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AUTOMATION--SOME CLASSIFICATION AND MEASUREMENT PROBLEMS.
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BY- SULTAN, P.E. PRASOW, P.
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THE PURPOSE OF THIS PAPER WAS TO REVIEW HOW "AUTOMATION" IS DEFINED, GIVING CONSIDERATION TO CONVENTIONAL USAGE OF THE TERM AND TO THOSE CONSIDERATIONS WHICH DETERMINE THE CONVENIENCE OR SUITABILITY FOR RESEARCH PURPOSES OF PARTICULAR CATEGORIES OF TECHNICAL CHANGE. AN UNDERLYING ASSUMPTION IS THAT THE ADJUSTMENT DEMANDS IMPOSED BY TECHNOLOGY CANNOT BE DELAYED UNTIL SUFFICIENT REFINEMENT OF RESEARCH TECHNIQUES ENABLES THE CONSEQUENCES OF AUTOMATION TO BE CLEARLY AND PRECISELY DEFINED. SINCE THE SIGNIFICANCE OF A TECHNICAL CHANGE IS LARGELY DETERMINED BY ITS "SPAN" OF APPLICATION, THE SIGNIFICANT CHANGE IS ONE LIKELY TO AFFECT THE ENTIRE STRUCTURE OF THE PRODUCTION PROCESS. TECHNICAL CHANGE MUST BE ANALYZED IN TERMS OF THE FACTOR SAVINGS INVOLVED, THAT IS, IN TERMS OF ITS IMPACT ON UNIT CAPITAL AND LABOR REQUIREMENTS. THIS APPROACH WOULD REQUIRE MORE INFORMATION ABOUT THE QUANTITY, FORM DISTRIBUTION, AND COST OF CAPITAL. ALTHOUGH MEASURES OF MANPOWER, STATISTICALLY SPEAKING, ARE MORE ADEQUATE, MORE ATTENTION MUST BE GIVEN TO DIRECT LABOR-SAVING INDIRECT LABOR-USING IMPLICATIONS OF TECHNOLOGY. ATTENTION MUST ALSO BE GIVEN TO THE RESPONSES OF THE MARKET TO AUTOMATION'S SPEED OF PENETRATION. THE DIMENSIONS OF THE ECONOMIC IMPACT OF AUTOMATION WHICH CAN BE ANALYZED ARE CAPITAL AND LABOR SAVINGS, ALTERATIONS IN THE RATIO OF LABOR AND CAPITAL, RATE OF CHANGE OVER TIME FOR PER-UNIT CAPITAL AND LABOR REQUIREMENTS, AND THE CHANGES OF THE DEGREE OF SUBSTITUTABILITY OF LABOR AND CAPITAL INVOLVED WITH THE TECHNOLOGY. THIS ARTICLE IS A REPRINT FROM "LABOUR AND AUTOMATION," BULLETIN NO. 1, 1964. SINGLE COPIES OF THIS DOCUMENT ARE AVAILABLE WITHOUT CHARGE FROM INSTITUTE OF INDUSTRIAL RELATIONS, UNIVERSITY OF CALIFORNIA, LOS ANGELES, CALIFORNIA 90024. (EM)

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by

PAUL E. SULTAN AND PAUL PRASOW

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INTERNATIONAL LABOUR OFFICE

Automation: Some Classification and Measurement Problems

by

P. E. SULTAN ~~and~~ P. PRASOW

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Paul E. SULTAN
Paul PRASOW

Automation: Some Classification and Measurement Problems

"But how to define an elephant? The man had the right idea who said: I cannot define an elephant but I know one when I see it." [1]

After hearing over 150 expert witnesses, and collecting 3,933 pages of evidence and documents in 56 days of hearings, the Clark Committee on Manpower Policy of the United States Senate observed:

> This lack of understanding [of the impact of technological change] stems from a confusion of tongues—a failure to define terms and a tendency to lump all technological developments under one increasingly meaningless term: automation. A paucity of statistical data and a tendency to ignore that which does not square with cherished preconceptions is also to some extent responsible. A final element has been the natural tendency of every expert to examine only his own part of the elephant. [2]

The conceptual confusion surrounding the word "automation" is such that it is used to characterise technology as both an evolutionary

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[1] Joan ROBINSON: *Economic Philosophy* (Harmondsworth, Middlesex, Penguin Books, 1964), p. 8.

[2] United States Senate, 88th Congress, Second Session: *Toward Full Employment: Proposals for a Comprehensive Employment and Manpower Policy in the United States,* A Report Together with Minority and Individual Views Prepared by the Subcommittee on Employment and Manpower of the Committee on Labor and Public Welfare (Washington, Government Printing Office, 1964), p. 15.

and a revolutionary process, to describe the novelty of arrangements that link one machine with another, and to denote the unusual capabilities of engineering forms, particularly those that improve upon the contributions otherwise made by labour. In brief, it is used to describe almost every economic change that might be contemplated, including changes in plant layout, product design, job design and methods for quality control. Because this label has been applied so indiscriminately, because we have not yet been able to fashion a classification system appropriate for the analysis of the myriad forms that technical change is now assuming, and because we have not yet developed theoretical models that can allow in full for the consequences of these varying engineering forms, there exists a feeling that the subject has become a stalking-horse for the pamphleteer or polemicist.

The absence of rigour or analytical discipline in much of the research on automation must not, however, be attributed to intellectual softness on the part of those concerned, but rather to the practical hardness of the problems of analysis that technology poses. This is borne out by the evolution of economic analysis in the first half of this century. Neo-classical analysis, in its simplicity and elegance, assumed a " given " form of technology. When the dynamics of time was introduced into such analysis, order was preserved by admitting changes in the amount of capital, but seldom changes in its form. Capital theory flourished, while technology theory was largely ignored. There were some isolated exceptions: the impact of technical change played a major role in the analysis offered by Schumpeter[1], but it was quickly observed that his analysis was " non-theoretical ". Technology emerged, too, in the sporadic discussion of the appropriate classification system for innovation, and of definitions that would most clearly explain effects on capital's and labour's shares.[2] And technology was the variable that American institutionalists felt was neglected in " marginal " (viz. neo-classical) analysis. But because the institutionalists were unable to fashion a theoretical system of their own that would give a central position to technology, they were held to abhor rigour in analysis, or perhaps more charitably, to believe that unstructured analysis of markets " as they are " is preferable to rigorous analysis of markets as they are not.

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[1] *Capitalism, Socialism and Democracy* (New York, Harper & Brothers, 1942), pp. 131-134.

[2] See, for example, Joan Robinson: " The Classification of Inventions ", in *Review of Economic Studies*, Vol. V (1937-38), pp. 139-142; Oscar Lange: " A Note on Innovations ", in *Review of Economic Statistics*, Vol. XXV (1943), pp. 19-25; J. R. Hicks: *The Theory of Wages* (London, Macmillan & Company, 1963, second edition), pp. 114-135.

As American economists debated the relative merits of realism and rigour, studies of the impact of technology at the macro level found a forum in anthropological analysis, at the micro level in industrial sociology.

