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Factor Substitution and the Composition of Input

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Scope of the Paper

THE introduction of a new method in the production of commodities or services regularly involves substitutions between input factors, including such "factors" as general business organization, technique of financing, etc. In the last few centuries the development of industrialism has been largely dominated by the substitution of durable producers' goods for human labor. The main stimulus for the absolute and relative intensification of investment in real capital was supplied by technological innovation. Substitution of real capital for labor in response to innovations which made the increased use of machinery and equipment technically feasible and economically profitable is even today the main instrument for actualizing productivity gains which the preceding change in the "production function" has made potentially available. However, even without change in technology, the rate of capital investment may be affected by changes in certain economic variables. This paper discusses some questions connected with the impact, upon the rate of mechanization and capital investment within a *given* technology, of exogenous changes in either of the following two variables:

1. The price of labor, by upward pressure on money wages. This is a chapter in the economics of factor substitution in response to a change in relative factor costs. The discussion on the following pages will be focused on the problem of evaluating the quantitative importance of this substitution effect, compared with other determinants of the relative intensity of capital investment. A few remarks will be added on the question of whether, and under what special assumptions, the stimulating effect of increased wage rates on mechanization and real capital investment may be welcomed as indirectly promoting general progress in industry.

2. The rate of the income tax imposed on industrial producers. While this variable is not itself a factor cost, it affects the (rational) choice between productive factors involving different degrees of capitalization. The mechanism by which, and the direction in which, this effect operates, will be made the subject of a brief analysis. Questions regarding the comparative quantitative importance of this variable, as well as questions of value judgment, will be left outside the discussion. But a brief glance will be cast at the probable connection of this mechanism with the development of capital coefficients in American industry during the last few decades.

The "Ricardo Effect" and the Development of Labor Productivity

It is rarely questioned that an upward pressure on money wages exercised by powerful unions may under certain conditions spur the adoption of more capital-intensive methods in industry. But as to the importance of this stimulus, compared with other incentives to increased investment in real capital, contemporary expert opinion is far from united. In a recent article "What Makes Productivity Grow?" Karl Borch of the European Productivity Agency, without definitely committing himself, inclines to the extreme view that the pressure for higher wages by organized labor, occasionally backed by legislation, is the main prime mover behind the steady increase in industrial productivity. (Borch seems to think primarily of labor productivity while management plays a more or less passive role.)[1] He says that little statistical evidence seems to be available to support any other hypothesis.[2] American union officials, trying to bring out the merits of an aggressive wage policy, have repeatedly reasoned along similar lines.[3] For a recent statement propounding the opposite view we may refer to Marvin Frankel's contention that the effect of upward wage pressures on the rate of investment in additional equipment can be no more than marginal by comparison with the

[1] *Productivity Measurement Review*, No. 14, August 1958, p. 28.

[2] *Ibid.*, p. 29.

[3] In a symposium based on talks given at the 1956 Pennsylvania State University Automation seminar (*Labor and Management, How They Look at Automation*), T. F. Silvey, of the National AFL-CIO Department of Education, epitomized this argument in favor of an aggressive union wage policy in the sweeping antithesis that employers were willing to use cheap labor as long as it was cheap, but turned to their engineers and ordered machines and equipment to take the place of men as soon as trade unions made labor expensive. (*Ibid.*, p. 74.) Cf. also S. Barkin, "Trade-Union Attitudes and Their Effect on Productivity," in *Industrial Productivity*, ed., Industrial Relations Research Association, 1951, p. 122.

really basic determinants of this rate.[4] The fact that so sharply divergent views have been advocated quite recently seems to justify taking another look at the matter.[5]

At the outset it will be useful to distinguish between two questions. For one thing, it has been asserted that an upward pressure on money wages stimulates discovery and invention by making the search for new labor-saving procedures even more imperative than it would otherwise be. Factual evidence on the quantitative significance of this tendency is scanty and inconclusive.[6] One leading authority has assured us some time ago, in fairly definite words but without going into corroborating empirical details, that collective bargaining does tend to accelerate technological discovery, and that this is one of its most useful effects.[7] On the other hand, a study of 1951 (which seems to be the only available empirical investigation) concludes that the effective rate of research and discovery in industry has little or no relation to either the level or the movement of wage rates.[8] Until substantial evidence to the contrary becomes available, the latter view must be regarded as the probable state of the matter, at least in this country.

The second question turns on the proposition that an upward trend in the price of labor accelerates the rate at which industrial management adopts labor-saving devices already known. The proposition defines a process of substituting capital for labor in response to the latter having become relatively more expensive, the assumption being that before the change in the cost ratio the various labor and nonlabor resources were used approximately in what was then the optimal (least-cost) combination. Of course, the incentive to substitute machinery for manpower becomes blunted to the extent that the upward push of wages raises the cost of machines, too. But it would probably be too mechanical to assume, as is sometimes done,[9] that machine prices always rise *proportionately* when wages go up.

[4] M. Frankel, *British and American Manufacturing Productivity*, University of Illinois Bulletin No. 81, 1957, p. 12, Footnote 5.

[5] For an earlier discussion, see Bloom and Northrup, *Economics of Labor and Industrial Relations*, 1950, Chapter 19.

[6] See the recent summarizing survey by G. H. Hildebrand, "The Economic Effects of Unionism," in *A Decade of Industrial Relations Research, 1946–1956*, Industrial Relations Research Association, Publication No. 19, 1958, p. 133.

[7] S. H. Slichter, *The Challenge of Industrial Relations*, 1947, pp. 90–1.

[8] G. F. Bloom, "Union Wage Pressure and Technological Discovery," *American Economic Review*, September 1951, p. 606 f. Cf. also J. Shister, "Trade Unionism, Collective Bargaining, and Economic Growth," *American Economic Review, Papers and Proceedings*, March 1954, p. 220.

[9] Cf. Friedrich and Vera Lutz, *The Theory of Investment of the Business Firm*, 1951, p. 137, and the literature quoted there.

Besides, it normally takes time for the effects of rising wages to work themselves through the price system. Sometimes, e.g., in the first postwar decade in this country, the rise in machinery prices has lagged the upward movement of wage costs quite markedly.

As Ricardo was one of the first to discuss this substitution,[10] it is today frequently referred to as the "Ricardo effect."[11] Under what conditions may this effect be expected to come into play, and how frequently are these conditions present in industrial practice? Let us first ask what light is shed on this question by the traditional textbook theory of the demand for productive inputs, that is, by the marginalist models which describe the connection between relative factor costs and the proportions in which the factors should be used to make net revenue a maximum.

One important qualification of the contention that a relative rise in the cost of labor is bound to stimulate capital investment is suggested by the marginalist approach itself, which postulates that any change in the relative costs of two productive factors generates not only a "substitution effect" but a "scale effect" as well.[12] The combined net impact of the two effects on the demand for each of the factors is quite different according to whether a change in the price ratio between the two factors is caused by a decline in the price of one factor or by a rise in the price of the other (or by a combination of both movements). Suppose that the cost of L (labor) relative to the cost of C (capital) goes up 5 per cent. Let us assume for the moment that the conventional capital/labor surface is a suitable analytical tool. This may have come about by a 5 per cent rise in the cost of L, the cost of C remaining unchanged, or by a 4.762 per cent decline in the cost of C, the cost of L remaining as before. In the latter case, the impact of the scale effect on capital investment is in the same direction as that of the substitution effect; they both stimulate it. Production as a whole becomes cheaper, total output of the final product, assuming an unchanged (downward) slope of the demand and marginal revenue curves, expands, and the demand for both C and L

[10] D. Ricardo, *The Principles of Political Economy and Taxation*, Chapter I, Sec. 5, Everyman's Library, No. 590, p. 25.

[11] The term was coined almost two decades ago by F. A. Hayek (*Profits, Interest, and Investment*, London, 1939, p. 8), who attempted to make this "effect" the cornerstone of a theoretical explanation of the upper and lower turning points of the business cycle. In this theorem, which we are not planning to go into, the term "Ricardo effect" refers, not to an exogenous wage increase originating in union action (the case we are concerned with) but rather to endogenous changes in real wages due to price level shifts as the economic system moves from one cyclical phase to another.

