COMPUTERS AND ECONOMICS: PROGRESS, PROBLEMS AND PROSPECTS

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I. INTRODUCTION: MODERN ECONOMICS = THEORY + DATA + COMPUTERS

During the past two decades, computers -- and computer software -- have provided for economics and economists what the side of the mushroom provided for Alice, what linear accelerators provided for high energy physicists, and what transistorized circuitry provided the electronics industry: a tremendous impetus toward growth. The explosive growth of computer use in economics (and, reciprocally, of economics in response to opportunities provided by expanded computer use) has been closely related to the rates of change in some of the key parameters reflecting advances in computer technology: for example, since 1955, compound rates of decrease of about 58 percent and 36 percent annually, in computer costs per operation, and computer size, respectively; and annual rates of increase in computing speed and total installed computing power in the United States of 69 percent and 90 percent, respectively! (See Figures 1-4.)

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This paper was prepared for a Conference in August 1971, and a subsequent book, sponsored by the American Federation of Information Processing Societies (AFIPS) on the subject "Computers and the Problems of Society."
Fig. 1

SIZE
CPU/Storage size in cubic feet

Fig. 2

COST
CPU/Storage cost in dollars per million additions

Fig. 3

SPEED
CPU/Storage speed in thousands of additions

Fig. 4

Computing power in the United States

Source: Ware (1967). For other calculations showing improvements in CPU technology, see Sharpe (1969, Chapter 9).
Although these rates do not translate directly into growth rates for computer use in economics, they are suggestive of the scale of increased applications in economics. The effect of this growth on the style and content of modern economics, and economists, has been equally dramatic -- a point we will return to later in the discussion.

What have been the principal reasons behind this explosive growth? Among the social sciences, economics has evolved over the past century, and particularly during the past three or four decades, an increasingly rigorous, mathematically-formalized body of theory. This growth has been associated with the work of Cournot, Walras, Edgeworth, Marshall, Pareto, Fisher, Ramsey, Keynes, Leontief, Tinbergen, Frisch, and Samuelson. The resulting body of theory has included a wide assortment of potentially powerful concepts and tools: general equilibrium, supply and demand functions, marginalism, time preference and discounting, internal and external economies, elasticities, the consumption function, production functions and rates of substitution, input-output matrices and activity analysis, linear and dynamic programming, instrument and target variables. Though potentially powerful, the new concepts and tools were often highly abstract and sometimes quite remote from empirical content. The principal reason for their continued remoteness was certainly the lack of appropriate quantitative data with which to test, apply, and modify the growing body of theory. Perhaps another contributory reason lay in the incentives, propensities, and life-style of academic economists, often preferring to do "their thing" with only limited intrusion into, or from, the outside world.
At the same time as this tremendous growth in formal theory was taking place, the principal reason for its remoteness from the real world was gradually diminishing. Especially since 1920, with the founding of the National Bureau for Economic Research by Wesley Mitchell and others, there has been a dramatic surge in the collection and structuring of data. The result has been to permit a growing share of the concepts and tools of economic theory to be applied, with further stimulus to the growth of theory, through the familiar sequence: theory → hypothesis-formulation → data and testing → new theory → etc.

Originally, much of the impetus for generating data came from the concern of economists with the business cycle, which was the initial focus of the NBER's interest. Indeed, over much of the last five decades, the National Bureau has been both a major source and a major user of empirical data, heavily emphasizing time-series data for a wide range of economic indicators, varying over the cycle.

A second major impetus to the surge in data generation has been the growth in government activities, both those relating directly to public expenditure programs, and those affecting resource use through the activities of regulatory agencies. Included in the first category are government programs in social security, education, health care, agriculture and transportation; examples of the regulatory category are the functions of the Federal Trade Commission, Federal Power Commission, Interstate Commerce Commission, Securities and Exchange Commission, National Labor Relations Board and, most recently, the Cost of Living Council and the new Wage and Price Boards.

Furthermore, the Employment Act of 1946, and the Council of Economic Advisers which it created, provided a strong and continuing
stimulus to more and better data collection through these and other agencies, including the Census Bureau. Growth in government activity required and produced massive data bases, dealing with production, employment, prices, investment, inventories, wages, salaries, money and credit, interest rates, profits, etc.

Closely related to this growth of data sources was the impetus given by Keynesian economics to the organizing and structuring of the component data into improved national accounts, focusing on gross national product (output), national income at factor cost (input), disposable income, factor shares, international transactions, money and credit, and index numbers of price and value. Much of this work was concentrated in the National Income Division of the Commerce Department, and the Bureau of Labor Statistics.

The central role that computers and computer technology have played in the growth of modern economics can be stated quite plainly: computers have provided the bridge between the accumulated body of formal theory on the one hand, and the growing availability of large data bases, on the other. The result of this crucial bridging function has been the growth of modern econometrics and, more recently, an increasing policy orientation of economics. Feedback plus occasional serendipity, have in turn provided stimuli to new theoretical developments, as well; for example, in work on technological change (Solow 1957), organizational behavior (March-Simon, 1958), and decision theory and optimization under uncertainty (Raiffa, 1968).

The crucial role that computers have played in providing a bridge between theory and data has been facilitated by several factors. One
factor has been the tremendous growth of hardware and computer capacity, as reflected by the key technological parameters referred to earlier. Besides growth in capacity, computer technology has provided increased flexibility, through the widening range of computer systems, extending from the ILLIAC IV, and the IBM 360, down to time-shared systems like CPS and JOSS, to systems using display terminals, and to various mini-computers. Time-shared systems, with individual consoles, have greatly expanded the opportunities available to economists for direct interaction and experimentation with hypotheses and data. Finally, the bridging role of computers has been measurably enhanced by the development of software and program libraries, which enable the increased capacity and flexibility of computer systems to be more widely and efficiently used.