In recent years, however, economists have become increasingly interested in technology, as reflected in developmental economics and growth models, as the suspicion grows that the quality of both capital and labour inputs may be more important determinants of output than their quantities, and as innovations in economic methodology (such as input-output analysis and data-processing techniques) widen the scope for more elaborate theories and improve prospects for empirical verification. It remains true, however, that the classification systems of technology, as well as measurement procedures for technical change, and even the collection of data on forms of technology remain to this day largely undeveloped. Further work at this level will permit more rigorous research, which in turn can give its appropriate role to the dynamics of technical change that much of economic analysis still lacks. But meanwhile many economists still prefer to leave aside the issue of innovation, feeling that the only alternative to production and distribution theory built on stable production functions is the utter confusion so much in evidence in the existing literature of automation.

The purpose of this paper is to review how automation is defined, giving consideration to conventional usage of the term and to those considerations which determine the convenience or suitability for research purposes of particular categories of technical change. After viewing the applications of the term " automation ", can we locate the common elements in that usage? How does automation differ from technical change and mechanisation? What problems do we face when we employ " technical change " (however defined) as a springboard for empirical research? While we do not presume to resolve the problem of definition, the point will be stressed that systems of definition are inextricably related to research methodology and, equally, to the kind of problem being analysed. It will be further contended that the significance of automation cannot be assessed in terms of its engineering characteristics alone. Indeed, the market setting in which the change occurs is probably a much more significant determinant of its impact than its engineering character. And the capacity of a particular sector to digest particular forms of technology depends in large part on their rate of diffusion in that sector. The forces accelerating the tempo of research and innovation activity will be delineated. The definitions of technical change lending themselves best to economic analysis will then be indicated, and a few operational or research problems which such definitions imply briefly touched on. The final question considered is whether it is more appropriate to launch research, not by categories of technology, but by ranges of productivity change.

The discussion that follows is based on the assumption that our understanding of technical changes, like our understanding of any other issue, requires that we progress from the vague to the definite; beyond this, the adjustment demands imposed by technology cannot be delayed until such time as a sufficient refinement of research techniques enables the consequences of automation to be clearly and precisely defined.

Automation in Popular Usage

Many efforts have been made to distinguish automation from other forms of technical change. One group sees it essentially in terms of organisation, and the other in terms of the engineering characteristics of automated equipment.

Those who see automation as an organisational revolution stress the novelties of production planning and product design that mechanisation now allows. The essential element in automation is the rationalisation of the entire production process. Each stage, from raw materials to the final product, is carefully designed. The plant's organisational chart must be redrawn to integrate purchasing, production, quality control, distribution and marketing activities. Even the end-product may be redesigned to optimise the use of production facilities.

Can it be said, then, that automation is simply a new word to describe an " old " process, a resurgence of interest in what can be accomplished by thoughtful and scientific planning of production, reminiscent of F. W. Taylor and scientific management? If we have here a revolution of technique, can it be attributed simply to the increased ingenuity of man in planning production efficiently? D. J. Davis implies as much:

> Automation is the result of nothing more than better planning, improved tooling, and the application of more efficient manufacturing methods which take full advantage of the progress made by the machine tool and equipment industries.[1]

To identify automation with production planning fails to bring out the drama usually associated with it. This less striking device for improving efficiency may, nevertheless, be significant. For example Drucker has contended that innovations in industrial engineering, human relations

[1] " Automation in the Automotive Industry ", in *Automation and Society*, edited by Howard Boone Jacobson and Joseph S. Roucek (New York, Philosophical Library, 1959), p. 60.

and personnel techniques, and the development of other management tools involving inventory controls, cost accounting and so on—this entire range of " non-technical innovation "—have been much more significant in raising American productivity than all " technical " innovations.[1] In 1946 the word " automation " was first proposed by D. S. Harder in the production-planning sense, as " . . . the automatic handling of parts between progressive production processes ".[2] But the integration of production activity, such as Harder describes, with distribution and marketing functions can have significant implications. First, and most obvious, the linkage of the production process offers the opportunity for drastic curtailment of materials handling. Second, production emerges as a " flow " rather than a " batch " process. When such integration allows for an increasing speed of output (as is usually the case), substantial (but not always apparent) capital economies may emerge.

John Diebold is one who champions the view of automation in this broader sense, labelling it a new approach to production:

> It is no longer necessary to think in terms of individual machines, or even in terms of groups of machines; instead, for the first time, it is practical to look at an entire production or information handling process as an integrated system and not a series of individual steps. . . . Automation is more than a series of new machines and more basic than any particular hardware. It is a way of thinking as much as it is a way of doing.[3]

Similarly, Peter F. Drucker observes:

> Automation is a concept of the organisation of work. It is therefore as applicable to the organisation of distribution or of clerical work as to that of industrial production.[4]

The flow of production that such planning allows is an element emphasised in many definitions of automation:

> . . . automation means continuous automatic production, linking together more than one already mechanised operation with the product automatically transferred between two or among several operations. Automation is thus a way of work based upon the concept of production as a continuous flow, rather

[1] Peter F. Drucker: " The Coming Labor Shortage ", in *America's Next Twenty Years* (New York, Harper & Row, 1957).

[2] As noted by L. Landon Goodman: *Man and Automation* (London, Unwin Brothers, 1957), p. 24.

[3] Congress of the United States, 86th Congress, Second Session: " Bringing Automation Up to Date ", in *New Views on Automation*, Papers Submitted to the Subcommittee on Automation and Energy Resources, Joint Economic Committee (Washington, Government Printing Office, 1960), pp. 83, 84 and 91.

[4] *The Practice of Management* (New York, Harper & Row, 1954), p. 19.

than processing by intermittent batches of work. (Herbert R. Northrup, Professor of Economics, University of Pennsylvania.)[1]

Automated production makes it possible, with the help of machinery, to ensure a continuous manufacturing process, untouched by human hands, but under human supervision. This is a revolutionary change, not only in techniques, but also in technology and the organisation of the manufacturing process. (K. Klimenko, of the Academy of Sciences of the U.S.S.R., and M. Rakovsky, Deputy Minister, Automation Tools and Equipment Industries.)[2]

The essence of the automation concept and programme is that it integrates the several parts of a complex total process so that its successive or related steps shall mesh smoothly together without conflict, lost motion, or lost time. (Edwin G. Nourse, former Chairman of the Council of Economic Advisers.)[3]

Automation can be defined as continuous automatic production, largely in the sense of linking together already highly mechanised individual operations. Automation is a way of work based on the conception of production as a continuous flow, rather than processing by intermittent batches of work. (Ralph J. Cordiner, Chairman of the Board of the General Electric Company.)[4]

A second and more common emphasis in definitions of automation is placed on the performance characteristics of the technology itself. Such considerations stress *(a)* the range of sensory capacities now mechanised; *(b)* the role of instrumentation in closed-loop control systems, and *(c)* the integration of information technology (viz. computers) with production technology.

