output per manhour may ignore certain types of technical change or give rise to incorrect inferences concerning their magnitude. As far as final effect is concerned, a substitution between two nonlabor factors resulting in increased output is indistinguishable from more intensive labor effort or training, which also brings about an increase in output. Indeed, the attempt to measure in terms of a single factor the change in the input-output relations of a combination of factors is necessarily misleading. If the same number of manhours produced the same amount of product with one half the raw material or one half the amount of plant, it would be absurd to say that no technical

[12] The phenomenon of "undermaintenance" cannot be readily handled within the framework of traditional economic analysis.

change had taken place simply because output per manhour remained unchanged. The fundamental difficulty of measuring input-output relations in terms of a *single* input factor is illustrated in Chart 5. It is presumed that output is roughly equivalent to crude oil input in the petroleum refining industry. Then input of labor per unit of "output" is compared to input of BTU (heat) per unit of "output."

Chart 5
INPUT OF LABOR AND HEAT
PER BARREL OF OIL REFINED, 1925-1937



B. t. u. from TNEC Hearings, Part 15, p. 8635.
Manhours from WPA National Research Project, PETROLEUM AND NATURAL GAS PRODUCTION, p. 329.

As would be expected, the two curves show materially different movements for the period 1925–37. Another drawback associated with indexes of output per manhour is that such measures take on all the limitations of production indexes noted above in Chapter V. Technical change which eventuates as improved quality of product, for instance, defies statistical measurement.

These difficulties raise the question of how indexes of output per manhour could ever have been presumed to measure technical change. Some explanation is required because changes in output per manhour would appear to bear little necessary relation to technical change, particularly for the short run. It can be suggested that this emphasis on output per manhour is consistent with the labor theory of value. If capital goods and all other factors can be reduced to units of stored-up labor power, then the relative change in manhours required to produce a unit of output (factor prices and output unchanged) is a measure of the effectiveness of the input factors. All factors are reduced to the single denominator. This view would, however, require the inclusion, in the estimates of manhours employed, of the manhours "stored up" in other factors, a procedure which has not been adopted in statistical work. If it were adopted, indexes of output per manhour would be meaningful, at least within the framework of the labor theory of value.

The wide use of indexes of output per manhour as measures of "productivity" is still somewhat perplexing in view of their potential divergence from the theoretical concept of technical change developed in Section 1. Yet available measures of this sort show an upward trend, indicating largest increases at the points where they might be expected in the course of the cycle; in brief, they seem to work. This is not entirely inconsistent with the above criticisms. Should the dominant pattern of substitution be that between other factors and labor, and should this tendency be very pronounced, indexes of output per manhour would be significantly influenced by this movement. While such indexes would still overestimate and underestimate technical change in the ways suggested immediately above, the "errors" could be relatively small compared to the major movement. The indexes might serve as rough approximations to technical change where the rate of substitution between other factors and labor came close to the rate of substitution in all other cases. Since no way exists of verifying the importance of these possibilities, one cannot place much confidence in indexes of output per manhour as measures of technical change. The mere fact that they move in the direction that might be expected cannot instill any faith in the magnitudes they indicate.

Series of per unit cost or total cost and output offer an opportunity for measuring technical change which has not as yet been exploited. Apparently the basic problem in measuring changes in input-output relations is to find common denominators for the diverse factors combined to produce different kinds of output.[13] Aside from money costs, there are no units with economic meaning whereby diverse inputs may be combined into a unit of productive factors. Hours of labor service, tons of steel, miles of wire, and yards of cloth can be amalgamated only through costs. In fact it is precisely this problem, in its practical aspects, that confronts business executives. They must seek the least cost combination of factors at each alternative output level, given the technical productivity of each possible grouping. If all the influences affecting costs other than technical change are measured and their impact is removed from the series of per unit cost, then the remainder may be attributed entirely to technical change. Specifically, the effects of factor price movements and variations in the rate of operation would have to be eliminated.[14] For this purpose the following data in addition to the per unit cost series would have to be available: (a) all factor price variations, (b) a cost breakdown showing the relative importance of each factor in total costs, and (c) the shape of the cost function. The first two series make possible the removal of the effects of factor price changes and the third permits elimination of the effects of varied output.