[12] See, for instance, K. Boulding, *Economic Analysis*, 3rd ed., 1955, pp. 764 ff.; P. A. Samuelson, *Economics*, 3rd ed. 1955, p. 482–3; R. G. D. Allen, *Mathematical Analysis for Economists*, 1947, p. 374.

rises (although the latter at a smaller rate). In the other case, only the substitution effect makes for enlarged investment; the scale effect acts in the opposite direction. A rise in the price of one factor while the price of the other remains constant is bound to exercise some upward pressure on the supply price of the product, even when factor substitution is possible in some degree. For the producing agency, the substitution of *C* for *L* is here, in contradistinction to the first case, always a "lesser evil" measure. While it reduces total cost below what it would be without the substitution at the new wage level, it cannot entirely prevent total cost from rising above what it was at the old wage level. Again assuming an unchanged downward slope of demand and marginal revenue curves for the product, this means that some depressing effect on the rate of the salable output is bound to remain despite the intervening substitution. In the net impact on the demand for *C*, the scale effect may in many situations outweigh the substitution effect. In other words, production may have to be curtailed to such an extent that even the demand for *C*, while rising relative to the demand for *L*, will decline absolutely, or at least in relation to what it would be had the price of *L* remained unchanged. In any event, the asymmetry in the manner the two effects combine in the two cases suggests one of the few safe generalizations about our question: Other things equal, a rise in labor costs (capital costs unchanged) should not be expected to stimulate real investment to nearly the same degree that an equiproportional decline in the cost of capital equipment (labor costs unchanged) would do.

The actual relative weights of the substitution effect and the scale effect in the case of a rise in wage costs depend on several variables, and the interrelations are, in part, rather complex. Thus, when the demand for the product is highly inelastic and the producer is therefore able to pass much of the wage increase on to consumers, the scale effect will not be much in evidence; but then the incentive to substitute will not be very strong either. Or, consider another variable, the relative importance of the wage bill in the expenditure budget of the producer. It has been emphasized that an addition to a wage bill which had already bulked large will make entrepreneurs more alert to substitution possibilities than a comparable addition to a relatively smaller wage bill would do.[13] However, in the former case there is greater likelihood that, after all substitution possibilities have been exhausted, the new wage bill will yet be too high to justify continuing the production on the former scale. Still another important variable is the size of the wage increase itself. Here again, a large increase will produce a relatively large substitution effect and a relatively large

[13] Bloom and Northrup, *ibid.*, pp. 471 ff.

counteracting scale effect as well. In all these instances it seems hazardous to generalize about the net impact on the demand for capital.

For the rest, the net impact depends primarily on the extent to which substitutions of the kind here called for are possible in given situations. Thinking in terms of what has long been the basic analytical tool in the theory of the business firm, the neoclassical production function—with its gently sloping curves suggesting unbroken factor substitutability over wide ranges—one might be tempted to conjecture that opportunities for substitutions between labor and capital in response to even minor shifts in relative costs would turn up at every corner. Here, however, certain limitations of the conventional model in explaining the decision-making of individual producing units come into the picture. It may be useful at this point to recall some of these limitations before casting a brief glance at the empirical evidence.

In all commodity or service production, factor substitution is incidental to process substitution. Primarily and directly, it is processes, not factors, that are being substituted for one another. By the strict definition which activity analysis has adopted, and which is specifically tailored to reflect the economics of industrial decision-making, a process is a productive event (or a series of such events) in which inputs of specified quality (or input composites of specified qualitative and quantitative mix) are combined in specified proportions to produce output that is likewise specified as to qualitative composition. Two productive events that differ only in over-all scale of production are instances of the same process, although at different levels. Otherwise—when the qualitative input or output mix is altered, or when the internal ratios of qualitatively unchanged input or output elements are varied—the two productive events are instances of different processes.[14] Obviously, the technology available to a firm at any given "state of the arts" consists of what may be called a family of processes whose members are technologically substitutable for one another.

Let us now recall the basic marginalist model, the production function for a single output. In the two-factor case it is represented by a contour map on which technological possibilities of factor combinations for assumed output levels are pictured by a family of downward-sloping isoquant curves. Total factor cost at these levels is represented by a family of declining straight isocost lines, and the optimum level

[14] Cf. R. Dorfman, *Application of Linear Programming to the Theory of the Firm* 1951, p. 14.

of use of the two factors at any assumed rate of output is determined by the familiar tangency condition, the point of tangency shifting as the angle of the cost line (representing the ratio of factor prices) changes. Calling the two factors measured along the two axes "labor" and "capital," the question arises whether the substitution possibilities between labor and nonlabor inputs in industrial practice are as near-ubiquitous and as direct as this representation suggests.

They would be if all the families of processes covered by this representation were what we might call *input homogeneous*. Whenever, in producing some output, homogeneous labor can be combined in various proportions with individual capital goods, or with "kits" of capital goods whose aggregate size varies but whose internal composition remains constant as we change processes, we have an input homogeneous family of processes. In agriculture one can find some instances of this type: given quantities of practically homogeneous labor applied to larger or smaller areas of qualitatively equal land; homogeneous compounds of capital, consisting, e.g., of some more or less standardized combination of seed, fertilizer, manure, etc., applied in varying "doses" to given areas of land in cooperation with labor of unchanged quantity and quality. Here it is sometimes possible to vary, over relatively wide ranges, the quantities of individual capital goods or even of fairly complex composites of capital goods without altering the other specifications of the productive process such as quantity of labor used, general organization of work, etc. The relatively frequent occurrence of this invariance in agriculture is largely due to the fact that in this field there are changes of processes which do not involve any substitutions *between* capital goods.

In nonagricultural industry, where a change of processes usually does necessitate intracapital substitution, this invariance is rare.[15] It is present in certain special cases; if—to use an example given by Solow[16]—the intracapital substitution does not involve anything else than the use of aluminum fixtures in lieu of steel fixtures, the quantity of labor required is not altered, and the same is true of the other arrangements on the input side. Despite the technical difference in the two capital inputs, the two processes are here input homogeneous in our sense, and, for purposes of factor proportion analysis, representation of the two equipments as two different quantities of capital-in-general is operationally meaningful. In the great majority of cases,

[15] Friedrich and Vera Lutz, *op. cit.*, p. 7, emphasize that in the case of substitution between durable capital goods and labor the type of durable capital goods usually changes as the substitution proceeds. They hold that this fact makes the apparatus of constant product curves "clearly inapplicable."

[16] Robert M. Solow, "The Production Function and the Theory of Capital," *The Review of Economic Studies*, 1955, p. 103.

however, process variation by merely changing "doses" of individual input elements is precluded by fairly strict technological complementarity constraints. Most of the intracapital substitutions which in nonagricultural industry are normally associated with redesigns of processes affect quite a number of other input factors. They often call for far-reaching reallocations and reassignments among human as well as material input elements. Different machines require different numbers of machine attendants, etc.[17] In fact, given the present degree of technical specialization in industry, the family of processes making up the technology available at any given time to a productive unit in nonagricultural industry is predominantly input heterogeneous, its "members" being more or less sharply demarcated against one another by qualitatively and quantitatively specified sets of input factors (including such "factors" as organization, work outlay, etc.).

To be sure, this is not the whole story. It is sometimes possible to use several very different members of a family of processes side by side in various proportions (e.g., to move materials partly by hand, partly by processes involving various degrees of mechanization). Then something equivalent to substitution between labor and capital-in-general over sizable ranges may result in an indirect manner. In one particular field of industrial activity, materials handling, such possibilities are fairly common, and this may help to explain why, in this field, empirical research was able to trace stimulating effects of wage pressures upon the rate of mechanization with greater certainty than elsewhere. But even here, the decision to alter a combination of processes in response to some exogenous change normally affects a number of distinct inputs simultaneously. Hence, if one complicated combination is "least cost" at given prices of the various inputs, it may take a rather drastic change in the price of one single input to deprive the combination of its least-cost character. At more moderate price changes, the economic advantage of the existing combination will remain inframarginal, and no substitution of processes or factors will take place.