Definitions often stress the range of sensory capacities now mechanised:

[Automation] contemplates the wholesale reproduction of the sensory and mental functions of human operators in production systems which go far beyond the fixed sequence-fixed operation variety of automatic production. (Jack Rogers.)[5]

Automating control (and its auxiliary, inspection) means replacing man's sensory organs and brains by machines, while automating material handling means supplanting his muscles. (Paul T. Veilette, Connecticut Department of Motor Vehicles.)[6]

Automation includes the mechanisation of more direct labour activities . . . material movements . . . control activity . . . testing and inspection activities . . . and the mechanisation of data processing through the computer. (James R. Bright, Harvard University.)[7]

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[1] Industrial Relations Research Association: "Automation: Effects on Labor Force, Skills and Employment", in *Annual Proceedings* (1958), pp. 35-36.

[2] "The Technological and Economic Problems of Automation in the U.S.S.R.", in *Automation and Society*, op. cit., p. 417.

[3] "What's New About Automation?", ibid., p. 201.

[4] "Automation in the Manufacturing Industries", ibid., p. 19.

[5] *Automation: Technology's New Face* (University of California, Institute of Industrial Relations, 1958), p. 7.

[6] "The Rise of the Concept of Automation", in *Automation and Society*, op. cit., p. 7.

[7] George W. TAYLOR and Edward B. SHILS (edited by): *Industrial Relations in the 1960's: Problems and Prospects* (Feb. 1961). See also James R. BRIGHT: *Automation and Management* (Harvard University, Graduate School of Business Administration, 1958), pp. 3-21.

The power machine lifted the burden of physical toil from the backs of the tool wielder. The automated battery of machines lifts the burden of fallible human judgment and unremitting attention from routine workers. (Edwin G. Nourse.) [1]

Automation is the mechanisation of sensory, control and thought processes. (Charles Killingsworth, Professor of Economics, Michigan State University.) [2]

As a corollary to this function, machines are now talking to machines:

The central idea [of automation] is that mechanical or chemical processes are directed, controlled and corrected within limits automatically, that is, without further human intervention once the system is established. (John T. Dunlop, Harvard University.) [3]

Automation is the use of machines to run machines. (Peter F. Drucker.) [4]

The computer is now assigned complex logical and decision-making tasks. It searches its memory, learns, refines, discriminates, identifies, and transmits its knowledge to its mechanised partners. The computer emerges as the information centre, the system's brain centre. These automatic control mechanisms allow an unusual measure of self-regulation and can digest market, inventory and production data with phenomenal speed and accuracy.

The elements common to these views of automation are:

(a) the integration of production planning to fuse purchasing, production and distribution activities, and in the technical sphere the linkage of one machine activity to another;

(b) the application of instrumentation techniques that simulate human skills through both open- and closed-loop control systems. Both input and output behaviour are communicated to control systems which in turn induce necessary changes in the production process;

(c) the integration of informational technology involving market variables with process variables to influence production.

The novelty of this process is in the challenge it poses to the full range of contributions traditionally offered by the human agent: category *(a)* minimises labour's physical and manipulative contributions; *(b)* its

[1] "What's New About Automation?", in *Automation and Society*, op. cit., pp. 196-197.

[2] United States Senate, 88th Congress, First Session: *Nation's Manpower Revolution*, Hearings before the Subcommittee on Employment and Manpower of the Committee on Labor and Public Welfare (Washington, Government Printing Office, 1963), Part 5, p. 1463. This statement is reproduced under the title "Automation, Jobs and Manpower", in *Exploring the Dimensions of the Manpower Revolution*, Selected Readings in Employment and Manpower of the Subcommittee on Employment and Manpower (Washington, Government Printing Office, 1964), Vol. 1, pp. 194-219.

[3] John T. Dunlop (edited by): "Introduction: Problems and Potentials", in *Automation and Technical Change* (Columbia University, The American Assembly, 1962), pp. 1-2.

[4] *Harper's Magazine*.

discretionary and control functions; and *(c)* its mental functions. Capital savings can be involved too. Moving from the factor to the product market, output can respond much more speedily to changes in the level of demand; the product itself is usually more uniform, produced to stricter tolerances, and of higher quality.

CAN WE DISTINGUISH AUTOMATION FROM ADVANCED TECHNOLOGY?

Considering these definitions and characteristics, can we assume that automation is, in fact, simply " advanced technology " or " high-level mechanisation "? In a classification system proposed by Charles Killingsworth[1], changes of economic activity are viewed as a series of concentric circles, with the outside circle representing all forms of economic change. Such activity is affected by changes in the availability of resources, changes in trading boundaries, the development of new and substitute products, changes in the " mix " of resources used in production, or changes in managerial efficiency. Contained within this circle is technological change, defined as inventive activity such as the use of pure oxygen in steelmaking. It represents, in effect, changes in those capital forms through which economic resources are transformed into goods and services. Within the circle of technology is the circle of mechanisation, a specific kind of change in production technique. This involves the application of machinery to tasks formerly performed by human or animal labour or the application of labour-saving techniques. Automation is represented as the core circle, and is defined as engineering forms that increase the degree of self-regulation of the mechanisation process. The perimeters of the circles cannot always be clearly established, however, and the fuzziness of the distinction becomes even greater as one approaches the core circle of automation. There is, in reality, a considerable range to the degree of sophistication and the form of such regulating mechanisms.

Roughly equivalent distinctions are proposed by Walter Buckingham[2]: technology encompasses mechanisation, mass production and automation, evolving historically in that order. Mechanisation involved the use of machines to perform work; mass production involved a new technique for production organisation; and automation, the third phase, is a technology based on communication and control.

[1] *Nation's Manpower Revolution,* op. cit., pp. 1462-1466.

[2] " Automation, Employment and Economic Stability ", in *Automation and Society*, op. cit., pp. 231-233; see also the same author's *Automation: Its Impact on Business and People* (New York, Harper & Row, 1963), pp. 11-48.

One might prefer to divide technical change into two major categories. The first industrial revolution involved the development of machines and natural sources of power. The second revolution now upon us represents technical developments that make automatic production and control feasible.

Such efforts to isolate the distinctive elements of automation stress the self-regulation of the production process. Indeed, one dictionary defines automation as:

> The modern-day engineer's word for the state of being automatic. Once referred to machine tool applications, but has come to mean the act or method of making a manufacturing—or processing—system partially or fully automatic.[1]

But proposals that would modify our view of automation in terms of the degree of automatism it allows have also been made. Donald N. Michael has contended that the word " automation " does not typically imply computer applications. To delineate that situation, he proposes that information technology involving the use of computers (and labelled by Norbert Wiener as " cybernetics ") be joined with automation under the term " cybernation ".[2] Any automatic control mechanism involves automation, but when those control functions involve the use of computers, including the numerical control of production operations or other hybrid applications, we have cybernation.

Proposed Classification Systems: Diebold and Bright Contributions

Two studies, one conceptual and the other a field analysis, have proposed classification systems for automation, leaning rather heavily on the degree of sophistication of the control instruments. The Diebold Group[3] has proposed that automation be restricted to control functions that are " without human assistance during operations ". Such definitions of automation as the " substitution of non-human for human

[1] Society for the Advancement of Management: " Automation Dictionary ", in *Advanced Management* (New York, July 1956).