[13] Since output indexes were considered in Chapter V, only the problem of a common denominator for input is considered here.

[14] Costs are made a function of three variables: rate of output, factor prices and technical change. If technical change is made a statistical residual, it cannot exactly approximate the formal definition of Section 1. Factors not specified as determinants of cost, such as rate of change of output and size of order, will influence this statistical measure of technical change.

Among other difficulties, this procedure involves a logical snag. The measurement of technical change is required before the cost function is approximated. But the shape of the cost function itself is a prerequisite to the measure of technical change proposed above. After the effects of factor price variations have been eliminated from a series of per unit costs, no entirely satisfactory method is available to "split" the time series into the component attributable to output fluctuation and that derived from technical change. If some shape be assumed for a cost function—for instance, a linear relationship between costs and output—then the residual pattern can easily be ascribed to the influence of technical changes. Only if a specific relation between output and costs is presumed can the influence of technical changes be isolated. Unless the technical change and output components are presumed to fluctuate in precise and *different* patterns, no separation is possible. The difficulty is identical with that involved in splitting output per manhour series into output and technical change components. The comparative patterns are imposed on the data since the effects of technical change are presumed to be linear.

An index of the rate of innovation derived from cost data would seem to have many advantages over the usual output per manhour series. In the first place, the effects of all possible types of technical change would be included, whereas, as has been noted, series on output per manhour attempt to measure the change in input-output relations for all factors in terms of a single one, namely manhours of labor services. Second, the effects of changes in factor prices would be eliminated from cost data; in output per manhour series no correction is ever made for substitutions between factors attributable solely to relative price changes.[15] Third, the difficulty arising from the influence

[15] The deflation of costs to remove the influence of factor price changes does not indicate exactly how costs would have varied when factor price changes have caused substitution. It is not ordinarily practical in dealing with empirical data to separate precisely the influence of technical change and substitution.

of variations in the rate of plant utilization is not peculiar to cost data. Moreover this problem may be circumvented in several ways. Engineering estimates of cost, showing different elements in cost over time, can be made for the same rate of utilization.[16] Or spot comparisons can be made for two similar levels of output. Again, as has been suggested above, an assumption can be made as to the shape of the cost function, based upon specific estimates of management or general knowledge of the enterprise. Several estimates of the rate of technical change may be derived on the basis of different assumptions concerning the shape of the cost function. If two extreme estimates of the shape of the cost function are reached, they will at least establish limits for the rate of technical change. There is no guarantee, of course, that these limits will be narrow enough to be useful.

A final point relevant to the subject matter of this section concerns the *direction* of technical change. It is usually asserted that technical change is irreversible, moving always in the direction of increased output per unit of input.[17] This statement is not without ambiguity. It may simply imply that once a technical change has been made the experience is not forgotten by the enterprise. But much more is usually intended—that input-output relations always vary in the direction of a larger product with the same "amount" of factors or the same product from a smaller "amount" of factors. From the perspective of the enterprise, of course, no decision to worsen the input-output relation would be made unless there were serious price changes. In this sense technical change is always positive. From the viewpoint of an observer, however, the input-

[16] Boris Stern, "Mechanical Changes in the Woolen and Worsted Industries, 1910 to 1936," *Monthly Labor Review* (January 1938), used such engineering estimates to calculate output per manhour changes between the two years at 100 percent of "capacity operations."

[17] This proposition is inconsistent with output per manhour series as a measure of technical change, for some series show decreases in output per manhour, at least for short periods in certain phases of the business cycle.

output relations of an enterprise may become less favorable in response to considerations other than the rate of operations. The technical productivity of wage earners, for instance, may be deliberately reduced in a "slow down" or fall as a result of excessive hours of work under war conditions. The quality of available raw materials may become poorer. Or, because of the immediate financial position of an enterprise, plant and machinery may be retained in use for such a long period that the "same" input factors result in a smaller output. In this report, nevertheless, positive technical change will be considered the normal case.