All this points to the conclusion that, at least in nonagricultural

[17] Solow, *ibid.*, p. 103, points out that even in the case of so closely similar capital goods as one-ton trucks and two-ton trucks the possibility of intracapital substitution is not invariant against changes in the factor labor, since this possibility depends technically on the number of drivers available. Solow uses the invariance criterion for deciding whether it is meaningful to sum up the various capital inputs in a single index figure defining a quantity of capital-in-general (scil. for the specific purposes of a production function—nobody doubts, of course, that for numerous other purposes it is perfectly legitimate to sum up one-ton trucks and two-ton trucks in an index representing "trucks-in-general"). We are using the same criterion to get a preliminary "feel" for the frequency or infrequency, in industrial practice, of direct interfactor substitution in the marginalist sense.

industry, marginal improvements—new machines or processes for whose profitable introduction a rise in the price of one input such as labor makes the decisive difference[18]—are less frequent than is suggested by the conventional smooth two-factor surface on which one factor is a generalized something called (physical) capital.[19]

Without attempting a systematic review of the empirical evidence on the Ricardo effect,[20] let us add a few observations on certain aspects which empirical research has brought to light. In this field one must guard carefully against *post hoc ergo propter hoc* inferences. In quite a few instances there is some indication of investment decisions having been influenced by an upward pressure of wages, but no safe conclusions can be drawn because of the difficulty of disentangling the effects of the changed factor price ratio from those of simultaneously developing technological invention, or economies of scale, or better capacity utilization, or several of these factors.[21] This difficulty reduces the value of attempts to trace the "Ricardo effect" in such indirect statistical indicators as the slower rise of labor costs compared with wage rates in individual firms or industries.[22] Attempts have been made to circumvent this difficulty by questionnaire investigations into the response of business firms to autonomous wage rises, but these have often produced answers difficult to reconcile with each other. It suffices to recall the discussion, which was conducted in the course of the "marginalism controversy" of the late 1940's, about the results of a questionnaire inquiry reported by Lester.[23] Of questioned firms from various industries, all of them having plants both in the North and in the South, the great majority denied that lower wages in the South caused the company "to use production techniques or methods in its Southern plants that require more labor and less machinery than the proportions of labor to

[18] Cf. Bloom and Northrup, *op. cit.*, p. 462.

[19] Indeed, in many instances even labor is so process-specific that it cannot be properly thought of as a homogeneous "factor" whose use in various processes is differentiated only by quantity.

[20] For further empirical material, see especially Bloom and Northrup, *ibid.*, Chapter 19.

[21] Cf. *Cost Behavior and Price Policy* (NBER, 1943), pp. 129 ff. The dearth of empirical material on redistribution of factors purely in response to increases or decreases in wage rates was emphasized by R. A. Lester, "Shortcomings of Marginal Analysis for Wage-Employment Problems," *American Economic Review*, XXXVI, 1, March 1946. The statement by Joel Dean, *Managerial Economics* (1951, p. 254), that "much is known about the way in which they [high wages] alter the pattern of adoption of existing technology, hence the depth of capital" may well refer to theoretical rather than empirical knowledge.

[22] For a discussion of earlier attempts in this direction, cf. *Cost Behavior and Price Policy*, *op. cit.*, pp. 131–2.

[23] *Op. cit.*, pp. 74 and 78.

machinery used in its Northern plants," and stated that "the most efficient equipment available" was being used regardless of relative wage levels. On the other hand, when asked what adjustments in the South were most probable should a sharp narrowing of the North-South wage differential occur, many firms gave a higher probability rating to "introduction of labor-saving machinery" than to five other types of possible adjustment.[24] Somewhat more definite evidence was given not long ago by Brinker in a study analyzing the effects of the increase in the Federal statutory minimum wage rate (from \$0.75 to \$1.00 an hour) on March 1, 1956.[25] The study covered 136 medium-sized firms belonging to fifteen different low-wage industries in Oklahoma. Twenty-six of these firms paid all their employees more than \$1.00 even before March 1, 1956. The remaining 110 firms had before that date employed some workers at less than \$1.00. One among several classes of adaptive steps listed and tabulated by the author was "adding new machinery." Of the 110 firms which had to raise wages, thirty-four introduced new machinery in 1956, whereas none of the firms in the other group did so. Applying the conventional test for sampling reliability, Brinker's result is statistically significant well below the 1 per cent level. But the sample is obviously too local and sectional to support any far-reaching conclusions.

As mentioned above, materials handling is one field of industrial activity in which the operation of the Ricardo effect could sometimes be traced with a relatively great degree of certainty, one of the reasons being, probably, that marginal-improvement situations occur here relatively often. While even in this field the alternatives may be narrowed to either continuing entirely with the old procedure or switching completely to a new one (as was the case with some continuous-flow processes, whose introduction was, characteristically, quite independent of any change in wages), it is frequently possible, probably more frequently than in fabrication proper, to use little mechanized and more highly mechanized processes simultaneously in proportions which can be altered gradually as factor costs change. One major instance in which a differential effect of differential wage developments on the rate of mechanization and capital investment could be ascertained with some confidence was the gradual adoption of mechanical loading by American bituminous coal mining since the late 1920's. Regional differences in the rate at which mechanical

[24] On the difficulty of reconciling these answers, and the general difficulty of basing conclusions on questionnaire material of this kind, cf. F. Machlup, "Marginal Analysis and Empirical Research," *American Economic Review*, September 1946, p. 553 and *passim*.

[25] Paul L. Brinker, "The \$1 Minimum Wage Impact in 15 Oklahoma Industries," *Monthly Labor Review*, September 1957, p. 1092 f. Cf. K. Borch, *op. cit.*, p. 29 f.

loading was substituted for hand loading were here for some time so definitely associated with regional differences in wages (caused mainly by differences in the extent of unionization) that little doubt remains about the causal connection.[26] It was even possible in this field to show the Ricardo effect operating in reverse—a rare feature which deserves a word in passing. Conventional marginalism portrays the factor substitutions induced by changing relative factor prices as perfectly reversible. In practice, substitutions in the direction of intensified mechanization are, if not completely irreversible, at least strongly unidirectional. In part, this may be due to a general "mechanization preference" which goes beyond the strictly economically rational: we are more reluctant, *ceteris paribus*, to abandon an already achieved degree of technical perfection than we are to introduce it as something new. Apart from this, however, the economic advantage of a more mechanized over a less mechanized method, even when only marginal at the time of the substitution, usually soon outgrows the marginal zone, owing to cheaper and better machine models becoming available soon afterwards, gradual improvement in handling the new method organizationally, etc. So the economic optimum life of the machines installed in the process of switching over to the more mechanized method normally outlasts the time during which the relative advantage of this method remains marginal. Hence, while wage increases do sometimes stimulate mechanization, subsequent wage reductions, although they may slow up the reinvestment turnover of the machines,[27] do not normally lead to outright demechanization (switchback from machine operation to hand operation). Loading in coal mines is one of the rare instances where this seems to have happened in some regions for a brief period during the early 1930's, thanks to the relatively long time during which in

[26] Cf. Hotchkiss, *et al.*, *Mechanization, Employment, and Output per Man in Bituminous Coal Mining*, WPA-Nat. Res. Project, Vol. I, pp. 136–7 (1939); Vol. II, pp. 209–10, 300, 333, 345; Ch. M. James, *Measuring Productivity in Coal Mining*, 1952, p. 68.

[27] If the outlays incurred by the upkeep of a machine rise as a result of rising unit maintenance costs, e.g., rising repair wages, the (optimum) service life of the machine will be shortened, i.o.w., the rate of reinvestment turnover will be accelerated. Declining unit repair costs will have the opposite effect. To the extent that unit repair costs depend on repair wages, we have here a case of true substitution between labor and capital. This relationship should not be confused with another one that operates in exactly the reverse direction. If maintenance outlays rise as a result not of rising unit repair costs but of a managerial decision to spend more on maintenance, the service life of the machine, to the extent that it is determined by wear and tear rather than by obsolescence, will be extended. There exists, obviously, a (limited) range within which it is optional for management either to make durable assets last longer by spending more on their upkeep or to cut maintenance costs by accepting a quicker reinvestment turnover. For a tentative empirical verification, see Solomon Fabricant, *Capital Consumption and Adjustment*, NBER, New York, 1938, pp. 103-4.

this case the economic advantage/disadvantage comparison between the hand process and the machine process stayed in the marginal zone.[28] Today, of course, this phase is long passed. During the late thirties, the economic superiority of mechanical loading gradually outgrew the marginal region, and today it is so far from this region that no practicable wage cut could induce mines where loading has long been mechanized to switch back to the hand process.