[2] For an analysis of cybernetics, see Norbert Wiener: *The Human Use of Human Beings—Cybernetics and Society* (Garden City, Doubleday and Co., 1954, second edition), p. 15. See also Donald N. Michael: *Cybernation: The Silent Conquest* (Santa Barbara, Center for the Study of Democratic Institutions, 1962), p. 6, and his statement in *Nation's Manpower Revolution*, op. cit., Part 1, 21 May 1963, pp. 151-155.

[3] *Criteria and Bases for a Study on the Extent of Automation in American Industry*, A Study Prepared by the Diebold Group, Inc., for the Manpower Administration of the U.S. Department of Labor, Office of Manpower, Automation and Training (Jan. 1964).

control " or as simply the " assumption of the control function by the machine " have the advantage of simplicity, but fail to acknowledge the vast range of form that such control mechanisms encompass. The problem is described in a Diebold study paper—

> If a very simple machine is used to time-stamp mail we speak of it as " automatic ". Yet only the activating switch and the clock setting of the print heads are automatic; the process itself still requires human insertion and positioning of the mail in the throat of the device and human removal of the stamped document. The degree of automatic control is, in terms of labour displacement, trivial. But if a system is built that automatically puts the mail in the proper position from a large hopper, cyclically feeds it to the time stamper, stacks and opens it, automatically rejects jammed letters and so forth, we are dealing with a highly programmed device that has significant impact upon control labour. The degree of complexity of programme is used as a discriminator between automation and non-automation in automatically controlled machines where control is not process-adjusting.[1]

The Diebold Group proposes a " ladder of automatic control " as a classification system, in which each higher rung of the ladder represents more complexity of the control mechanism. First, a distinction approximating the open- and closed-loop system is drawn, and each category contains three forms of control. The open-loop category comprises *(a)* single-programme controls, to instruct machines designed for only one sequence; *(b)* variable-programme, built-in controls, where the sequence or nature of operation can be changed at the outset, but not varied during the production programme; and *(c)* the variable-programme but separate control units. The closed-loop category represents self-adjusting controls, or devices that cause the system to respond automatically to input, output or process variables. These include *(a)* built-in controls with pre-set control limits; *(b)* pre-set control units removed from the operating unit; and *(c)* controls, whether built in or separate, that have variable control capacities rather than pre-set control limits. Further classification categories are proposed in terms of operating function and industry location of automated equipment.

A second study developed by James Bright[2] offers an alternative technique for measuring the automation process, although resting on essentially similar principles that identify automation with the " level " or degree of sophistication of the control activity. His own field study of " more automatic " production methods is accompanied, incidentally, by cautions against blind trust in empirical information showing the manpower effects of technology.[3]

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[1] *Criteria and Bases for a Study on the Extent of Automation in American Industry*, op. cit., p. 3.

[2] *Automation and Management*, op. cit., particularly Chapter 4: " The Nature of Mechanization and the Concept of a Mechanization Profile ", pp. 39-56.

[3] Ibid., pp. 9-10.

Bright has developed what he calls the "mechanisation profile", a scale designed to show, among other things, the relative functions of man and machine as the levels of mechanisation are increased. His scale represents 17 stages of mechanisation, divided into five major groups.

Group one involves the most elementary production technique in which a man makes use of his hands with no supporting capital. Advances in levels are seen when the worker makes use of a hand tool, then a powered hand tool, then a powered hand tool with hand control. In group two, the four stages of advance involve a control mechanism that directs the actions of the operator in a predetermined manner. The power tool may have a fixed and single-function cycle, then be programme controlled with a sequence of fixed functions; or it may be remote controlled. The mechanisation may be actuated by the introduction of the work or piece of material. In this group the control functions are set within the machine itself. In group three, mechanisation involves instruments that measure the characteristics of work, signal errors, detect and record performances, or produce information on its own performance. In the fourth group, the mechanism responds to those same signals within a limited range of possibilities. In the fifth group, the mechanism responds to such information by modifying its own performance over a wide range of possibilities.

What is the operational significance of the mechanisation profile? Bright has made use of it to examine the flow of the work process for particular products in various industries. He emerged with the conclusion that the term "automation" is indeed applied loosely, for his analysis reveals sharply different levels of technology for the same product at varying stages of its manufacture. Plants thought to be automated had only "islands" of such automated activity. What he defines as the "span" of mechanisation was frequently limited. Furthermore, supportive or secondary activities were frequently not "penetrated" with mechanisation. Automation analysis, he contends, must give attention to these span and penetration dimensions of the mechanisation process.

Research Applications: Some Methodological Problems

We have seen that popular usage links automation with automatic control. What problems do we face in making use of this single dimension of technology as a springboard for research on the effects of technology?

Those who are intent on establishing the dramatic possibilities for cybernation will find cause for enthusiasm in confining analysis to the advanced applications of sophisticated control mechanisms. Such case study analysis of the lead-sectors can provide important clues to their manpower consequences. But these remain only clues, not reliable guidelines to general manpower requirements of the future. There is considerable variation in the capacity of industries to make full use of such equipment when we give consideration to the nature of the product, the structure of industry, and the scope of the market. The successful application of integrated control systems found in petroleum refining, pulp and paper, and the chemical industries reflects the product being handled. Similar techniques are not likely to have equal application to such other major sectors as, say, service. General inferences on future manpower needs may not be drawn from isolated case studies of advanced technology.

Furthermore, the most sophisticated equipment may not induce the most important manpower effects. The taped guidance or numerical control of equipment may be represented as a " low level " of mechanisation, but this arrangement appears to have rapid penetration prospects with significant manpower effects.

More important but less obvious than this, it is likely that the modest day-by-day efforts to improve efficiency have cumulative effects that are highly significant. Any attempt to measure such effects is complicated, however, because the changes in production technique are subtle and diffused over time, and easily obscured by concurrent changes of a non-technical nature.

It should be appreciated that normative influences can determine the suitability of any classification system too. Let us say that public policy is framed to deal with the problem of labour displacement, and research is proposed to trace the form of technology said to be contributing to such displacement. The emerging " sample " of technology associated with such labour displacement may not in any sense be typical of all technology, or even labour-displacing technology. It is tempting, of course, simply to work back from the defined problem to identify the technology associated with the problem, but the mere fact of association should not be taken as causality.

Yet at the same time the selection of a sample that maximises the prospects of establishing cause and effect may not yield a sample of technical forms that is any more representative. A sample drawn to insulate causation from distorting external influences may mean that purity has been achieved at the expense of representativeness.

Behind these considerations is the reality that it may not be reasonable to attribute the manpower effects of technology to the engineering characteristics (viz. the degree of sophistication of control mechanisms) of such technology. A host of environmental influences (technical, social, political), a range of strategies (pragmatic, altruistic, opportunistic) and an equally wide range of market parameters combine to determine what the manpower impact might be. Certainly employment effects cannot be imputed to the unit labour requirements of particular engineering forms. Production and employment responses depend on relative capital and labour costs, the alteration of the amount, quality and price of material inputs related to the change, price and quality adjustments of the product, buyer responses to those changes involving both price and income elasticities, and the intricate web of interdependence involved in cross elasticities. Needless to say, such linkages are difficult to establish. We should not delude ourselves about the simplicity of establishing causation.