3. Decisions Concerning Technical Change

The translation of inventions into technical changes, it has been noted, requires the active decision of business executives. This section discusses the kinds of calculations and the types of considerations involved in the formulation of such decisions. Since technical change has been regarded in this chapter as much broader than mechanization alone, more decisions are associated with it than with, say, the purchase of a new machine.[18] A number of innovations concern only those factors which have been classified under the major headings of labor and materials, and may contribute, moreover, only to the output of the current period. For instance, the substitution of one type of steel for another or the introduction of a bonus wage scheme presents a relatively simple problem to be decided on the principles of comparative marginal costs and marginal receipts. No "capital" expenditure is involved in the sense that the output of more than a single period is necessarily affected. Any such change is completely reversible for the next period without "loss." Few changes, in fact, are confined in their effects to a single period.

In addition to these technical changes which affect only current receipts and costs, certain innovations may involve no change in either current or prospective costs but are

[18] See Appendix C.

expected to influence the stream of receipts. Variations in style and minor changes in design are frequently of this character. Here the innovation will be adopted whenever the present value of all prospective receipts is increased. The corollary case of a technical change affecting costs alone and leaving the expected stream of receipts unchanged will arise whenever the present value of all future costs is lowered. This type of technical change may be illustrated by variations in the methods of production which do not appreciably alter the product. It is possible to give a much more detailed statement (as is done below) of the circumstances under which technical changes will be undertaken by an enterprise, and at the same time keep the statement broad enough to include the case in which both prospective costs and receipts are altered. But added details in no way affect the fundamental proposition, ordinarily stated with reference to replacement, that "a producer continues to use existing equipment as long as, *ex ante*, it is cheaper to operate equipment in use than to buy and operate replacement equipment" [19] or that "replacement occurs whenever enterprise value is enhanced thereby." [20] Any decision involving technical change consists of a comparison of cost and revenue prospects under current methods of production and existing styles and designs of products with cost and revenue prospects under all possible alternative methods, styles and designs.

The test of the desirability of a replacement is made on the basis of the present worth, at a specified date, of prospective payments and receipts. The payments and values which are affected by purchase or nonpurchase, and should therefore be included in any formula, are as follows: [21]

[19] Joe S. Bain, "The Relation of the Economic Life of Equipment to Reinvestment Cycles," *Review of Economic Statistics*, XXI (May 1939), p. 82. See also John B. Canning, *The Economics of Accountancy* (Ronald Press, 1929), Ch. XIV.

[20] Canning, *op. cit.*, p. 83.

[21] All payments or receipts which remain unchanged whether or not the new machine is purchased have been canceled from the formulation. The term "machine" is used in this context to refer to any technical

(1) The expected operating savings in each future year. Let us call this saving in the first year T_1, in the second year T_2, and so on up to T_n in the nth year, where n is the number of years in the period of comparison. This period is the interval between the proposed date of purchase and the date at which a reconsideration of the problem will be required if no machine is purchased, ordinarily the end of the expected life of the old machine or machines. It should be noted that because of (a) variations in the volume of business, (b) possibilities of still newer machines or different methods of production, and (c) changes in wage rates or other factor prices, the different T's will usually not be the same, and the error of estimate will almost always be larger for later years than for those in the near future.

(2) The total present worth of expected operating savings for the next n years, discounted at the interest rate "r," is:

$$\frac{T_1}{1+r} + \frac{T_2}{(1+r)^2} + \ldots + \frac{T_n}{(1+r)^n} = \sum_{i=1}^{i=n} \frac{T_i}{(1+r)^i} = P_n, \text{ say.}$$

(3) Designate the cost of the new machine "C."

(4) The net salvage value (V) of the new machine at the end of its normal life, N years hence.