Against this background, we turn in Sections II and III to review the extensive literature reflecting the growth of computer use in economics during the past two decades. The review is not exhaustive, but touches on some of the main areas and highlights.

In Section IV, we then consider some of the principal current uses to which computer capacity and software are being applied most intensively, as well as trends for the future. Both current uses and future trends relate especially to such areas of public policy as the economics of health, education, welfare, and poverty. Inasmuch as many of these current uses and future trends tie in closely with subjects to be discussed by other contributors, we will be brief in discussing their economic aspects.

Nevertheless, it is worth noting that the overlap between this paper on economic problems, and other essays contributed to this AFIPS
study (for example, those relating to education, and health care), is itself indicative of an important and growing trend. Increasingly, economic problems, as perceived and pursued by economists, are becoming more closely intertwined with socio-environmental policy issues than they have been in the past. What economics and economists formerly ignored, or treated simply as "externalities," are acquiring increasing attention in the formulation and evaluation of public policy. Indeed, there is a growing disposition to make these externalities a matter of direct scrutiny in economic studies, and to regard economic analyses, cost-benefit analyses, and cost-effectiveness studies that do not adequately treat them, as unsatisfactory.

In Section V, we will consider some of the problems attendant to computer uses and accomplishments in economics. We will be concerned with several major economic problems that computer use hasn't yet helped much to clarify, let alone solve. Perhaps the most pressing example relates to the goal of combining reasonable price stability with full employment and growth. In contrast to this goal, current economic conditions embrace both inflation and unemployment, with the tradeoffs between them seeming to be politically, as well as economically, quite unattractive.

Section V will also consider several methodological problems that previously existed in economics, but have been intensified in several respects by the growth of computer capacity and access. One such problem lies in the use of computers for hypothesis-testing versus their use in hypothesis-formulation; often there is some obscurity as to which process is underway in economic research. Another
example arises in connection with the economist's role as an influence on, as well as an observer of, the phenomena he is analyzing. Both roles have been measurably strengthened by computer use, in the process raising important issues of management and planning for the future. The summary and conclusions are presented in Section VI.
II. APPLICATIONS TO ECONOMIC PROBLEMS (1)

The following review of economic literature concentrates on some of the main problem areas in which computers have found significant application, either in performing particular analytic operations, or in simulations of economic behavior and process.

**Interindustry Economic Analysis**

The increasing complexity of modern economies has led economists to devote greater attention to designing more complex models intended to reflect interdependencies among industries and geographic regions. Applied empirical work in this area began with Leontief (1936 and 1951). His approach was to simplify the complete general equilibrium system originally developed by Walras. Leontief's input-output matrices showed transactions between sectors, or activities, or regions -- entered in the form of inputs purchased by sector \( i \) from all others, and outputs produced by \( i \) and sold to all others. Matrix inversion by digital computers enabled speedy solutions for large simultaneous equation systems, thereby generating coefficients, which in turn could be used to determine the total economic effects of any specified change in final demand. One of the results of Leontief's early work was to stimulate quantitative studies on interindustry relations in other countries besides the United States [see Chenery and Clark (1959)]. While initially only the developed countries (Denmark, Netherlands, Great Britain and the United States) compiled input-output statistics, more recently many governments of the less-developed nations have begun using such analyses in development planning (see below).
The primary purpose of the input-output model is to explain the levels of interindustry flows by examining the magnitude and composition of production in each sector. Toward this end, the Leontief system relies on several special assumptions, the most important of which are: (a) a given product is only supplied by one sector (hence, there are no joint products); (b) the quantity of each input used by any sector is determined by the level of output in that sector, and (c) these input/output coefficients are fixed, or at least exogenously determined. Thus, the input-output scheme is essentially a simplified theory of production. Often, studies of consumption, investment and other components of final demand, precede the use of an input-output analysis; for example, in setting goals or targets for final demand. Once these components are specified, the computerized model determines the requisite pattern of production.

Other economists have relaxed and modified the assumptions of the Leontief system, with the result that several types of interindustry models have become established tools for research and planning. Linear programming, or activity analysis, models have provided a rapidly growing literature. In comparison to the early Leontief system, linear programming contains two innovations. First, alternative sources of supply are included as separate activities whose levels then become variables in the model. Second, a criterion function is added which allows the choice of one solution over another, based on some objective such as maximization of output value, or cost minimization for a specified sector of final demand. These models and the techniques for their solution are described in Dorfman, Samuelson
and Solow (1958), and in Koopmans (1951).

The choice between a Leontief-type model, and a linear programming formulation, depends primarily on the purpose of the analysis. When the focus is on government policy and planning, the most useful model is one which contains those choices over which the government has some control. For example, an input-output model might be used to determine the effect of an increase in exports or imports on a given industry. On the other hand, if the objective is comparison of alternative programs to achieve specified goals, then a programming model is more useful. The design and choice of such models is discussed in Chenery and Clark (1959).

Regional Economics

Broadly speaking, regional economics involves any economic problem scaled down to measure economic activity in a specific geographic area, and to trace its interaction with other regions. In both developed and less-developed countries, there has been a rapid increase during the past two decades in the literature on regional economics. Meyer (1963) has provided a complete survey of this field and its many ramifications. As Meyer notes, the experience of the thirties and forties led many governmental agencies, both domestic and foreign, to undertake major efforts to improve the status of backward areas through direct governmental intervention. Such efforts as the Tennessee Valley Authority, and the regionalization of the Federal Reserve Banks, provided growing stimulus for research in regional economics in the United States.
The development of input-output analysis provided regional economists with a useful tool for their research. An early study by Isard (1951) describes a model of a local economy, in which interregional production and supply problems could be analyzed. Isard uses such a framework, employing input-output data, to show the effect of distance on economic activity in different regions. More specifically, such a computerized model can be used to investigate how possible changes in population location will affect trade among regions. At the metropolitan level, Hirsch (1959) has presented a study which employs an interindustry flow table for the St. Louis area. Under certain assumptions, he shows the effect of changes in final demand upon the levels of income, output and employment. Such an analysis can provide both public and private sectors of the area's economy with estimates that are useful for future planning decisions. In both the regional and metropolitan examples, computerized models enable the analyst to test the sensitivity of results to a wide range of alternative assumptions about industrial location, population location or final demand.