A more recent example was furnished by Melman's investigation of increased mechanization in British automotive industries between 1938 and 1950.[29] Characteristically, the clearest results were obtained for materials handling, where the switch to new methods consisted mainly of increased use of mechanized trucks and conveyors of various designs. Melman traced a fairly unambiguous pattern of decision-making at the firm level, leading from an increased labor/machine cost ratio as the motivation, to increased mechanization as the response. He emphasized that the process redesigns completed or under way in 1950 were technically possible in 1938 as well, but were not then introduced even by firms that were affiliated with American automobile producers and thereby had special knowledge of the more highly labor-productive methods used in the United States.[30] So the difficulty of disentangling the effects of changing ratios of factor costs from those of simultaneous changes in the known production function (technology) itself, could be kept out in this case.

It would seem that the statistical findings so far available are either too uncertain or too sectional and fragmentary to answer the question of the general importance of the Ricardo effect compared with other influences on the development of capital investment and labor productivity. While Borch may be right in saying that there is little statistical evidence to support any view which does not hold that wage movements are of paramount importance, neither is such a more conservative view clearly *refuted* by the available statistical record. All one can probably do at present is to fall back on the over-all impressions conveyed by broad historical development. And these impressions definitely confirm what is suggested by the theoretical considerations outlined above: the marginal improvement is not a much more frequent phenomenon than the marginal invention.[31] It is certainly

[28] Hotchkiss, *et al.*, *op. cit.*, Vol. II, pp. 287, 290, 306; Ch. M. James, *op. cit.*, pp. 32, 62, 64.

[29] S. Melman, *Dynamic Factors in Industrial Productivity*, 1956, especially Part I. See also his article "What Does Productivity Measure? The Pulp and Paper Industry of the United States," *Productivity Measurement Review*, No. 6, August 1956, p. 5 f.

[30] Melman, *Dynamic Factors in Industrial Productivity*, p. 59.

[31] Cf. Bloom and Northrup, *op. cit.*, p. 462.

infrequent by comparison with redesigns of industrial processes independent of any change in labor costs. The great mass of these redesigns has always been, and probably will always be, the result of invention and discovery rather than of shifts in factor price ratios within a given technology. The economic advantages of the really path-breaking innovations have in most cases been inframarginal soon after their invention. No wage movement was therefore required to secure their prompt introduction, nor could acceptance of wage cuts have delayed their introduction appreciably. In this respect, the experience of 1923–29, a period of sharply rising production and productivity, goes a long way toward settling the question. During those years, while labor remained "cheap," entrepreneurs nevertheless did "turn to their engineers,"[32] and on an unprecedented scale.

There remains, of course, a further question which would require separate discussion: To the extent that a rise in labor cost does stimulate mechanization and capital investment, should one infer with some labor economists and other observers that this is one of the beneficial effects of an aggressive wage policy, one that goes a long way toward justifying such a policy even in the face of objections which otherwise would be serious? Suppose that an upward pressure on wages is about to push their level above what is in line with the currently prevailing level of productivity. Assume (for the sake of argument, without going into the pros and cons of this hotly debated question) that in a society insisting on unconditional maintenance of full employment the direct impact of such a pressure is inflationary. Is there something to be said for the idea that such increase in mechanization and labor productivity as may be indirectly induced by the pressure will neutralize some or all of the inflationary impact? The sketchy survey attempted in this paper does not provide the basis for a final answer, but it does provide at least one preliminary warning: If capital is substituted for labor in response to rising labor costs rather than to declining costs of capital equipment, then the effect on *total* productivity (output per unit of total input) is negative, despite the rise in *labor* productivity. This is an obvious corollary of the "scale effect" discussed earlier. Based as it is on an essentially static theory of production, this reasoning may not be the final answer in view of possible dynamic long-run repercussions. But it is certainly inadequate to discuss the question exclusively with an eye on what happens to man-hour productivity.

[32] Cf. Footnote 3.

Income Tax, Real Investment, and Capital Coefficients

This section analyzes, on the basis of a simplified model, the way in which the rate of income tax affects the choice between two durable producers' goods, one of which requires a higher capital investment but is superior in what we might call *productivity on current account*, meaning that it yields higher (time-adjusted) annual earnings. ("Earnings" are defined for this purpose as the excess of the revenue generated by the asset over the operating costs—before depreciation—incurred by it.) To simplify our model as far as possible, let us assume that the acquisition of either of two machines competing for installation is financed entirely by equity capital[33] and that neither of them has any salvage value at the end of its service life. Under these assumptions, the value of either machine at the time of installation equals the aggregate present worth of all future net (after-tax) earnings "stored" in it, discounting these earnings back to installation time at the prevailing rate of capitalization. Returns at that rate represent, in a sense, a cost element (the "opportunity cost" of investing in this particular activity), with the implication that a particular investment breaks even if it yields no more than a net return at just this rate. The cost price of the asset may or may not equal the aggregate present worth of the prospective net earnings. The stipulation that it does defines either a theoretical competitive equilibrium of all input and output values or, with respect to fluctuating real-world developments, a condition which the cost price must satisfy in a given situation to make the investment a break-even proposition. If the cost price of the investment equals its initial value as defined, the investment project is just at the borderline of eligibility.

Suppose now that we have the choice, for installation in some productive service, between machine *A*, having a specified schedule of prospective annual earnings, and machine *B*, which is more expensive but gives the prospect of a superior contour of annual earnings. Then we may study the development of the substitutability of *B* for *A* in response to changing variables by asking how the break-even capital costs of the two machines are related to each other at various income tax rates, or rates of capitalization, or other variables. For example, at any given tax rate, the break-even cost price—the maximum cost permissible if the machine is not to be a loss project—will normally be higher for the machine having greater current productivity. If the tax rate goes up, the break-even capital cost of either machine will be reduced—either will have to be cheaper to represent

[33] Under existing tax laws, the assumption that the investment is partially financed by borrowed capital would complicate the model because the tax status of interest paid on debt capital differs from that of return on equity capital.

a paying investment project. But in what relative proportion? Will the increase of the tax impinge upon the eligibility of the two in the same degree?

The first element we need for building up our model is the contour of annual before-tax earnings of the two machines. Empirically to ascertain the earnings imputable to individual machines is normally impossible, since the revenue generated by an individual productive asset operating in combination with many others is generally unknown and unknowable.[34] But if we assume the depreciation method used for tax purposes, and if we specify empirically plausible model values for a few variables characterizing the asset economically (initial capital value, service life, tax rate, and rate of discount), then we can deduce for our model the series of annual before-tax earnings (revenue minus cash operating costs) implied in these values, provided we make certain general assumptions as to the shape of the earnings series. Our first and most general assumption is that the earning power of a productive asset is normally highest at the time of its installation[35] and declines gradually as the asset ages, due to accumulating performance deterioration, rising maintenance and repair costs, and accruing obsolescence. For an asset with no salvage value, the point at which its earnings have dwindled to zero under the erosive impact of these forces, which marks also the running out of the after-tax earnings,[36] obviously defines the optimum economic service life of the asset. Finally, we need an assumption as to the most probable specific pattern of the declining before-tax earnings. While various assumptions are possible, a decline at a uniform (absolute) annual rate is the simplest of all, and since in the absence of special information this assumption is at least as plausible as any other, we shall use it here. Under this assumption, diagrammatical representation of the before-tax earnings as a function of time would show their contour to be a declining straight line, forming the hypotenuse of a rectangular triangle whose sides are the x-axis from the origin to the

[34] The way our accounting systems are organized, it is only for the enterprise as a whole, or at most for major divisions, that *both* earnings and cost data are obtainable from records. For the individual productive assets in a firm with diversified plant and equipment the books yield, at best, cost figures. No accounting record enables us to tell what fraction of the firm's gross earnings should be imputed to the contribution of this or that individual piece of equipment, nor is there any other basis for venturing such an imputation.