(5) The net salvage (v) of the old machine or machines to be replaced by the new machine, at the end of its or their expected life n years hence.

(6) The net salvage value (v + e) of the old machine or machines if sold at date of purchase of new machine. If the old machine is not sold, but is transferred to other uses in the plant, an imputed value of not less than what it could be sold for should be used.

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change involving a commitment in one period designed to contribute to the output of future periods. For instance, expenditures on a training program for foremen or the installation of "improved" lighting facilities are included in this term in the following pages.

The discussion of the next few pages is drawn from a memorandum entitled "Theoretical and Actual Criteria for Purchase of a New Machine" prepared by R. W. Burgess of the Western Electric Company, a member of the Committee.

(7) The residual value (R) of the new machine at the end of n years. If, as is usually the case, available engineering and economic information is not adequate to justify a real estimate of residual value, R may be taken to be

$$C - \frac{s_n}{s_N}(C - V)$$

where s_n is the compound amount of $1 per annum at the end of n years, s_N at the end of N years.

The purchase of the new machine will therefore be desirable if the present worth of the net gains resulting from its purchase exceeds the present worth of the net costs, that is to say, if

$$P_n + v + e + \frac{R}{(1 + r)^n} > C + \frac{v}{(1 + r)^n}.$$

If we neglect the salvage values of the old machine and the residual value of the new n years hence (as may often be done without significant error), this formula reduces to the statement that the new machine will be profitable if the present worth of the operating savings in the period of analysis (n years) exceeds the cost of the machine.[22]

The above discussion has been presented specifically in terms of replacement of a "machine" (see footnote 21, above), but a modification in form will allow for instances of technical change that cannot be construed to involve any "replacement." Although a consideration of the question is beyond the province of this chapter, an investment expenditure will be undertaken if the present value of the net proceeds from the expenditure exceeds by a small margin the rate imputed to funds on hand on the basis of alternative uses.[23]

[22] This is the end of the material drawn directly from Mr. Burgess' memorandum.

[23] See J. M. Keynes, *General Theory of Employment, Interest and Money* (Harcourt, Brace, 1936), pp. 135-64, Michal Kalecki, "The Principle of Increasing Risk" in *Essays in the Theory of Economic Fluctuations* (Farrar and Rinehart, 1939), pp. 95-106. Also Walter Rautenstrauch, *The Economics of Business Enterprise* (John Wiley and Sons, 1939).

It would require much empirical study to estimate the extent to which the economically correct calculations represented in the above formulae are approximated by business executives who are considering a technological change.[24] The formulae assume that accurate and precise knowledge is available for each of the magnitudes influencing the decision,[25] but these magnitudes at best can only be estimated, and with varying degrees of confidence. Logically, the allowance for the difficulties of estimation could be made by a single average probable error after the calculations had been carried through with the most probable value of each magnitude, *or* each separate item could include an element of uncertainty in estimation. Under the second alternative the most probable operating savings would be deflated and the service life of the new assets reduced in proportion to the confidence in the most probable values. What is known of the actual thought processes of business executives indicates that the latter procedure is generally followed. Mr. Burgess suggests[26] that these "safety factors" are characteristically introduced into calculations in the following ways: (a) The possible salvage or residual value of the new machine at the end of the period of analysis is neglected. (b) In calculations an interest rate is used that greatly exceeds the rate at which an enterprise may borrow in the open market or at banking institutions.[27] Insofar as such a rate is simply that which

[24] Appendix C surveys some of the numerous "methods" and "formulae" suggested as guides to replacement by engineers and business managers.

[25] This discussion does not imply that actual decisions are made by the steps indicated in the above formulae. The models only provide a logical construction of the factors which would explain technical change decisions within the framework of ordinary economic theory.

[26] See footnote 21, above.