Problems of urban development have assumed an increasingly important role in the empirical literature of regional economics. Studies of transportation systems, and the difficult questions surrounding the design of such systems, constitute a large portion of these writings. Meyer (1963) contains an excellent summary of the earlier transportation models and applications. An example of more recent work, where computers have played an important role, can be found in Kain (1964). This work involves a nine-equation econometric model dealing with the residential and trip-making behavior of individual workers employed at
over two hundred employment locations in Detroit. Kain's objective is to study the decisions leading to choice among alternative transport modes, and thereby to design a more efficient transportation policy for the future.

Computer simulation techniques applied to intraregional problems are described in Kain and Meyer (1968). As they point out, "the use of computers is particularly appealing for evaluating public investment characterized by important externalities, broad social objectives and durable installations (necessitating very long-range planning horizons)." Computer-oriented models of metropolitan growth have been reported on for Chicago (1960), Detroit (1956), Boston (Hill, 1965), and Philadelphia (1964). Finally, the demand for air transport and airport facilities has been the subject of increased research; one example is presented in a large econometric analysis by Baxter, Howrey, Miller, and Sand (1967).

Planning in Less-Developed Nations

Development planning literature also reflects an increased use of quantitative analysis. Three types of models have been used extensively by economists engaged in analyzing and planning economic growth. First, aggregative macro-models, which apply to the entire economy, have been employed to deal with single aggregates such as consumption and investment, and to project growth rates of national income. Second, sector models, emphasizing agriculture, exports or industry, have been used to plan and allocate resources between competing investment projects. Third, interindustry models have provided a means of analyzing the relationships between sectors during the growth process.
The use of aggregative macro-models has become very popular in formulating the short and medium-range economic plans of the less-developed countries. A good example of such efforts is discussed by Condos and Thorbecke (1966), who present a ten-equation macroeconomic model for Peru which focuses on potential government policy instruments. The general methodology for such planning models is discussed by Leicester and Stone (1967). Examples of sectoral planning models for Mexico and India may be found in Manne (1966), and Heady, Randhawa and Skold (1966). The uses of input-output analysis for planning in India are described by Ghosh (1969), and a linear programming model for planning in India has been presented by Sandee (1959). The programming approach to the study of development is discussed and evaluated by Chenery (1967), as well as in the work of the United Nations (1961).

One of the main obstacles to using both input-output analysis and linear programming models for less-developed countries lies in their great demands for accurate statistical information. Often the technology, which the development plans consider, does not yet exist in the country being studied. Hence, estimates based on the experience of other nations must be utilized. As data collection in the less-developed nations improves, aided by the computer, the use of such models for planning growth should become more worthwhile. One such use lies in testing the consistency among the separate sub-plans of a development effort; for example, manpower and education plans, capital expansion plans, financial plans, and sectoral inputs and outputs (Lewis, 1966). Nevertheless, the inability to incorporate technological
change into computerized development planning models — an inability that relates to the unsatisfactory state of development theory, even more than to the absence of adequate data — is a major handicap to a fruitful use of such models.

Computers potentially have numerous other constructive uses in less-developed countries, besides those associated with development planning. The broad range of such applications has been surveyed by the United Nations (1971), including such uses as demography, censuses, government administration and accounting. Yet the underutilization of equipment already installed in these countries should give pause — perhaps more than is reflected by the U.N. report — to plans or predictions of expanded computer use in the developing countries in the near future.

**Microeconomic Decisionmaking**

The last decade has seen many new approaches applied to the traditional problems of microeconomics. These new methodologies have, in great part, been spawned by the growth of computer capacity and software, referred to earlier. In the area of investment theory, the design and selection of optimal investment portfolios has been studied by Markowitz (1959), with risk and rate-of-return as criteria. The approach is gaining wider application in several Wall Street investment firms. Clarkson (1962) followed Markowitz's work with a simulation study of the trust investment process. His approach is to model the investment behavior of the trust officer of a medium sized bank, and compare the resulting portfolio selections with those actually observed. The computer simulation provided accurate estimates for
two quarters of 1960.

Other models of firm behavior are now being explored which contain multiple goals, production possibilities and information structures. Cyert and March (1963) have developed several computer models of decisionmaking in the firm. They strongly suggest that understanding and prediction of the firm's decisionmaking can be improved by combining analysis of market influences with examination of the internal structure of the firm. The authors formulate three simulation models: an oligopoly model, a duopoly model, and a model of a department store. The models are used to analyze a general behavioral theory of price and output determination. Bonini (1963) presents a model of the firm which focuses on the information system, changes in the decision system and changes in the external environment. The author then simulates the results of various alternatives, such as changes in the rate of growth in company sales.

Models of industry behavior have also received increasing attention by economists, aided by computers. Cohen (1960) presented a mathematical model describing the behavior of shoe retailers, shoe manufacturers, and leather tanners. Balderston and Hoggatt (1962) studied the West Coast lumber industry, examining the dynamics of the market where information is limited and costly. Wallace, Sasser and Naylor (1967) have developed a nine-equation model of the U.S. textile industry for the purpose of simulating the effects of alternative government policies on the performance of the industry.