[35] Allowing, in some cases, for a brief initial break-in period, but this qualification does not alter the general picture.

[36] Assuming as we do that the tax-deductible depreciation charges end with the last service year, which is economically defined by the running out of the before-tax earnings, it is easily demonstrable that there are after-tax earnings so long as, but only so long as, there are before-tax earnings. See the model schedule on p. 476.

end of the service life and the y-axis from the origin to the level of the initial earnings.

The setting up of our model is now a simple matter. Let us use the following symbols:

V = initial capital value of the machine (equal to the aggregate present worth of all after-tax earnings) in dollars.

n = service life of the machine in years.

g = annual decline of the before-tax earnings in dollars.

i = rate (in decimals) of capitalization (discount) to be used in deriving V from the after-tax earnings.

v = the present-worth factor for i for one year, equaling $1/(1+i)$.

b = rate (in decimals) of income tax.

The first step is to develop the series of after-tax earnings. Since under our assumptions the annual depreciation allowance as charged for tax purposes is the only tax-allowable deduction from the annual before-tax earnings, we have, for each individual year,

After-tax earnings = before-tax earnings $-b\cdot$ (before-tax earnings $-$depreciation allowance), or

After-tax earnings = $(1-b)\cdot$ before-tax earnings $+b\cdot$ depreciation allowance.

The series of before-tax earnings for successive years 1, 2, 3... $n-1$, n, is clearly: ng; $(n-1)g$; $(n-2)g$; ... $2g$; g. The series of annual depreciation allowances depends, of course, on the tax depreciation method. Let us first assume that straight-line depreciation is used. In this case the depreciation allowance remains constant from year to year at the level V/n.

We have thus the following series or schedule of after-tax earnings:

Year	*After-Tax Earnings*
1	$(1-b)ng + \frac{bV}{n}$
2	$(1-b)(n-1)g + \frac{bV}{n}$
3	$(1-b)(n-2)g + \frac{bV}{n}$

. . . .

$$n-1 \qquad (1-b)[n-(n-2)g] \quad + \quad \frac{bV}{n}$$

$$n \qquad (1-b)[n-(n-1)g] \quad + \quad \frac{bV}{n}$$

Assuming that the rate of capitalization remains constant during the service life, and treating the annual after-tax earnings as year-end magnitudes, we have for their aggregate present worth,

$$\begin{aligned} V = {} & (1-b)ngv && + \frac{bV}{n}v \\ & +(1-b)(n-1)gv^2 && + \frac{bV}{n}v^2 \\ & +(1-b)(n-2)gv^3 && + \frac{bV}{n}v^3 \\ & \dots\dots\dots\dots && \\ & +(1-b)[n-(n-2)]gv^{n-1} && + \frac{bV}{n}v^{n-1} \\ & +(1-b)[n-(n-1)]gv^n && + \frac{bV}{n}v^n \end{aligned}$$

for which we may write

$$V = \left[(1-b)ng+\frac{bV}{n}\right](v+v^2+\dots+v^n)$$
$$-(1-b)g[v^2+2v^3+\dots+(n-1)v^n].$$

For the two serial expressions in this equation, non-serial equivalents can be worked out. Doing this, and simplifying as far as possible, we finally obtain

$$V = \frac{gn(1-b)(in+v^n-1)}{i[in-b(1-v^n)]} \tag{1}$$

or, if we take g as the dependent variable,

$$g = \frac{iV[in-b(1-v^n)]}{n(1-b)(in+v^n-1)}. \tag{2}$$

The next step is to select for our representative standard model machine A absolute values of the variables whose proportions somehow reflect real-life conditions. Let us assume a cost price of around \$10,000, a service life of fifteen years,[37] an income tax rate of 50 per

[37] This is close to what was obtained in the study by G. Terborgh, *Realistic Depreciation Policy* (Washington, 1954, p. 83), as the weighted average "life expectancy" of machinery and equipment in this country in 1953.

cent (for the reference model; later we are going to vary this rate)[38] and a rate of capitalization of 10 per cent per annum.[39] Then, assuming that the cost price of the machine represents its break-even cost value, and that the before-tax earnings imputable to the machine have a "triangular" contour, the series of these before-tax earnings is determined by equation (2). If V is exactly \$10,000, we obtain $g=\$201.92$. For the purposes of our analysis it will be more convenient to construct the model the other way around, assigning a fully rounded figure to g and deducing the implied V, which in this case will be a nonrounded figure. Setting $g=\$200$, which means that the annual before-tax earnings start at \$3,000 in the first year and decline to zero in the fifteenth year with an annual run-off of \$200, equation (1) yields \$9,905.06 for the break-even capital cost satisfying the stipulations of the model. Table 4 (page 476) makes explicit the development of all relevant annual values during the service life of this machine. It will be seen that the before-tax earnings each year just cover (1) the stipulated tax liability, (2) annual capital consumption in such amount that 10 per cent interest on the capital value still outstanding at the beginning of each year can also be covered, and (3) the 10 per cent interest on the unrecovered capital.

Suppose now that we are given the choice between installing this machine and installing a machine B of superior design whose before-tax earnings exceed those of machine A by \$600 each year, owing to lower annual labor or nonlabor costs connected with its use, but maybe also to higher annual gross revenue due to better performance. As for the forces which gradually squeeze down the earnings as the asset ages—service deterioration, increase in certain operating costs, obsolescence—let us assume that they affect B with equal strength as they do A. Then the before-tax earnings of B start at \$3,600 (20 per cent above those of A), decline by \$200 annually, and run out in the eighteenth year. The breakeven capital cost of B is found by equation (1) to be \$12,689.45. If the actual cost prices of the two machines are as indicated, there is economic indifference between the two alternative investments.

Let us now see how these breakeven capital costs change when we vary the rate of income tax over the full possible range from $b=0$ to $b=1$ (zero to 100 per cent tax). The technique of deriving the breakeven V's by equation (1) needs no further elaboration. Table 1 gives the results, and Chart 1 portrays them diagrammatically.

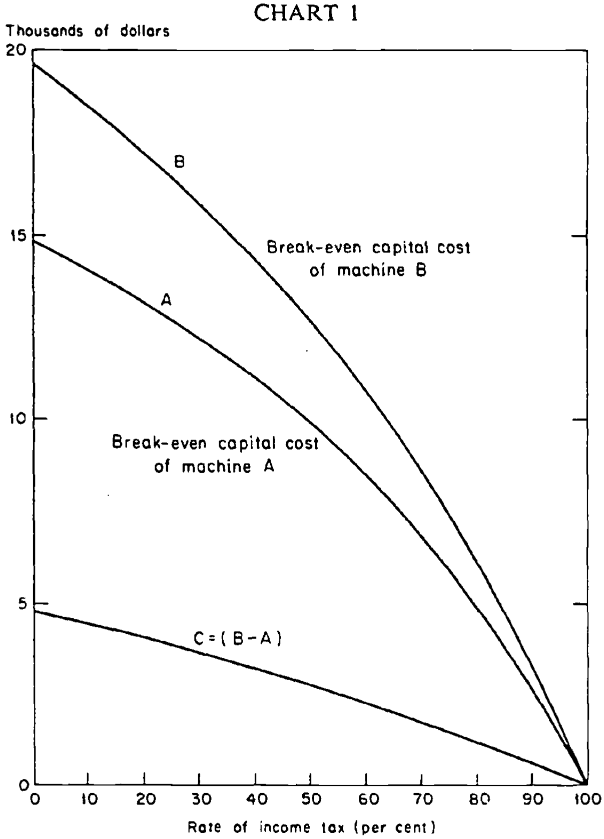
[38] The rate of 50 per cent approximates the present general rate of corporate tax (52 per cent).

[39] What rate of discount should be assumed as the "minimum attractive rate of return" for investment in plant and equipment, depends on various circumstances. Five per cent to 15 per cent may be a plausible range.