[27] If the interest rate or credit terms change with the amount of borrowing of a firm, as may very well happen, "we must distinguish a marginal cost of outside funds higher than the interest rate paid. This marginal cost then becomes the rate appropriate for calculations within the firm." Albert G. Hart, *Anticipations, Uncertainty, and Dynamic Planning* (University of Chicago Press, 1940), p. 43.

the enterprise can earn on its funds in other uses, no "safety factor" or allowance for errors of estimation is involved. Essentially the same sort of calculation is applied when a profit rate is added to the "market" rate of interest. (c) The use of the straight line method of depreciation as compared to the sinking fund involves an overestimation of the probable depreciation costs of the new machine. "The investment which is entitled to draw interest should be reduced by the accrued depreciation." A factor of conservatism may be added in this fashion. (d) The most probable service or time life of the new asset may be reduced by an amount proportionate to the degree of confidence in the calculation. What will determine this confidence will be the possibility of shifts in demand, style obsolescence, the emergence of superior assets within a relatively short period and the amount of previous experience with the particular machine. The rates of depreciation so employed in the calculations preliminary to the adoption of a "machine" thus may be higher than those carried on the books of the enterprise for income accounting. While the validity of this differential is certainly questionable, the device of changing the most probable estimate of service life by an amount to correct for the reliability of estimation is not subject to debate. Allowances for the degree of confidence that can be put in estimates may be introduced into calculations of "replacement" in at least these four ways.

There is considerable scattered evidence relating to the kinds of calculations business executives make in introducing technical changes that involve outlays for *equipment* lasting "over" several periods. This evidence is frequently in the form of answers to the question of how long new equipment will take to "pay for itself." A questionnaire sponsored by *Manufacturing Industries* in 1927 reveals that of 88 companies replying, 37 had no definite period in which new equipment must pay for itself, 12 allowed varying periods depending on the type of equipment, and 39 had fixed periods. Of the last 39, twelve companies had set 2 years as the period, six companies 3 years, eight companies 5 years, and a single company 7½ years.[28] The weighted average of the companies specifying definite periods was about 3 years. This kind of evidence is ambiguous, however, because the types of plant or equipment are not specified.

The Bureau of Labor Statistics study of an enterprise in the agricultural implement industry showed the necessity of distinguishing between various types of assets which were purchased for a single plant in the period 1930–39.[29] Certain minor appropriations, shown in Table 9, "paid for themselves" very rapidly. The same story can be told from

TABLE 9

COMPARISON OF SELECTED APPROPRIATIONS AND "SAVINGS"[a] IN AN AGRICULTURAL IMPLEMENT FIRM

Year of Installation	*Appropriations on which Estimates of Specific "Savings" were Calculated*	*Estimated Annual "Savings"*	*Actual First Year "Savings"*
1935	$ 61,900.00	$ 66,853.80	$ 48,697.00
1936	160,160.00	124,027.80	102,645.00
1937	180,260.00	326,059.40	250,217.00

[a] The specialized meaning of "savings" must be noted. The volume of "savings" effected is greatly influenced by the volume of production—the larger the production the larger the "savings" from an appropriation. Furthermore, estimated and actual "savings" are calculated for only the first twelve months rather than over the expected life of the machine.

an array of 23 of these appropriations by the length of time in which it was estimated they would "pay for themselves." The annual savings anticipated on 18 of these 23 appropriations were sufficient to return the investment involved in two years.

[28] Questionnaire sent out by L. P. Alford, editor. Volume XV (January 1928), pp. 27-30.

[29] Temporary National Economic Committee, *Monograph No. 5* (Washington, 1940).

But these appropriations were almost exclusively for such items as tools, minor equipment, rearrangements of assembly line or parts manufacture in keeping with a change in design of the product, and adjustments in storage facilities and plant organization. The appropriations that "turned themselves over" so rapidly were largely, although not exclusively, for items on which one would expect very rapid obsolescence because of changes in style or design, new methods of production, or contemplated changes in lines of production. In the language of the discussion above (pp. 161-62), the confidence in the estimates of the service life of these types of assets would be very low. This need not be true for all appropriations which are similarly expected to "pay for themselves" in periods of one to three years. Rules of thumb, resulting in errors, may develop in an enterprise. Under such circumstances a proposal for technical change may be rejected although a more careful inquiry by the firm could have shown that the change would be profitable.