The uses of computers in industry simulations are further discussed by Shubik (1960). He notes that the new methodology offers
an opportunity to construct more complex theories and to attempt to validate them. A good example of such a detailed model is found in Armstutz' (1967) model of the marketing process, including submodels of the manufacturer, consumer, retailer, distributor, and salesman. Quantitative data are developed for such variables as consumer purchasing decisions, responses to various advertising media, responses to word-of-mouth communication, and new product acceptance. A simulation of behavior in the consumer sector is discussed and the results analyzed.

An ambitious micro-model for simulation of the national economy has been described by Orcutt, Greenberger, Korbel, and Rivlin (1961). This study concentrates on demographic behavior utilizing family units as basic components. A number of simulation runs were carried out covering the period 1950-60. Experiments were made changing various parameters, and the results compared with available aggregative data on U.S. population and its composition.

**Public Finance and Government Decisionmaking**

Until recently economists have tended to regard public expenditures (and the related decisionmaking process) as exogenously determined. Increasingly, they are recognizing that the behavior of federal, state, and local spending units is a complex process, warranting much closer scrutiny. With over seventy percent of the U.S. population in urban areas, municipal finance is an extremely important part of the economic system. Consequently, the relationship between federal, state, and local spending programs has become a major concern of public policy.
Hirsch (1968) has recently investigated the possibilities of using a computerized regional input-output model to project the expenditure requirements of local urban governments. His study treats the governmental spending units as an "industry," whose production levels depend upon the demand for government services and the input coefficients of the other sectors. Using this framework, he suggests that urban fiscal planners can gain insight into future expenditure patterns; in addition, the effects on revenues derived from taxation, due to shifts in an urban area's industrial mix, can be investigated.

Another recent study by Manser, Naylor and Wertz (1970) attempts to assess the effects of alternative policies for allocating federal aid for education to the States. The authors develop an econometric model of state expenditures on education, and then proceed to conduct computer simulation experiments to determine the effects of six alternative schemes for federal allocation of funds. One objective of the study is to discover under what conditions federal aid acts as a stimulant or merely as a substitute for state and local spending. Their model approaches the question of expenditure determination by regarding the governmental unit responsible for dispensing funds as the focus of analysis. As an aid to decisionmaking, the simulation results can be presented to a policymaker as a range of alternatives with quantitative rankings.

A final study of government behavior, which relies heavily on computer use, has been presented by Crecine (1969). He studies the budgeting process of three municipal governments by simulating the behavior or many individuals -- department heads and budget officers --
in a simultaneous decisionmaking process. The results provide good postdictive estimates of the outcome of budgetary decisionmaking.

**Quantitative Economic History**

Empirical research, relying heavily on computer use, has also become increasingly, and perhaps surprisingly, prominent in the field of economic history, which some economic historians have renamed "cliometrics." The basic style and computerized orientation of the field was initiated by the germinal work of Conrad and Meyer (1957), dealing with the economics of slavery in the *ante bellum* South. Subsequent applications of quantitative methods to historical problems are surveyed and evaluated by Fishlow and Fogel (1971). The focus of this research has been on American and English history and, due to data limitations, has primarily concerned the nineteenth and twentieth centuries. A partial list of other topics to which these efforts have been addressed includes agricultural productivity, investments in human capital, and governmental promotion of social overhead investments.

The quantitative contribution of the railroad to American economic growth has been studied by Fogel (1964). Friedman and Schwartz (1965) have compiled an exhaustive history of monetary growth for the United States. A collection of historical analyses, relying heavily on computer models and data processing, is contained in Rowney and Graham (1969). Williamson and Swanson (1971) suggest various historical research that, if carried forward, could provide important insights into current economic problems. Urbanization, growth of the labor force and industrial location studies are three areas in which
quantitative historical analysis may shed some light on socio-economic structure, and perhaps offer some guidelines for the future.
III. APPLICATIONS TO ECONOMIC PROBLEMS (2) -- MACROECONOMETRIC MODELS

Probably the most substantial applications of computers to economic analysis (certainly from the standpoint of both the financial and human resources involved, less assuredly, from the standpoint of results obtained) lie in the area of large-scale macroeconometric modeling.

Since the experience of the 1930s, and passage of the Employment Act of 1946, economists have become increasingly interested and involved in national economic policymaking. The last two decades have presented the President, the Joint Economic Committee, and the Council of Economic Advisers with a myriad of often conflicting economic and social objectives, and policy proposals. At one time or another such goals as economic growth, price stability, equilibrium in the balance of payments, full employment and a more balanced distribution of income have been responsible for new legislation and new policy initiatives. The relationships -- some conflicting, some reinforcing -- among these goals (variables), as well as the predicted and actual effect on them of public policies and programs, have been the subject of growing attention. Increasingly, this attention has moved from concern with gross effects to more exact and precise effects: to what has been referred to as the problem of "fine-tuning" of a tremendously complex, as well as imperfectly competitive, economic system, (see below, pp. 45-46).

The rapid improvement of computer technology has transformed the character of economic research in national economic policymaking in a few short years. Initially, economists used the computer as a high-speed, computational aide. Increasingly, however, they realized that
large-scale computers provide possibilities for developing more complex, and hopefully more realistic, descriptions of economic systems. Further, the computer can be used as an experimental tool to permit a wide range of alternative assumptions, initial conditions and policies to be evaluated. As a result of these changes, which have both influenced and been influenced by corresponding changes in the training and skills of economists, the development and use of large macroeconomic models has proceeded at a rapid pace. Nerlove (1966) has provided a survey of 25 such models through 1965. (Since 1965, the proliferation of such models has continued unabated.) Nerlove's tabulation shows the steady increase in size and complexity of these efforts: whereas the early models of Klein and Goldberger (1955), and Tinbergen (1939), contained 12 and 32 equations respectively, the Brookings Quarterly Model (1965) contains over 300 equations and endogenous variables, and more than 100 exogenous variables.