Beyond this, other practical realities suggest themselves. The firm with the most successful experience may be the one most willing to co-operate with field studies, distorting if not the sample of technology, at least the analysis that would identify the manpower effects of technology. Furthermore, profiles of labour requirements (in both quantitative and qualitative dimensions) are sharply influenced by machine reliability. A process that has yet to be fully " debugged " has vastly different manpower effects from one operating to the smoothly integrated rhythm of the enterprise, one with a lengthening history of reliability. A certain measure of pragmatism must still characterise research in this area. Frequently ad hoc definitions of technology must be fashioned after the investigation has been completed, so that operational and empirical obstacles do not completely inhibit all research in the area.

AUTOMATION: THE PENETRATION OF TECHNICAL CHANGE

However appropriate it is to classify automated equipment in terms of the sophistication of its control system, or more specifically, whatever success we have in obtaining data about the manpower effects of these categories, the significance of technology may not be fully reflected by such performance capabilities or measurement prospects, but rather by the pace of its penetration and assimilation in industry. Unfortunately, the penetration and assimilation of technology is not simply a function of its engineering characteristics. This difficulty contributes to the conflicting views as to just what automation is, whether its impact is evolutionary or revolutionary.

Testimony that would place automation as a revolutionary or evolutionary process appears equally divided. Yale Brozen, for example, contends—

Although automation may be more than an engineering revolution, in the economic sense it is nothing more than a continuation of an evolution which has been going on for centuries.[1]

Proponents of the evolutionary school are inclined to scoff at the anxiety and dismal prophesies said to characterise the "revolutionists". They deny that labour lacks the innate ability or incentive to make the educational, training, occupational, industrial and geographic shifts that automation demands, that society's wants are in any sense sated, or that the free market forces (complemented if necessary with public programmes) cannot speed society's capacity to assimilate technical change.

When this group looks at the issue in more global terms, the high productivity experienced in many nations is viewed as simply the obvious consequence of the capital reconstruction made necessary by the havoc of the Second World War. Obviously, growth rates assume spectacular proportions when they start from a modest base. Further, in most industrialised nations there is no conclusive evidence of any pronounced shift in the proportions of income accruing to labour and capital or of any radical alteration in the proportion of income expended for capital formation. The buoyancy of economic growth can be attributed to changes in trading areas and the scale effects allowed by expanded markets. Nor should we assume that such growth, however accelerated by technology, can be readily adapted to less developed areas. In such areas population pressures often prevent the diversion of substantial domestic resources for capital formation, and scarcities of technically skilled manpower can complicate the task of operating such technology, even if it is available. We should not expect, therefore, that the diffusion of technology throughout the world will be rapid. Even within developed nations and developed industries, lyrical descriptions of what is technically feasible must be tempered with analysis of what is economically possible. Yale Brozen explains the dimension of the budget constraint in America:

To automate as completely as possible with present technology, only one major segment of the American economy manufacturing would require an expenditure of well over $2.5 trillion, assuming output is not increased ... this would require two centuries at current rates of modernisation.[2]

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[1] "Automation's Impact on Capital and Labor Markets", in *Automation and Society*, op. cit., p. 280. For a more technical analysis of automation see the same author's "Determinants of the Direction of Technological Change", in *American Economic Review, Papers and Proceedings*, Vol. XLIII, No. 2, May 1953, pp. 288-302; and "Economics and Changing Terminology: The Economics of Automation", ibid., Vol. XLVII, No. 2, May 1957, pp. 339-350.

[2] "Automation, The Impact of Technological Change", Statement by the American Enterprise Institute of Public Policy Research, reproduced in *Exploring the Dimensions of the Manpower Revolution*, op. cit., pp. 432-433.

In addition, automation itself has mixed influences on investment activity. Innovation increases the obsolescence rate of existing capital, and firms having an opportunity to develop the industrial applications of a new technique may be constrained because of commitment to conventional capital forms.[1]

Behind this conservative or evolutionary view of automation is the contention that journalists enchanted with the novelties of technical change have led the public to believe that what is being accomplished on the frontier of innovation will have immediate application throughout the economy. A further distortion arises because of the popular impulse to make innovation the scapegoat for all the unresolved economic problems we face. In the absence of precise information on its actual effects, it is at least safe to attribute our difficulties to it.

The contrasting view—namely that automation represents combinations of so novel a form and with such widespread application as to represent a sharp break with the evolutionary process—appears to be gaining ground. Writers often stress the uncertainty of the future, along with admonitions that we " prepare " for changes yet to be defined. Edwin G. Nourse indicates " [We] are now in a critical situation which might, hopefully, be described as pregnant, or, apprehensively, as explosive ".[2] Heilbroner calls for a bold intellectual assault on the problem indicating that " . . . this belief in the benign social impact of technology may turn out to have been the most tragic of all contemporary faiths ".[3] Norbert Wiener dismissed the contentions of classical economists that changes today were purely matters of degree: " The difference between a medicinal dose of strychnine and a fatal one is also one of degree." [4]

The measurement problem faces us again in assessing this controversy, but fragmentary evidence has been offered to support the

[1] D. Hamberg observes: " . . . no firm is likely to be willing to conduct research that will result in the obsolescence of products that are highly profitable and the markets for which may have been painfully built up in the fairly recent past. Instead, such firms are likely to confine their research activities largely to extensions and refinements of the profitable products, that is, to improvements within the existing framework, in the interest of consolidating past gains." See " Invention in the Industrial Research Laboratory ", in *Journal of Political Economy*, Vol. LXXI, No. 2, Apr. 1963, p. 105. For a discussion on how innovation reduces the average life of capital, increasing its real cost and thus encouraging labour-intensive technology, see W. E. G. Salter: *Productivity and Technical Change* (Cambridge University Press, 1960), Chaps. 4 and 5. For a fairly comprehensive summary of views on the environment most conducive to inventive activity see *The Rate and Direction of Inventive Activity: Economic and Social Factors*, Report of the National Bureau of Economic Research (Princeton University Press, 1962).

[2] " What's New About Automation? ", in *Automation and Society*, op. cit., p. 201.

[3] " The Impact of Technology: The Historic Debate ", in *Automation and Technical Change*, op. cit., p. 25.