TABLE 1

Rate of Income Tax (per cent)	*Capital Costs at Breakeven Level* Machine A (Dollars) (1)	Machine B (Dollars) (2)	*Excess of Col.* (2) *Over Col.* (1) (Dollars) (3)
0	14,788	19,597	4,809
10	14,020	18,479	4,459
20	13,166	17,250	4,084
30	12,208	15,890	3,682
40	11,130	14,379	3,249
50	9,905	12,689	2,784
60	8,502	10,788	2,286
70	6,877	8,632	1,755
80	4,976	6,167	1,191
90	2,720	3,322	602
100	0	0	0

CHART 1



As expected, the breakeven capital cost of each machine is a monotonically declining function of the rate of tax. It is equally obvious why curve *B* remains above curve *A* at any tax rate short of 100 per cent, at which limit, for either machine, no cost price is small enough to make the investment break even. The main result of the analysis is the convergence of the two curves as we go up with the tax. Over the whole range of conceivable tax rates, any rise of the rate brings the breakeven capital cost of machine *B* closer to that of machine *A*.

The interpretation of this result for the problem of input substitution here analyzed is clear. The area between the curves *A* and *B* defines a zone of economic preference for the more capital-intensive project *B*. If the actual capital cost of *B* is within this area, rational decision-making will favor machine *B*; if it is outside the area (that is, above curve *B*), machine *A* will be preferred. The narrowing of the area as we move from left to right shows how the rise of the tax rate cuts into the range of capital costs within which *B* remains preferable to *A*. It shows, in other words, how the scope for *B* to give economic effect to its superior productivity on current account shrinks under the impact of rising tax rates. In the model as set up, this has been shown by reference to a situation in which *A* as an investment project is itself just at the breakeven level. But obviously, the finding about the impact of varying tax rates on the relative economic attractiveness of projects of different (current) efficiency is not dependent on this particular technique of exposition. We could stipulate any positive degree of profitability as our standard of reference, and would again find that the zone of preference for project *B* is narrower under a high than under a low tax rate. The reference to a breakeven situation merely simplified the exposition.[40] Nor are the other stipulations of the model (linear projection pattern of the before-tax earnings, etc.)

[40] It permitted us—this is perhaps its most important advantage—to avoid a controversial preliminary question which would have arisen had we based the analysis on the assumption of machine costs different from, that is normally lying below, their breakeven levels. In this case, we could not say anything about the relative economic attractiveness of the two assets without first determining whether a firm prefers the machine showing the higher excess of its true aggregate present worth (as derived by discounting its prospective earnings at the going rate of capitalization) over its cost price, or whether it prefers the machine showing the higher internal rate of net return, this rate defined as that rate of discount whose application to the prospective earnings equates their total present worth to the cost price. Demonstrably, it is only under certain conditions that the two criteria give identical preference rankings—a fact, incidentally, which shows that whenever durable producers' goods are involved, the basic assumption of "net profit maximization" on which the whole marginalist theory of the firm was originally built, is by no means as unambiguous and self-explanatory as was long believed. But when we approach the substitutability problem by analyzing what happens to the breakeven costs of the machines, that preliminary question does not arise. For when the cost is assumed to equal the total present worth of the earnings discounted at the going rate of capitalization, then this rate *is* at the same time the internal rate of net return as defined above.

vital for the general result[41] which may be summarized by saying that, other things equal, the "terms of trade" between a (currently) more efficient but relatively capital-requiring factor and a less efficient but relatively capital-saving one change more and more in favor of the latter as the rate of income tax is raised.

Since 1954, accelerated methods of depreciation for tax purposes have been authorized in this country, and American business, which until then had used straight-line write-off almost exclusively, has partially switched to the new methods. It might therefore be of some interest to ask how far the results of our analysis are modified if we use, say, sum-of-digits write-off, the most accelerated of the new methods authorized. In this case the annual depreciation charge varies with the age of the asset, being

$$\frac{2(n-t+1)}{n(n+1)}.V$$

in the t'^{th} service year. For the rest, the buildup of the model completely parallels that outlined above for straight-line depreciation. Using the same symbols as before, we now obtain

$$V=\frac{gn(n+1)(1-b)(in+v^n-1)}{i^2n(n+1)-2b(in+v^n-1)} \qquad (3)$$

and

$$g=\frac{i^2n(n+1)-2b(in+v^n-1)}{n(n+1)(1-b)(in+v^n-1)}.V \qquad (4)$$

Again setting $g=\$200$, $n=15$ years for machine A and 18 years for machine B, $i=0.10$ (10 per cent p.a.),Table 2 shows, and Chart 2 portrays graphically, the breakeven capital costs and their interrelations:

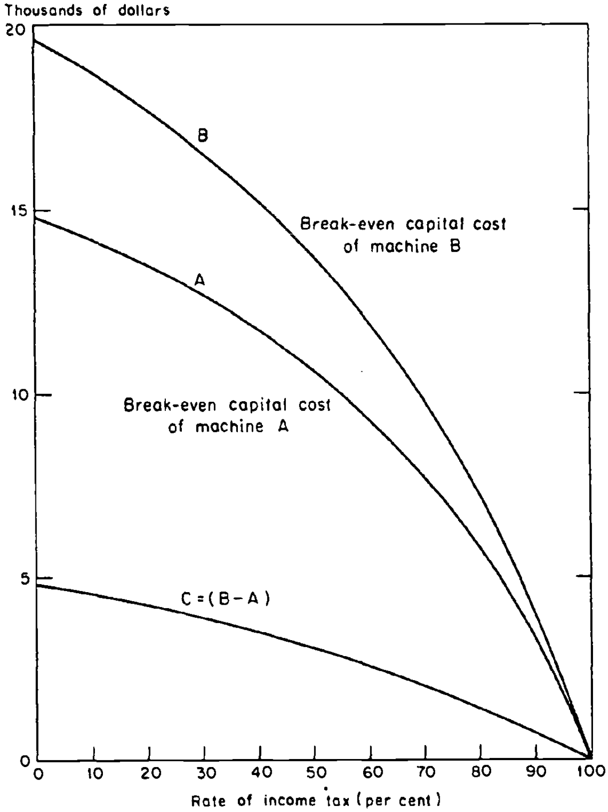
TABLE 2

Rate of Income Tax (per cent)	*Capital Costs at Breakeven Level* Machine A (Dollars) (1)	Machine B (Dollars) (2)	*Excess of Col.* (2) *Over Col.* (1) (Dollars) (3)
0	14,788	19,597	4,809
10	14,183	18,710	4,527
20	13,493	17,707	4,214
30	12,698	16,566	3,868
40	11,774	15,255	3,481
50	10,686	13,733	3,047
60	9,384	11,946	2,562
70	7,801	9,817	2,016
80	5,832	7,237	1,405
90	3,319	4,047	728
100	0	0	0

[41] On the degree to which the result depends on the assumption that straight-line depreciation is used for tax purposes, see the next few paragraphs.

For zero tax and 100 per cent tax, the figures of Col. (1) and Col. (2) are, of course, the same as in Table 1. In these two limiting cases the tax depreciation method makes no difference. Between, the permissible capital cost of either project is now a little higher, for any assumed tax rate, than under straight-line tax depreciation. Accordingly, the downward concavity of curve *A* as well as curve *B* is slightly more marked in Chart 2 than in Chart 1. This, of course, is

CHART 2



one of the facts in which the economic advantage of the accelerated write-off for the taxpayer finds expression. As the following comparison (Table 3) shows, the absolute advantage reaches its maximum around a tax rate of 70 per cent and tapers off on both sides of this value, whereas the relative advantage continues its increase.