TABLE 10

APPROPRIATIONS FOR WHICH ESTIMATED "SAVINGS" WERE CALCULATED, 1935-38

Time Required to "Pay for Themselves"	*Number of Appropriations*
Under six months	9
Six months to one year	4
One year to two years	5
Over two years	5

Decisions respecting technological changes, even more than most decisions, are in any modern corporation the joint product of a number of people. Such changes require the coordination of research engineering, sales and financial departments of an enterprise. Among these groups there may well be friction and conflict of interest. The sales department may want an innovation at once to "capture" a particular segment of the "market" while engineering officials prefer to wait until it has been perfected. Or the financial powers may regard outlays as too uncertain on the scale recommended. There is evidence to suggest that the cash position of the enterprise may have a decisive influence on expenditures for innovations. Joint discussion among these departments may be important only for major changes. An innovation may be introduced on the initiative of a single department if the change is small enough. Various types of technological change undoubtedly require different degrees of coordination among the organizational units within an enterprise. Here the steps and processes whereby technical changes are introduced constitute a field for useful study.[30]

4. *Cyclical Pattern*

It is not the purpose of this brief section to explore the relations between technological change and the business cycle.[31] The emphasis is rather on collecting the available evidence that would illuminate the question of the rate of innovation in different phases of the cycle. If adequate indexes of technical change existed, this would be a relatively simple matter, but Section 2 demonstrated the severe limitations of series on output per manhour. More scattered and less directly applicable bits of evidence must therefore be utilized. A variety of these isolated data suggest a cycli-

[30] See Ruth P. Mack, *Business Funds and Consumer Purchasing Power* (Columbia University Press, 1941), pp. 237-305.

[31] It must be noted in passing that many authors have linked the business cycle directly to technical change. Professor Schumpeter, for instance, contends that "[Economists] have a habit of distinguishing between and contrasting, cyclical and technological unemployment. But it follows from our model that, basically, cyclical unemployment *is* technological unemployment . . . Technological unemployment . . . is of the essence of our process, and, linking up as it does with innovations, is cyclical by nature. We have seen, in fact, in our historical survey, that periods of prolonged supernormal unemployment coincide with the periods in which the results of inventions are spreading over the system and in which reaction to them by the system is dominating the business situation, as, for instance, in the twenties and eighties of the nineteenth century." *Business Cycles: A Theoretical, Historical, and Statistical Analysis of the Capitalist Process* (McGraw-Hill, 1939), Vol. II, p. 515.

cal pattern in which the most rapid rate of technical change occurs during the middle of the expansion phase, with a slackening off toward the peak, some increase in the rate in the earlier part of the contraction, and another slackening off toward the trough. Variations in this pattern are to be expected, of course, from enterprise to enterprise. The separate pieces of evidence, statistical and qualitative, that support this cyclical pattern of technical change are discussed *seriatim*. Very few of the following items "demonstrate" the suggested thesis, but all of them are consistent with it.

(1) The expenditures on research in industry seem to follow the cyclical pattern for the rate of technical change outlined above. A questionnaire distributed by the National Research Council,[82] relating primarily to the personnel of research departments and agencies of business enterprises, was sent to a sample list of companies in the years 1920, 1921, 1927, 1931, 1933 and 1938. The number of research employees[83] in 575 identical companies for the years since 1927 is shown in Table 11. While these data do not refer directly to the volume of expenditures, it is probable that they show an essentially similar pattern.

TABLE 11

RESEARCH PERSONNEL OF 575 IDENTICAL COMPANIES[a]

Year	*Number*
1927	15,439
1931	22,342
1933	19,255
1938	26,956

[a] Perazich and Field, *Industrial Research and Changing Technology*, p. 65.