[4] *The Human Use of Human Beings—Cybernetics and Society*, op. cit., p. 45.

hypothesis of increasing tempo of penetration. Charles Killingsworth writes:

Automation appears to be spreading more rapidly than most major technological changes of the past. It is difficult, if not impossible, to measure the diffusion of technology in quantitative terms, of course. But I find these facts suggestive: about a century was required for the general adoption of the steam engine in those activities where it could be employed; the comparable time span for electric power was about 50 years. The first automatic accounting systems were installed in banks some seven or eight years ago. Today, about half of the banks are in the process of converting to this system.[1]

Arthur Goldberg views the increased obsolescence of American industrial plant as evidence of the quickening pace of automation: " A competent estimate has been made that it would cost $95 billion to replace our plant and equipment now obsolete." [2]

Lawrence K. Williams notes that in a ten-year period nearly 7,000 computers had been installed, and that at the terminal year of that period some 7,000 computers were on order.[3] Sales in the United States for the electronics industry increased from $500 million before the Second World War to $15,000 million in 1960.[4] The obsolescence cycle for machine tools is rapidly declining from eight or ten years to five years.[5]

While the penetration of automation cannot be easily quantified, the pressures encouraging such penetration can at least be delineated. Looking first at the public sector, the most obvious difference is the extensive participation of government in R and D (research and development) activity. Technologists point to the massive diversion of resources—both human and technical—in the Second World War to provide improved forms and to speed the production of military hardware as the source for the scientific and technical breakthroughs now in evidence. The development of high-speed cameras, optical measuring devices, transistorised technology, printed circuitry, control systems and the computer itself—all are spillover benefits of such public activity. The sustained interest of governments in the development of technology for both destructive and constructive purposes derives its impetus from pressures much more potent and universal than the profit motive.

[1] " Automation, Jobs and Manpower ", in *Exploring the Dimensions of the Manpower Revolution*, op. cit., p. 203.

[2] " Challenge of Industrial Revolution II ", in *New York Times*, 2 Apr. 1961.

[3] " Automation: Some Problems of Coordinating and Forecasting ", in *Nation's Manpower Revolution*, op. cit., Part 9, p. 2866.

[4] Congress of the United States, 86th Congress, Second Session: Statement by Don. G. MITCHELL, President, General Telephone and Electronics Corporation, and Chairman of the Board, Sylvania Electric Products, Inc., in *New Views on Automation*, Papers Submitted to the Subcommittee on Automation and Energy Resources, Joint Economic Committee (Washington, Government Printing Office, 1960), p. 324.

[5] Statement by Alan C. MATTISON, President, Mattison Machine Works, ibid., p. 317.

In the United States total research and development expenditure jumped from $3,100 million (or 1 per cent. of the gross national product) in 1951 to $13,900 million (or 2.8 per cent. of the G.N.P.) in 1960.[1] By 1963 it had reached $17,000 million. From 1953 to 1961 the G.N.P. increased some 43 per cent., while outlays for R and D from all sources increased 300 per cent.[2] Close to two-thirds of such research and development activity was financed by the federal Government.[3] In the fiscal year 1962 the President's proposed $12,300 million for research and development represented an amount greater than all federal government expenditures for research and development during the entire period from the American revolution up to and including the Second World War. This activity has become so momentous that we have, as one report put it, " invented the art of systematic invention ".[4] Discovery is no longer left to chance, but systematised and institutionalised.

In the United States the benefit of all this for the private sector is becoming a matter of vigorous debate. Since this issue relates directly to the pace of technical change a few contentions will be noted briefly.

First, the assessment one makes of such public activity depends, in part, on whether automation is viewed as a disruptive process or as one essential to economic growth. The concept of disruption was reflected in a query put by a Congressional committee to Labor Secretary Willard Wirtz. Was not public support of R and D activities in the defence industries accelerating technology and therefore a force behind the manpower problems America faced? Wirtz explained that the large allotments to defence projects had only an indirect effect on the private sector, and that such R and D activity was largely devoted to new product (rather than process) innovation. The former was not as likely to affect productivity as much as the latter.[5]

The same Committee asked Commerce Secretary Luther Hodges whether such governmental activity might not have adverse manpower consequences for quite a different reason. The private sector was being denied access to the sophisticated technical talent that could otherwise generate technological change and thereby energise economic development in the private sector. Hodges readily acknowledged this possi-

[1] Nester E. Terleckyj and Harriet J. Halper: *Research and Development: Its Growth and Composition*, Studies in Business Economics, No. 82 (New York, National Industrial Conference Board, 1963), pp. 21-22.

[2] United States Congress, 87th Congress, Second Session: Statement by Dr. Richard J. Barber, in *State of the Economy and Policies for Employment*, Hearings before the Joint Economic Committee (Washington, Government Printing Office, 1962), p. 860.

[3] *Research and Development: Its Growth and Composition*, op. cit., p. 27.

[4] Quoted from a Standford Research Institute report in *Yale Review*, Mar. 1963.

[5] Reply to questions by Senator Randolph, in *Nation's Manpower Revolution*, op. cit., Part 1, p. 55.

bility. He cited evidence that the United States suffered a competitive disadvantage in the availability of scientists and engineers for civilian research and development. For example, in 1962 the proportion of the total of such talent employed in the private sector was: United Kingdom 60 per cent.; France 70 per cent.; Netherlands 95 per cent.; Japan 95 per cent.; Germany (Fed. Rep.) 95 per cent.; United States 30 per cent. When the proportion involved in civilian research and development is compared to the total labour force in each nation, the ratios are: United Kingdom 12 per cent.; France 12 per cent.; Netherlands 14 per cent.; Japan 16 per cent.; Germany (Fed. Rep.) 28 per cent.; United States 16 per cent.[1]

No one denies, however, that public R and D activity has emerged as a major force capable of affecting the technological contours of our society. Even if it proves, years hence, that the scale of such activity in the last ten years was a temporary interlude, the acceleration it has given to the development of technical skills, technical information and automation itself will have major effects for the distant future.

In the private sector privately financed research has increased from $2,200 million in 1953 to $4,400 million in 1960, with estimates placing more than half of this for research activity in developing new products, and the balance for the improvement of production technique.[2] At the international level the spectacular growth of new trading areas, east and west, has intensified competition in world markets. There is clear evidence that the diffusion of new technique is correlated with competition, so we can expect such vigorous trade rivalries to stimulate interest in both product and process innovation.

Technical considerations, too, promise to speed the penetration rate of such equipment. The rapid expansion of instrumentation, electronics and computer output has been matched with a proliferation of engineering forms designed to meet highly varied production and resource require- [illegible] Leasing, rental and other service arrangements allow small firms [illegible] the services of equipment without the burden of overhead costs [illegible]stantial outlays. Computers are becoming more efficient, less [illegible]y, more flexible, more compact. The electronic components of numerical-control equipment are being reduced in price, vastly increasing potential markets and industrial applications. One can expect continued economies. It is not likely that firms pioneering in the manufacture of new technology would themselves be unaware of the opportunity and benefits that efficiency in their own production allows.

[1] *Nation's Manpower Revolution*, op. cit., Part 1, table 17, p. 94.

[2] *Research and Development: Its Growth and Composition*, op. cit., pp. 21-22.

Some Economic Dimensions of Automation

The economic significance of automation can best be measured by its consequence on the form and amounts of capital and labour required for production. At least four dimensions of this factor impact deserve attention in the definition and measurement of technical change.

(1) What savings in the use of capital and labour are involved with the technology? Such savings should be measured per unit of output, in so far as possible, and not in aggregate terms. Total factor use following the introduction of a change in technology reflects changes in total production, and the change in total output can reflect a multiplicity of non-technical market forces.