But the excess of the breakeven capital costs of machine *B* over machine *A*—see Col. (3) in Table 2 and curve *C* on Chart 2—differs for any given tax rate only moderately from what it is under straight-line tax depreciation. Whatever the merits of the accelerated writeoff

TABLE 3

EXCESS OF THE BREAKEVEN CAPITAL COST UNDER SUM-OF-DIGITS TAX DEPRECIATION OVER THE CORRESPONDING COST UNDER STRAIGHT-LINE TAX DEPRECIATION

Rate of Income Tax (Per cent)	*Machine A* Absolute (Dollars) (1)	Relative (per cent) (2)	*Machine B* Absolute (Dollars) (3)	Relative (per cent) (4)
0	0	0	0	0
10	163	1.1	231	1.3
20	327	2.5	457	2.6
30	490	4.0	676	4.3
40	644	5.8	876	6.1
50	781	7.9	1,044	8.2
60	882	10.4	1,158	10.7
70	924	13.4	1,185	13.7
80	856	17.2	1,070	17.4
90	599	22.0	725	21.8
100	0	(28.4 lim.)	0	(27.5 lim.)

may be in other respects, it does not appreciably alter the impact of varying tax rates on the *comparative* attractiveness of (currently) more efficient but more capital-requiring durable inputs and less efficient but less capital-requiring ones. The level of the tax rate remains the more strategic variable.

Certain behavior properties of the capital coefficient—defined in most cases as the ratio of net real capital to current output—in American industry during the last few decades have recently attracted widespread attention. For an extended period before the 1920's, some investigations (Creamer, Fellner)[42] indicate a moderately rising trend of the coefficient in most industrial lines. Other studies (Goldsmith)[43] suggest that in this early period the trend of the coefficient was more or less horizontal. But all students are agreed that since the end of the great depression the over-all ratio of the net capital stock to output has been distinctly below its predepression level, notwithstanding a resumption of the upward movement around 1948.

42 Daniel Creamer, *Capital and Output Trends in Manufacturing Industries, 1880–1948*, Occasional Paper 41, NBER, 1956; also "Postwar Trends in the Relation of Capital to Output in Manufacturing," paper presented at the annual meeting of the American Economic Association, Philadelphia, 1957 (*American Economic Review, Papers and Proceedings*, May 1958, p. 239 f.); William Fellner, "Long-Term Tendencies in Private Capital Formation," *Long-Range Economic Projection*, Studies in Income and Wealth, Vol. 16, NBER, 1954, esp. p. 306 f.

43 See the tabulation of Average National Capital Coefficients 1897–1950 (based on structures and producers' equipment) in Raymond W. Goldsmith, "The Growth of Reproducible Wealth of the United States from 1805 to 1950," *Income and Wealth, Series II*, 1952, p. 297.

Various explanations of this development have been offered. To say that in the earlier period technical progress in industry seems to have been predominantly labor-saving rather than capital-saving, and that this proportion appears to have been partially reversed in the later period, would hardly amount to more than a re-statement of the finding about the development of the capital coefficient, unless the contention were interpreted in some specified sense. Thus it might be interpreted to mean that the character of the technological innovations themselves has changed so as to produce a relative reduction in required capital intensity.[44] To lift this idea from a mere conjecture to a plausible hypothesis may well be difficult. The technological innovations harvested during any given period invariably add up to an enormously diversified crop. To prove, or even to make it appear probable, that in some period the crop was on balance more capital-saving (or more labor-saving) than in some preceding or subsequent period, much more would be required than "selective enumeration" of the kind that was popular in the stagnationist literature of the late thirties. One would have to try to draw up, for each period compared, a list of at least all major innovations, to rank each of them according to the degree in which it is relatively capital-saving or labor-saving, to weigh each of them by some indicator of its economic importance, and to construct for each period some sort of a weighted average degree of capital-saving (or labor-saving) tendency of technological innovation as a whole. Obviously, this is a fairly hopeless task.

But the contention about the changed relative importance of labor-saving and capital-saving investments may be interpreted in a different and more promising way. We may ask this: Assuming that technology at any period produces capital-saving and labor-saving innovations in varying and unascertainable relative proportions, and granting that business always strives to economize on all input factors, do we have reasons to suspect that in the later of the two periods business was comparatively *more interested* in economizing on the factor capital, and therefore more interested in the specifically capital-saving potentialities of innovations, than it had been in the earlier period? A look at curves *A* and *B* on Chart 1 above suggests such a reason. The relevant thing, in this connection, is not so much the convergence of the two curves as the rather rapid decline of each of them over the range of tax rates from the moderate levels of the twenties to the present 52 per cent rate of the corporate tax. The higher the tax, the lower, for a productive asset of given productivity on current account, must be its original capital cost if it is to be

[44] This seems to be Creamer's interpretation; cf. "Capital and Output Trends, etc.," *op. cit.*, p. 76; "Postwar Trends, etc.," *op. cit.*, p. 251.

eligible for installation, which means that its net capital value at any time point during its depreciation period, as well as the ratio of this value to the current output imputable to the asset, must likewise be lower. The relationship may also be stated the other way around: the higher the tax rate, the higher, for any given net capital value, must be the current operating capacity of the asset. In general terms: For any productive facility, the economically justifiable capital coefficient declines, all other things equal, with the rate of the tax. This indicates that, by comparison with the period 1880–1920, the higher level of tax rates in the postdepression period presumably had a depressing effect on the over-all capital coefficient in American industry. To be sure, this effect was only one of several causes, and detailed empirical study would probably be required to evaluate its relative importance. But there is reason to think that it was one of the contributing forces.

COMMENT

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Schiff's discussion of the impact on the rate of technological change of upward pressure on money wage rates by unions deals with three questions: (a) Does upward pressure on money wages through collective bargaining stimulate discovery and invention in industry by making the search for new labor-saving procedures even more imperative than it would otherwise be? (b) Does an upward trend in wages accelerate the rate at which industrial management adopts labor-saving devices already known? (c) What is the effect of factor substitution induced by rising wage rates on total cost?

No attempt is made to deal exhaustively with the first question. He does, however, interpret the literature and Bloom's survey in particular to imply that "the effective rate of research and discovery in industry has little or no relation to either the level or movement of wage rates."

Any attempt to provide a convincing answer to this question will have to deal first explicitly with the question of whether collective bargaining has acted to raise wage rates above equilibrium levels. If, as Rees[1] and others[2] have argued, there has been no general tendency

[1] Albert Rees, "Wage Determination and Involuntary Unemployment," *Journal of Political Economy*, April 1951, pp. 143–53; "Postwar Wage Determination in the Basic Steel Industry," *American Economic Review*, June 1951, pp. 389-404. See also the comments by Lloyd Ulman, "The Union and Wages in Basic Steel: A Comment" and Albert Rees, "Reply," *loc. cit.*, pp. 408–33.

[2] H. M. Levinson, "Union Wage Trends and Income Distribution, 1914–47," *Michigan Business Studies*, Vol. X, 1951, No. 4; S. P. Sobotka, "Union Influence on Wages: The Construction Industry," *Journal of Political Economy*, Vol. LXI, 1953, pp. 137–43.

TABLE 4

Breakdown of Projected Earnings, Given the Stipulations Assumed for Machine *A*
(in dollars)

Year	Before-Tax Earnings (1)	Depreciation Allowance (2)	Taxable Earnings[a] (3)	Income Tax[b] (4)	After-Tax Earnings (Service Values)[c] (5)	Capital Value Outstanding at Beginning of Year[d] (6)	Capital Consumption During Year[e] (7)	Interest on Capital Value Outstanding at Beginning of Year (10% p.a.) (8)	Col. (4)+ Col. (7)+ Col. (8)= Col. (1) (9)
1	3,000	661	2,339	1,170	1,830	9,905	839	991	3,000
2	2,800	660	2,140	1,070	1,730	9,066	824	907	2,801
3	2,600	660	1,940	970	1,630	8,242	806	824	2,600
4	2,400	661	1,739	870	1,530	7,436	787	744	2,401
5	2,200	660	1,540	770	1,430	6,649	765	665	2,200
6	2,000	660	1,340	670	1,330	5,884	742	588	2,000
7	1,800	661	1,139	570	1,230	5,142	716	514	1,800
8	1,600	660	940	470	1,130	4,426	687	443	1,600
9	1,400	660	740	370	1,030	3,739	656	374	1,400
10	1,200	661	539	270	930	3,083	622	308	1,200
11	1,000	660	340	170	830	2,461	584	246	1,000
12	800	661	139	70	730	1,877	543	188	801
13	600	660	−60	−30	630	1,334	497	133	600
14	400	660	−260	−130	530	837	446	84	400
15	200	660	−460	−230	430	391	391	39	200
		9,905					9,905		

[a] Col. (1)−Col. (2).
[b] 50 per cent of Col. (3).
[c] Col. (1)−Col. (4).
[d] Present worth, at beginning of year indicated, of Col. (5)—values still in prospect, discounted at 10 per cent p.a.
[e] First differences of Col. (6)—values.

for union pressures to push wage rates above equilibrium levels, one could hardly expect Bloom to find that such pressures have biased the general direction of innovation. As a minimum, it would seem necessary to identify specific instances in which wage rates have made substantial advances relative to the equilibrium level and then see if there was any response in either the level or the direction of research expenditures.