[82] George Perazich and Philip M. Field, *Industrial Research and Changing Technology* (National Research Project, Philadelphia, 1940), p. 55. The statistical data are based on the several surveys of the National Research Council, analyzed by the National Research Project. See also, National Resources Planning Board, *Research—A National Resource*, "Industrial Research" (Washington, 1940).

[83] Research employees included chemists, physicists, engineers, metallurgists, biologists, bacteriologists, and research assistants and technicians.

(2) A much less direct piece of evidence is contained in figures on patent applications filed. Although not so marked in regularity, a cyclical pattern is discernible in periods of wide fluctuation in income.[34] Table 12 shows patent applications for the period 1924–39.

TABLE 12

APPLICATIONS FOR PATENTS FILED, 1924–39[a]

Year	*Applications Filed*
1924	79,689
1925	82,213
1926	85,279
1927	89,360
1928	93,592
1929	92,029
1930	96,227
1931	88,707
1932	77,792
1933	64,244
1934	60,363
1935	62,414
1936	66,339
1937	70,830
1938	74,485
1939	74,153

[a] *Reports of the Secretary of Commerce.*

(3) The Bureau of Labor Statistics study of an agricultural implement firm suggests that since the research personnel fluctuates less than output, during periods of reduced output additional efforts can be directed toward basic research and the working out of plans for innovations. At high levels of output a great deal of semiroutine work is necessary. But in slack periods more coordinated attention can be given to plans for innovation which can be

[34] See, *Hearings before the Temporary National Economic Committee*, Part 3, "Patents, Proposals for Change in Law and Procedure" (Washington, January 16-20, 1939), Exhibit 179, p. 1123.

made effective as output increases again. This temporary diversion of routine personnel in research and engineering departments can be rather important.

(4) In general, the tendency to postpone replacement during depression periods and the disinclination to make financial outlays result in a bunching of innovations with the recovery phase of the cycle. In fact, it is frequently contended that this bunching is the core of the recovery. While it is commonly recognized that enterprises do postpone replacements at low output, this tendency can be explained on other grounds than the desire to conserve a cash or credit position. "User costs" (the nonlabor cost incurred in the substitution of current output for future output)[35] of replacement might be very large because of the possibilities of improved equipment at a later date. Since replacement is not necessary to current output in times of depression, user costs can be reduced by postponement of replacements. As output expands in the recovery phase, technical changes are introduced in the form of accumulated replacements as well as through additional expenditures on new equipment and other factors.

(5) The brief increase in the rate of technical change in the earlier part of the contraction phase of a cycle, suggested in the above pattern, is to be accounted for by attempts of business executives and departmental representatives to reduce costs with rapidly falling output. The "wastes and inefficiencies" of the boom are singled out for elimination. Such innovations are apt to be of a character that would not require large capital expenditures.

5. *Research Suggestions*

(1) As indicated in Section 2, an important contribution can be made to the measurement of technical change by the calculation of indexes based upon cost data with the technique suggested in the text. A comparison of these results with series on output per manhour could then be made.

[35] See Chapter IV, above.

(2) One of the topics relating to the impact of technological change on costs and prices that deserves empirical study is the way in which an innovation spreads from enterprise to enterprise in a market area. The circumstances surrounding the rates of acceptance of technical changes would undoubtedly show wide disparity between innovations. Some gain complete acceptance by all enterprises soon after they are first introduced; others spread much more gradually. Any persistent patterns of the rates of introduction among different types of innovations or types of market situations would be a discovery of considerable importance.

(3) A series of case studies could reveal the kinds of calculations made by business executives when they consider innovations. With reference to particular changes, it would be instructive to show all the data that were presented to those making the decisions, the length of time the project was debated, and the chief pressures for change both within the firm and outside it.

(4) As suggested in Section 1, a more extensive study of innovations could render a useful service by discovering typical patterns of substitution. Labor saving and capital saving categories of economic theory are not amenable to empirical use. It is possible to develop a more useful classification scheme which would encourage comparative studies of innovation in different firms and industries.