(2) What alterations in the ratio of labour and capital are involved with the technology? Has technical change involved more capital saving than labour saving? The direction of these savings determines alterations in the capital-labour ratio, of course.

(3) What are the time dimensions of the technical change? Has the change represented a sharp break in production technique, or has the alteration in per-unit capital and labour requirements been the cumulative consequence of gradual change over time?

(4) What changes in the degree of substitutability of labour and capital are involved with the technology? This measure has important implications for the elasticity of labour's demand schedule, and determines the consequences of any relative shift in factor costs after the technology has been introduced.

These several important dimensions of technology—while not exhausting all the vital dimensions of new technique—can be represented graphically. In figure I, the vertical axis measures unit capital requirements, and the horizontal axis measures unit labour requirements, the reciprocal of output per head. The curves indicate the alternative labour and capital requirements which would be necessary to produce a constant total of production for a given date. The curve designated T_1 reflects the varying combinations of capital and labour that lead to constant total production at time 1. The curve designated T_2 indicates a level of total production equal to that drawn for T_1. Each curve is a snapshot of alternative production techniques, where those techniques are described in terms of the unit labour and capital requirements necessary to sustain total output at an unchanged level. The successive shift of the curve from T_1 to T_2 towards the origin of the figure indicates the manner in which new technology has allowed for economy or savings in the use of both capital and labour.[1]

In other words, automation is defined as the reduction of unit labour and capital requirements necessary to sustain a constant level of output, with improvements of that technology related to time. Through such analysis it is possible to form concepts of the rate of change. The tempo of innovation can be measured by dividing the distance between curve T_1 and curve T_2 (indicating economies in factor use per unit of output) by the time span between time 1 and time 2. We emerge with a concept of per unit factor economy per month, or per year. While this concept may appear unnecessarily abstract, it is not a rate that would escape measurement. By making use of this concept we can calculate the " significance " of automation or any other engineering change in terms of these two important dimensions: the factor-saving opportunities of the innovation and the tempo of its application.

The direction of factor savings is, of course, equally important for analysis. In figure II, technical changes are introduced that are labour-saving. In figure III these technical changes are capital-saving. In figure IV the technical change is both capital- and labour-saving (as in figure I) but has produced corners in the production function. Such discontinuities as are found in labour demand may reflect such corners in the production function.

The major limitation of this definition is that we lack detailed information about capital. How should we define unit capital requirements? How should we designate capital coefficients when it appears that these vary substantially with the level of capacity utilisation? What assignments of overhead costs are appropriate to multi-product operations? What is the appropriate technique for amortising capital costs to production when the future activity of that equipment is uncertain? Calculations involving depreciation and obsolescence made to conform to accounting practices and law may not yield information that is very helpful in calculating actual capital costs per unit of output.

The Uses of Productivity

In the above two-factor scheme automation is related to those changes in technology that substantially alter input-output ratios. But because labour is, relative to capital, a much more homogeneous input, and because of the capital measurement problems listed above, it is tempting to by-pass capital and identify automation with changes in labour

[1] This measurement procedure follows the analysis offered by W. E. G. Salter in his pioneering effort to bridge conventional economic theory with empirical evidence. See *Productivity and Technical Change*, op. cit., pp. 27-30.

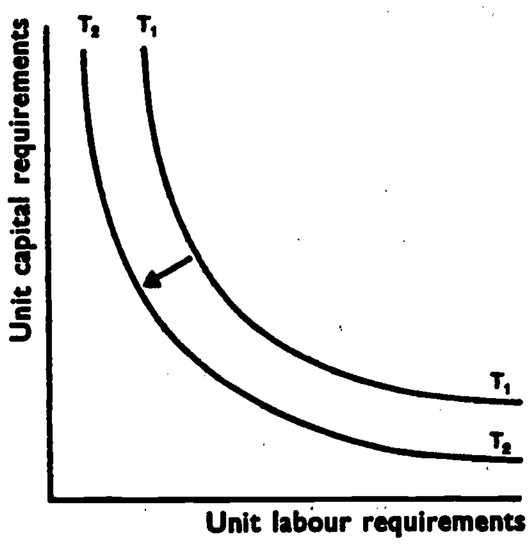

FIG. I. Shift in Capital and Labour Requirements for the Same Total Production at Two Points in Time (T. 1 and T. 2).

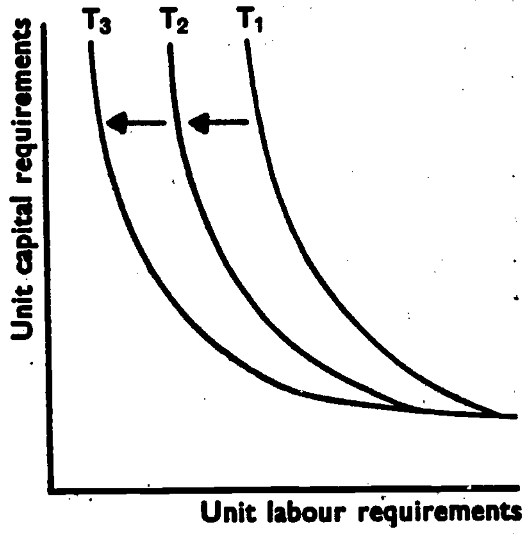

FIG. II. Impact of Labour-saving Technology on Capital and Labour Requirements for the Same Total Production at Three Points in Time.

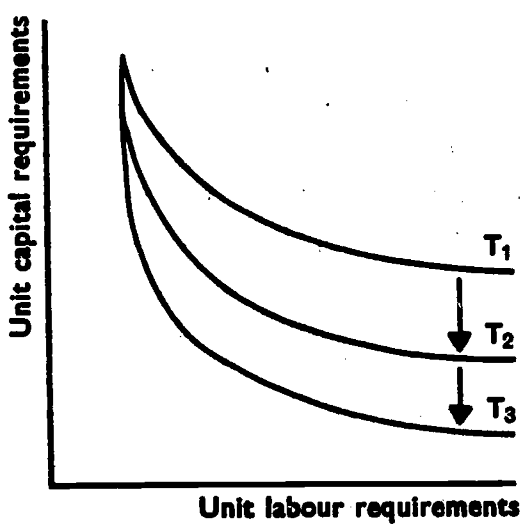

FIG. III. Impact of Capital-saving Technology on Capital and Labour Requirements for the Same Total Production at Three Points in Time.

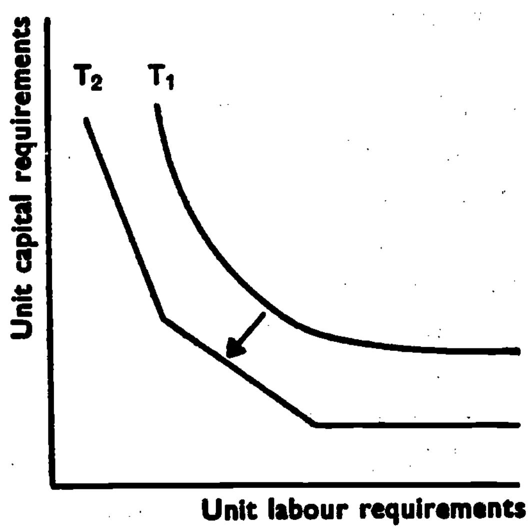

FIG. IV. Impact of Capital- and Labour-saving Technology on Capital and Labour Requirements for the Same Total Production at Two Points in Time, with Allowance for Discontinuities.

productivity alone. Indeed, labour productivity information is usually offered as "evidence" of the change that technology involves. The difficulty of tracing manpower effects to technology has been stressed here and has been acknowledged elsewhere.