Size itself is not always a virtue, but for some of the complex problems posed by a modern economy, it appears that large disaggregated models are likely to be particularly helpful in improving understanding. The Brookings model deserves special attention not only because of its size and complexity, but also because of the variety of purposes toward which it has been directed. The system gives explicit treatment to six aspects of the economy: (1) agriculture, (2) foreign trade, (3) housing, (4) money and finance, (5) government, and (6) demography. Each sector is subject to different institutional arrangements, and the structural equations attempt to include a wide range of relevant policy variables. The main endogenous variables
include various categories of outlays on consumption, business investment, residential and non-residential construction, inventories, imports and exports; demand deposits, time deposits, interest rates and required reserves; government wage and salary disbursements, and transfer payments; and numerous employment variables, wage rates, and prices. Among the exogenous policy variables are federal and state tax rates, and federal government purchases of goods in various categories, including construction. The Brookings model thus provides a tool for extensive analysis of the dynamics of the U.S. economy.

Nevertheless, despite its sophistication and breadth, the Brookings model is neither complete nor adequate for analyzing certain important problems. For example, it does not reflect explicitly the problem of diminishing competition in the market determination of prices and wages, nor of the possible means by which public policy might stimulate increased competition, e.g., through anti-trust measures, or through changes in commercial policy. Yet these issues may be among the most important questions for resolving the problems of economic "fine-tuning"--arriving at better combinations of unemployment and inflation than those we presently confront.

We now turn to summarize certain cases where econometric models have been applied with relative success.

Applications of Macroeconometric Models

Once an economic system has been specified and its parameters estimated, the model can be used in a number of different ways: for forecasting; for simulating the effects of policy actions; and for
simulating the behavior of the economy according to various business cycle theories.

a. **Forecasting**

The aim of a forecasting exercise is to derive the implications of a particular model for some future time period, $t$. The model's equations typically contain lagged values for both exogenous and endogenous variables, covering several prior periods, $t-1$, $t-2$, etc. Lagged values for some of these variables are specified as initial conditions, and values may also be specified for some of the exogenous variables at time $t$. Given these data, values of the endogenous variables can be computed from the reduced form equations.

Klein (1969) performed a forecasting experiment utilizing a condensed version of the Brookings system. The model was fitted to sample data for the period 1948-1960, and forecasts for real GDP, which turned out to be quite accurate, were then derived for the eight quarters during 1961-1962. A similar Wharton forecasting model is described by Evans and Klein (1967). In an earlier study Adelman and Adelman (1959) examined the properties of the Klein-Goldberger model (1955) (namely, the leads and lags in the turning points of its key variables), and compared these results with the actual performance of the U.S. economy. They concluded that the behavior of the model was stable, in the absence of large, random shocks.

A recent evaluation of forecasting via econometric models has been presented by Stekler (1968). He compares the forecasting ability of six aggregative models, according to three criteria: (1) percentage of turning points in business activity that are forecast correctly;
(2) degree to which predicted rates of change correspond to observed changes; and (3) performance of the model relative to naive methods of forecasting. Stekler's results demonstrate the difficulties involved in appraising a given model's ability to forecast. Some of the models he examined forecast short-range changes accurately. Others predicted turning points correctly, but failed to yield accurate quantitative forecasts. For periods beyond that used to fit a particular model, its forecasts were generally much less reliable. This suggests that the accuracy of parameter estimates is severely limited by economic change. As technology, tastes, and institutional arrangements change, the relationships represented by the equations are likely to shift. Hence, longer-range predictions become increasingly reliable.

One crude test of the accuracy of short-term econometric forecasting models is summarized in Figures 5-8. The figures show the relationship between annual forecasts by the Council of Economic Advisers (CEA) of GNP and unemployment, and the actual levels that resulted, for the nine-year period 1962-1970. During the period, macroeconometric models were used by the CEA for forecasting. Initially, the models were fairly simple. Over the period they became increasingly complex and computerized. Consequently, the scatter diagrams in Figures 5-8 give an indication of the extent to which increased complexity and computerization of forecasting models has improved the accuracy of forecasts.

Figures 5-8 show a mixed record. Using the percentage error in forecast as an index (Figures 6 and 8), the short-run forecasting performance of more complex macroeconometric models shows a continued
Fig. 5—CEA forecast versus actual GNP
Fig. 6—Percent error of CEA forecast of GNP
Fig. 7—CEA forecast of unemployment rate versus actual unemployment rate
Fig. 8—Percent error of CEA forecast of unemployment rate
improvement for GNP, but not for the unemployment forecasts, over the period 1962-1970. Regressing the percentage error in GNP, \( E_1 \), on time, \( T \), gives the following result for GNP (Figure 6):

\[
E_1 = -0.26T + 3.10 \\
(\text{R}^2 = .35)
\]

Regressing the percentage error in unemployment rate, \( E_2 \), does not yield a coefficient significantly different from zero (Figure 8):

\[
E_2 = 0.18T + 6.65 \\
(\text{R}^2 = .008)
\]

One may conjecture whether political considerations might have influenced econometrics in the unemployment forecasts, particularly in light of the fact that in six of the nine years, forecasts of unemployment were more optimistic (lower) than the actuals!