Schiff is willing to concede somewhat greater scope to the Ricardo effect—the effect of upward pressure of money wages on the adoption of known laborsaving devices—than on the rate of discovery of new labor-saving devices. He argues, however, that outside of agriculture and materials handling operations in industry, situations in which such substitution takes place are "certainly infrequent by comparison with developments which cause redesigns of industrial processes independent of any change in labor costs." In the very short run, which is the main focus of the controversy between Schiff and those who propose higher wages as a spur to increased labor productivity, one can hardly disagree that the opportunities for substantial direct factor substitution in modern industry are relatively limited. In the longer run, where the production function may resemble something closer to its classical form than do some of the models currently being employed, the possibilities for factor substitution may be considerably greater.

With respect to the effect of factor substitution induced by rising wage rates on total cost, Schiff correctly points out that, regardless of the effects on labor productivity, the effects on net returns or on total productivity must be negative.

The third section of Schiff's paper, the discussion of the impact of the corporate income tax on factor substitution, is the substantive contribution of the paper. His argument can be summarized as follows. Assume (a) an internal earning rate that is inflexible below a given level (10 per cent in the example presented), and (b) that capital acquisition is financed entirely by equity capital. In such a situation, a change in the corporate income tax has the same effect on factor substitution as a change in the required earnings rate. Thus, a rise in the corporate income tax, such as has occurred since the 1920's, encourages the substitution of processes that are relatively more labor intensive than would be employed in the absence of the higher rates. Within the set of assumptions imposed by Schiff, his analysis is formally correct.

Both of Schiff's assumptions are clearly essential to his conclusions. If, for example, we reverse the assumption of an inflexible internal earning rate by replacing it with the assumption that higher income tax rates are completely absorbed by equity owners and are reflected entirely through reductions in the prevailing industry earnings rate, no convergence of the two break-even lines will occur. The same result can be achieved by assuming 100 per cent debt financing rather than 100 per cent equity financing. I do not want to become involved in any extended discussion of the incidence of the corporate income tax or of the feasibility of alternative debt-equity ratios. I do want to insist that empirically satisfactory answers to these questions must be found if the analysis presented by Schiff is to have more than formal validity.

It seems likely that the net effect of introducing more realistic assumptions with respect to tax incidence and the debt-equity ratio will be to produce a pair of break-even lines which, while not parallel, show only partial convergence. Any attempt to interpret the decline in the capital output ratio in terms of such partial convergence should also (a) provide some explanation of the factors which gave rise to a decline in the capital output ratio in a number of important industries before the corporate income tax rate became an important factor, and (b) evaluate the importance of the income tax hypotheses in relation to several other hypotheses which might be suggested to account for the observed decline in the capital-output ratio in broad segments of the economy during the last four decades.

I would like to present three alternative hypotheses. Two seek an answer in terms of limitations in the data. The third looks to a fundamental shift in the pattern of innovation itself.

First, one might hypothesize that the decline in the capital-output ratio represents but little more than the temporary impact of depression and war. Kuznets, writing in the introduction to Creamer's study of *Capital and Output Trends in Manufacturing Industries, 1880–1948*, points out that in the depression-dominated decade of the 1930's there would naturally be great pressure for economic use of capital and for a high ratio of replacement to gross capital formation with a consequent decline in the capital-output ratio. And "in the 1940's the extraordinary pressure, first of World War II and then of demand for peacetime goods during the postwar years, would make for a high and intensive rate of use of existing capital stock and hence, for a low capital-output ratio again in 1948."[3] Schiff has also emphasized this possibility.

There seems to be little doubt that the effect of depression and war has been to bias the data in such a manner as to overemphasize the extent of the shift in the capital-output ratio. As Kuznets points out,

[3] Simon Kuznets, "Introduction" to Daniel Creamer, *Capital and Output Trends in Manufacturing Industries, 1880–1948* (NBER, 1956), p. 8. (Occasional Paper 41.)

however, this argument fails to explain the very significant rise in the capital-output ratio that occurred in some manufacturing industries even before World War I and which occurred quite generally throughout private domestic economy between World War I and 1929.

A second hypothesis is that the measure of capital input employed fails to provide an adequate measure of capital inputs. In his paper on *Resource and Output Trends in the United States Since 1870*, Abramovitz points out that

> "On the side of capital, there is a chronic underestimate of investment and accumulated stock because, for purposes of measurement, we identify capital formation with the net increase of land, structures, durable equipment, commodity stocks, and foreign claims. But underlying this conventional definition of investment is a more fundamental concept that is broader, namely, any use of resources which helps increase our output in future periods. And if we attempt to broaden the operational definition, then a number of additional categories of expenditures would have to be included, principally, those for health, education, training, and research."[4]

The Ruggleses, in their paper at this conference, have also stressed the inadequacy of capital-input measures, although on somewhat different grounds.

Again, one must grant considerable validity to this hypothesis. It seems unlikely, however, that improvements in measurement techniques would entirely destroy what appears to be evidence of a decline in the capital-output ratio during the last four decades. Creamer's experiments with alternative measures of capital input support the conclusion that a real decline in the capital-output ratio has occurred.

A third hypothesis suggested in a recent article by Henry Burton is that at the industry level the relative importance of labor- and capital-saving innovations is related to the stage of the industries' growth relative to advances in the basic scientific and technical fields on which the technology of the industry is based.[5] It is argued that the first applications of basic scientific or technical advances tend to be primarily labor-saving. After these basic advances have been translated into workable production processes and the technology

[4] Moses Abramovitz, *Resource and Output Trends in the United States Since 1870* (NBER, 1956), pp. 12, 13. (Occasional Paper 52.)

[5] Henry J. Burton, "Innovations and Equilibrium Growth," *The Economic Journal*, September 1956, pp. 465, 466. See also V. W. Ruttan, "Agricultural and Non-Agricultural Changes in Output Per Unit of Input," *Journal of Farm Economics*, December 1957, pp. 1566–76.

becomes widely disseminated, the industry's technology becomes subject to continuous experimentation and improvement. During this stage, increases in output per unit of capital input become an increasingly important component of the growth in output per unit of total input.

Burton's hypothesis does appear to be consistent with the history of at least three industries with which I am relatively familiar—the meatpacking, dairy, and fertilizer industries.[6]

This still leaves unexplained why capital-saving innovation should appear simultaneously in broad sectors of the national economy. An attempt might be made to bridge this gap by tying the above hypotheses with respect to the sequence of labor- and capital-saving innovation into the description of the sequence of innovation contained in the Schumpeterian theory of economic growth.[7] If Schumpeter's hypothesis with respect to long waves of inventive activity can be taken seriously, it seems likely that the first half of such a wave might well be characterized by a generally rising capital-output ratio and the second part by a generally declining capital-output ratio.

[6] Vernon W. Ruttan, *Technological Progress in the Meatpacking Industry, 1919–1947* (Washington: Govt. Print. Off., January 1954). (U.S. Department of Agriculture Marketing Research Report No. 59); C. E. French, and T. C. Walz, "Impacts of Technological Developments on the Supply and Utilization of Milk," *Journal of Farm Economics*, December 1957, pp. 1159–70.

[7] J. A. Schumpeter, "The Analyses of Economic Change," *Review of Economics and Statistics*, May 1935. Reprinted in American Economic Association, *Readings in Business Cycle Theory* (Philadelphia, 1944), pp. 1–19.