There is good reason, however, for the use of such ratios in automation analysis. Comparisons of productivity experience can be set against data on production experience, with the displacement effects of the former compared to the employment-generating effects of the latter. Unit labour requirements can be linked directly with the nature of the market in which the technical change develops. As stressed throughout, it is both the technology itself and the characteristics of the conductors that transmit its influence to labour and product markets which determine the "significance" of the technological change. One cannot be analysed without the other.

The use of the labour productivity ratio involves problems of its own, however. It is not a reliable guide to efficiency. The intensive use of one factor at the expense of another may not cause total factor productivity to increase. For example, Kendrick has contended that the high labour productivity in America in the post-war period does not necessarily establish over-all factor efficiency, but simply reflects the higher rate of substitution of capital for labour in the post-war period.[1] To meet this deficiency in the labour productivity ratio we must, of course, analyse all factor inputs, and we return to the problems of capital measurement discussed above.

Questions arise, too, as to whether indirect labour should be considered in calculating the labour productivity ratio. Since automation involves substantial savings of direct labour, and a deepening of manpower talent supporting or maintaining that automated function, it appears increasingly unrealistic to treat the appropriate productivity ratio as one that makes use only of direct or production labour.

But more serious problems arise when it is realised that technology is hardly the sole determinant of labour productivity. We need not recapitulate all of the arguments that loosen the linkage of technology to the labour market, but most of these are relevant to productivity too. The relationship of the labour input to total output is not likely to be linear. Clarence Long has found evidence that the increase of unit labour costs following the initial downswing of economic activity is more likely to reflect manpower policy than wage policy. Increases in unit costs reflect the perverse effects of labour productivity, reflecting in turn

[1] John W. Kendrick: "Productivity, Costs and Prices", in *Wages, Prices, Profits and Productivity*, edited by Charles A. Myers (The American Assembly, Columbia University, June 1959).

management's delay in reducing the labour force following a fall in production.[1] Labour productivity can be affected by scale effects, changes in labour motivation or morale, changes in the combination of skills of labour employed, changes in trading areas, and the endless array of possibilities not directly related to technology itself.

But until further information is available on capital, labour productivity information provides a useful mechanism for sorting alternative categories of economic change. High-productivity sectors can be analysed in terms of those which are releasing labour and those absorbing labour to determine the relative characteristics of technology in each, and the market characteristics of each.

In the former area, information can be obtained on the purchase of instrumentation, computer and other advanced technology, on capital/labour ratios, capital/output ratios, investment/output ratios, investment/capital ratios, investment/labour ratios, and wage/capital payment ratios, on changes in capital obsolescence, and on resources allocated to R and D activity. Such information provides valuable details on the nature of technology and relative factor use in production. In the latter area, information can be obtained on price policy, wage policy, unit labour cost, unit material cost, unit capital cost, marketing policy, quality changes, income effects, and so on. While these variables are one stage removed from technology, they largely determine its influence.

There is some risk, however, in treating the labour productivity ratio as the essential—if hypothetical—measure of labour displacement that technology involves. It is conceptually tidy and arithmetically simple to compare projections of labour productivity growth with projections of growth of the G.N.P. that are necessary to absorb all persons in the labour force, but such calculations obscure the complex interaction of productivity with production.

As a case in point, industry studies intending to trace the employment effects of particular technological forms may not reveal the reality that, whatever the employment effect where new technology is developed, the more significant consequence may be located where that new technology is not applied. It is misleading to treat productivity and production as mutually exclusive and opposing tendencies which, when taken together, explain employment. They explain what employment is, but they tell us little as to why we have that employment effect.

[1] "The Illusion of Wage Rigidity: Long and Short Cycles in Wages and Labor", in *Review of Economics and Statistics*, Vol. XLII, No. 2, May 1960, p. 144.

SUMMARY AND CONCLUSIONS

(1) The word " automation " is employed loosely, and there seems little advantage in distinguishing it from " advanced " forms of technical change. As John Dunlop has observed: " It is impossible to isolate the impact of automation from other forms of mechanisation and technical change. Many of the policy problems and implications are undifferentiated and only matters of degree."[1] Efforts to confine its meaning or graduate its capacities in terms of the sophistication of the control mechanism serve a limited purpose. The significance of any technical change, whether sophisticated or not, is largely reflected in what Bright has called the " span " of its application. The significant change is, therefore, one which is likely to affect the entire structure of the production process.

(2) In a broader sense, technical change must be analysed in terms of the factor savings involved, that is in terms of its impact on unit capital and labour requirements. Such an approach would require additional information about capital. We need to know much more about its quantity and form, about its distribution and cost. And we need more imagination in assessing all of the capital-saving implications that technical change makes possible. We are in better shape, statistically speaking, in measures of manpower, but additional attention must be given to the direct labour-saving and the indirect labour-using implications of technology. The barriers to the application of this proposed measurement are not conceptual, but statistical.

(3) The significance of automation involves not only the span of its application, but the speed of its penetration, and the responses of the market to it. We must not be so absorbed with engineering form as to neglect those responses. By " responses " we do not mean the establishment of advance warning systems, the rationalisation of labour through the use of attrition, training and retraining programmes alone. We mean the manner in which savings in the use of both capital and labour are transmitted to society in order to set in motion employment-generating impulses. Surprisingly little information in this area is yet available.

(4) Finally, while our review hardly encourages optimism, we cannot afford to neglect research needs in this area. Much of the commentary in this paper has a negative cast, but it is not intended to imply that empirical study of the subtleties and complexities of automation has little chance of success. We cannot dismiss as inopportune persistent questions about the effect of automation simply because we have not

[1] *Automation and Technical Change*, op. cit., p. 2.

yet gathered information, or even developed research methodologies, to answer them with confidence.

Just as we have diverted resources into the development of more sophisticated techniques of measurement and control of the production process, so must we pour resources into the development of techniques to measure their consequences. In the United States, for example, the federal Government's research expenditures in its own establishments provided only 2.5 per cent. of those funds for social science research. Raymond Fosdick, who during his years as President of the Rockefeller Foundation had an unusual opportunity to observe R and D's effects, sadly remarked:

> ... we have been undone by a technology which came too soon and which found us utterly unprepared in point of religion, ethics, law, philosophy or politics to meet the exigencies which it created.[1]

And he might well have added " unprepared in research methodology as well ".

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[1] As quoted by Dexter M. Keezer: " R and D: Its Impact on the Economy ", in *Challenge*, Vol. 12, No. 3, Dec. 1963, p. 10.