In spite of their shortcomings, econometric models provide an opportunity for investigating the cyclical tendencies of an economy. What sequential changes precede cyclical movements, and with what lags? Would cycles occur if policy variables moved smoothly to offset other disturbances? Are there systematic elements at work to cause periodic downturns? Computerized macroeconometric models provide expanded opportunities for investigating such problems, in the process improving our ability to anticipate them and, hopefully, to provide better remedies or adjustments.

b. Policy Simulations

In simulation experiments, an attempt is made to discover the implications of a given model with respect to various combinations of: (1) initial conditions; (2) specified policy actions, or rules for such action; and (3) specified sequences of values for exogenous variables not considered to be policy instruments, e.g., technological change, changes in tastes, etc. Many policy issues involve decisions
about the speed and magnitude with which policy changes will affect certain variables in the system. An econometric model, used in conjunction with high-speed computing capacity, is a powerful tool for such experimentation.

We now turn to some specific examples.

Fromm and Taubmann (1968) have presented results for simulations of eight different combinations of fiscal and monetary policy during the period 1960-1962, utilizing the Brookings model. Their results suggest that, after ten quarters, the largest impact on real GNP came from increases in government nondurable and construction expenditures. A combination of increased government employment, and an accommodating monetary policy, had the smallest impact after two and one-half years. When viewed on the basis of immediate impact, the increased government employment had approximately the same effect as the other expenditure increases, while changes in monetary factors actually caused a decline in real GNP through influences on interest income. Income tax cuts proved to be less of a stimulant than expenditure boosts. Needless to say, some of these results -- particularly those relating to the minimal effects of monetary policy -- are subjects of keen controversy among economists -- especially keen in the context of the "fine-tuning" problem to be discussed later.

The same authors also simulated the reductions in excise tax levels that occurred in July 1965, to indicate how the economy might have behaved during 1960-1962, had the reductions gone into effect in mid-1960. They conclude that the increase in GNP would have been between $0.9 billion and $1.6 billion for the first quarter
following the tax changes. For ten quarters, increases approaching $2.4 in real GNP were obtained for each $1 of taxes sacrificed. In this way, Fromm and Taubman were able to trace out the effect of an assumed policy change with respect to excise taxes, subject, of course, to the assumed constancy of their structural equations and parameter estimates.

Another tax policy simulation has been reported by Klein (1969), who studied the effects of the Revenue Act of 1964. Although this tax legislation is complicated, Klein was able to trace the new system's effects in the context of the Brookings model. However, Klein notes that, since other changes were taking place in the economy simultaneously with the income tax reductions, it is difficult to disentangle all of the factors that may possibly account for the observed results. Klein's results suggest that, as a result of the Revenue Act, the level of real GNP at the end of 1964 was raised $11.3 billion over the level which would have been experienced in the absence of a tax cut. In addition, the tax reduction was estimated to lower the unemployment rate by one-half of one percent. Klein also utilized the model to answer a different question: supposing that the Revenue Act had been passed in mid-1961, how would the 1961-1962 period have differed? He finds that the three-year delay held GNP levels some $10 billion below what might have been attained.

A historical battleground for economists has been the usefulness of monetary vs. fiscal policy in accomplishing national economic and social objectives. We have seen above that several attempts have been made to simulate the effects of fiscal policy. In a parallel effort,
other research has been conducted to inquire about the magnitude and speed of effects generated by changes in the variables associated with monetary policy. Fromm and Taubman (1968) have reported on such studies performed with the Brookings model. Although most econometric models contain a monetary sector, until quite recently very few have had as their major goal the quantification of monetary policy. One recent example is contained in a paper by deLeeuw and Gramlich (1968), which describes the Federal Reserve-MIT econometric model. The special features of the model are analyzed by Rasche and Shapiro (1968). Stabilization policy analysis, using the FRB-MIT model, has been discussed by Ando and Modigliani (1969).

DeLeeuw and Gramlich (1968) employed the FRB-MIT model to simulate and compare the effects of three government policy changes, one in monetary policy and two in fiscal policy. The change in monetary policy involved increasing unborrowed commercial-bank reserves by $1 billion. According to the simulation, the effects of monetary policy on GNP were slight for three quarters, accelerating as fixed investment increased and generated a multiplier effect, finally decelerating in the last few quarters of the three-year simulation period. The change in fiscal policy consisted of a $5 billion increase in defense spending. In this case, the positive effects on GNP were more immediate, although virtually exhausted after three quarters. Likewise, the second fiscal policy measure—that of raising the personal income tax rate by ten percent—provided the largest negative influence on GNP in the early quarters of the simulation period. Thus, the authors concluded that their simulation supports
the view that, while monetary policy may be ultimately quite powerful, it is likely to involve substantial lags which may detract from its usefulness as an instrument for stabilization. On the other hand, the fact that institutional and political factors generally make changes in fiscal policy much more time-consuming to enact, is ignored in these models.

As suggested earlier, these indications of limited effects from monetary policy are results obtained from analysts who have tended to be partisans of fiscal policy. Whether their partisanship should be viewed as cause or effect is, of course, moot. In any event, these results are not accepted by many other economists. Indeed, the relative effects, and proper balance between fiscal and monetary policies is currently an issue of more intense debate among economists than it has been during the past several decades. And the "monetarists" use computers, too!

One example, that has received considerable recent attention, and has exercised some direct influence on economic policymaking in the government, was developed by Laffer and Ranson at the Office of Management and Budget (1971). The Laffer-Ranson reduced-form model uses log-linear equations to predict: (a) growth of nominal GNP; (b) rate of change in the GNP deflator; and (c) rate of change in the unemployment rate. Predictions are based on quarterly unadjusted (and sometimes lagged) values of a number of variables, with emphasis placed on those affected by monetary policy, including the growth in the stock of money, the level of the Treasury bill rate, and the rate of change in stock prices, as well as the growth of Federal purchases.

The main, and most startling, conclusion of the Laffer-Ranson model is that fiscal policy (i.e., changes in Federal purchases) has a relatively small effect on GNP compared with the monetary variables,
and that the effect of the latter is far more rapid than had been implied by the fiscalist models referred to earlier!

There are numerous technical, as well as theoretical, reasons for treating these conclusions with skepticism. For example, the particular lags associated with the independent variables seem to be more a curiosity of the data, rather than to be well-specified from a theoretical point of view, in the Laffer-Ranson model. And the predictive accuracy of the model is much higher for 1970, than for either 1968 or 1969. Nevertheless, the Laffer-Ranson model provides a healthy counter to the fiscal-oriented models that previously predominated in computerized macroeconometric forecasting. Models that combine useful features of both types, in order to arrive at more satisfactory specifications from a theoretical standpoint, as well as more accurate forecasts, remain to be developed.
IV. NEW APPLICATIONS TO POLICY PROBLEMS AND FUTURE TRENDS

Most of the applications of computers to economic problems surveyed in Sections II and III are continuing, especially those applications relating to econometric forecasting, and to clarifying the relationships between monetary and fiscal, as well as structural, influences on GNP, prices, and unemployment. However, in the past five or six years there has been a major new development in the use of computers in economics. The innovation has arisen in connection with a surge of interest among economists in the analysis of public policy issues. The interest is especially keen in the fields of education, health, and poverty.

Each of these policy issues is treated at length elsewhere in this AFIPS volume, so we will be brief in reviewing their economic aspects. Yet, in all of them, economic aspects are important. As with all public policy choices, it is important to ask and to investigate four key questions: How much does it cost? Who will pay for it? How large are the benefits? And who will receive them? All of these questions have a substantial economic component.

It is also characteristic of these current policy issues that analyzing them, and evaluating alternative programs for dealing with them, depends heavily on large longitudinal and/or cost-sectional data bases. Hence, the use of computers has been extensive, and will increase further in the future. Thus far, computer use in these areas has been focused on basic analysis and exploration, in an effort to increase understanding of some of the key relationships -- understanding which
still eludes us in connection with some of the more fundamental aspects of these problems. In the future, it seems likely that computer use will be particularly focused on program evaluation, in an effort to pin down more precisely the costs and probable effectiveness of alternative programs.

In the following summary, we will touch briefly on several of these new fields. Comments will be confined to some of the recent literature by economists, as well as to discussing one or two examples of the major economic problems already dealt with or presently under analysis in each policy area, the principal data bases that have been used, and some general observations about trends and prospects for the future.

The education "industry" currently entails annual outlays of over 60 billion dollars, three-quarters of which is public expenditure. Nevertheless, it is remarkable how little we really understand of the relationship between inputs and outputs, between cost and consequences, in education. Considerable work has been done by economists on the returns to additional years of schooling, calculated in terms of lifetime earnings. Becker (1964), for example, has found that rates of return to investment in higher education seem to be at least competitive with rates of return on physical investment. Yet these results have been criticized on a number of grounds, for example, making inadequate allowance for differences in initial ability and motivation in trying to isolate the net effects on income attributable to education.
Kuznets (1966) and others, observing that education has spread widely as the United States and other economies have developed and grown richer, have argued that "the rapid spread of modern education must have been a basic element in increasing the capacity of developed nations to exploit and contribute to the available stock of tested and useful knowledge." Yet these arguments, and empirical results supporting them, have been criticized on the grounds that increased expenditure on education is perhaps as much a consequence as a cause of rapid economic development. Indeed, the empirical results, that have sought to show connections between increased income and education, have been most severely and radically criticized by Illich (1970). He argues that, to the extent such connections do in fact exist, they actually reflect rigidities in our social structure (that is, educational credentials are enforced by social convention as a requirement for advancement), rather than being a result of enhanced skills or learning.

Moreover, the numerous attempts that have been made to investigate empirically the direct relationship between educational inputs (costs), and outputs (learning), following in the footsteps of the pioneering Coleman Report (1966), have with a few minor modifications only served to reinforce the striking result obtained in Coleman's work. This result, which has also been obtained in empirical work applied to higher education by Astin (1968), is that educational inputs per se do not seem to add appreciably to learning (at least as measured in the admittedly imperfect ways we have available), after full and proper
allowance has been made for the effect of social, cultural and economic background variables.

Computer use has been extensive in all of the empirical work leading to this strong result, based on data from the original Coleman study on primary schools, and the data base of project TALENT for highschools.

Partly as a consequence of this significant and sobering result, there has been at least the faint emergence of receptivity in the educational community toward experimentation, innovation, and perhaps even competition in a field that has rarely been open to such intrusions. One example of such experimentation is the educational voucher system advanced several years ago by Milton Friedman. Another is the growing experimentation with performance contracting for educational "production" (Stucker and Hall, 1971). Results from such experimentation and analysis are very likely to have major effects on both the costs and the likely effectiveness of educational innovation.

Recent work in the economics of health care has begun to focus on factors affecting the supply and the demand for health services. On the supply side, some recent work has tried to analyze the pricing of physicians' services. Feldstein (1970) suggests that the pricing of physicians' services can best be understood by assuming that permanent excess demand prevails, which gives physicians discretionary power to vary both the prices and quantity of services which they supply. Moreover, he finds some evidence that, when physicians' fees rise, the quantity of services provided tends to fall (that is, the income effect tends to dominate the substitution effect). There are some possibly
important policy implications, relating to restraints on rising fees in this field, which follow from this work.

Economists have also investigated costs and pricing of hospital services, at both an aggregative industry-wide level (Kaitz, 1968), and at the micro, program-budgeting level of the individual hospital (Taylor, Newhouse, 1970).

On the demand side, work has begun on trying to estimate the effects of different current and prospective medical insurance plans on the demand for health services. Attempts are being made to estimate the effect of various patterns of co-insurance and deductibles on demand for health care, as well as on the demand for "quality" in hospital care. In turn, this analysis has led to the suggestion that a particular form of hospital insurance (so-called "variable cost insurance," in which the proportion of payments covered would vary inversely with the expensiveness of the type of care received) might have a substantial effect in holding down the rate of cost increase in hospital care, by giving the consumer a stronger incentive to seek efficient, more economical care (Newhouse, Taylor, 1969).

In most of this work, the data bases that have been used have ranged from the more general sources of vital statistics (e.g., decennial census data for demographic variables) to more specific sources of data on hospital costs gathered by the American Hospital Association, and on physicians' fees and hours gathered by the American Medical Association. Computer use has been essential in relating these data sources to supply and demand modeling, with potential benefits for public policy, as exemplified above. In the future, computer use
in health economics is bound to grow. As in the case of education, it also seems likely that the future will see considerably expanded use of computerized analysis in experimentation and evaluation of alternative policies and programs, for example, relating to different types of co-insurance and deductible arrangements.

A third area of public policy that has become of increasing interest to economists is poverty. The field is intimately inter-twined with the sociology, as well as economics, of race and minority groups, even though we know that most of the chronically poor are not blacks, and most blacks are not chronically poor.

Several economic problems that have received considerable attention in this field are worth brief mention. One concerns the merits of a guaranteed annual income, or negative income tax, compared with current welfare programs. In particular, this work has been concerned with the effect of GAI on incentives to work. In a technical sense, this work has tried to estimate the elasticity of labor supply with respect to non-wage income of the sort that a guaranteed annual income would provide. Greenberg and Kosters (1970) have provided some estimates of the probable magnitude of such adverse effects, without answering the question of whether these effects are large enough to offset the strong merits of the GAI proposal. Although it is important to have a more precise notion of these quantitative effects, it is quite clear in this case, as in many others, that the preferability of GAI over welfare programs depends on a wider range of considerations than those for which economists and computers can provide quantitative estimates.
In work done on race differences in income, Wohlstetter and Coleman (1970) have dislodged some widely prevalent, but erroneous, beliefs on this subject. For example, they have shown that race differences in income have been persistently diminishing over the last several decades, but that the differences have diminished most markedly at the lower end of the distributions without changing at all, and in some cases even changing adversely, at the upper end of the black-white income distributions.

To cite a final illustration of economic work in this field, Kosters and Welch (1970) have provided estimates of the effect of the business cycle on the relative incidence of unemployment among blacks and whites. Their work provides tangible evidence of the distinctly heavier impact of downturns in the cycle on unemployment among blacks than among whites, although the differential has been diminishing.

Like the work in education and health, this work, as well as a great deal of other work on poverty which we have not touched on, has also drawn on large data bases: the Survey of Economic Opportunity in 1966 and 1967; the monthly Current Population Survey Data; the Decennial Censuses; and the special ghetto surveys undertaken by the Census Bureau for the Department of Labor, at various times. In this field, as in others discussed earlier, computers have provided a bridge between economic theory and newly emerging data bases. In some cases, the results to date have clarified public policy issues (for example, in the case of the guaranteed annual income problem). In others, the result has been to increase our understanding, and to correct some of the conventional errors in widely-held beliefs (for
example, in connection with racial differences in income). As in the case of education and health care, future trends seem especially likely to emphasize experimentation (for example, the experiment with non-wage income payments conducted by Mathematica and the Poverty Institute in New Jersey, for the Office of Economic Opportunity), and evaluation of planned or operating programs.
V. UNRESOLVED PROBLEMS

The brief tour d'horizon in Sections II-IV, should convey some sense of the growth and breadth of computer use in modern economics. The range of applications has been steadily widening. Perhaps, more significantly, the link provided by computer technology between economic theory and the growth of new data bases has increasingly redirected the attention of economists toward major current policy problems. These accomplishments, and the promise they carry with them for the future, are substantial and encouraging.

Yet one should avoid euphoria in regard to what computers and advances in computer technology can do to solve economic problems. Some major economic problems remain unresolved, nor is their resolution likely to be appreciably accelerated by widened computer use. An example, perhaps the principal one, lies in what we have referred to earlier as the problem of "fine-tuning" of the economy: the problem of how to improve the set of choices between price stability on the one hand, and employment and growth, on the other (i.e., the so-called Phillips-curve tradeoff possibilities) that we can choose from. How can we explain, and remedy, an economy which currently combines inflation, and balance of payments deficits, on the one hand, with unemployment and very modest growth, on the other?

Part of the explanation surely lies in an economic version of Heisenberg's paradox: uncertainty is generated by the very process of trying to reduce it. Having learned, via Keynesian economics, how to "stabilize" the economy against severe depression, we have in the process aggravated the difficulty of stabilizing it
against inflation. Apparently, moderate unemployment (around 6 percent currently) appears to be part of the price of keeping inflation (recently at an annual rate of about 5 percent) from being still worse. The reason for this unhappy state of affairs seems to have as much to do with individual and group psychology as with economics. Consumers, workers, unions, industry, and governments are confident that a deep depression won't occur. Consequently, they are energetic and persistent in sustaining demand, and in maintaining or raising prices and wages. And the institutional arrangements in labor, business and government seem to prevent, or at least to blunt, the operation of competitive forces in reversing these tendencies.

Computer technology can help on these problems in some respects. For example, more rapid data collection and processing can shorten the feedback loop, and provide more rapid signals on what is and is not working. Nevertheless, major solutions to the "fine-tuning" problem may very well lie in directions that are very different from those opened up by advanced computer technology. For example, a more active antitrust policy, and a judicious use of liberalized commercial policy, are likely to be much more important in stimulating competition than are advances in computer technology. And if these don't work, selective wage and price controls may be needed in order to keep prices down, while increasing employment.*

* Since this was written (July 1971), the President's new economic policy has moved in this direction. However, one important qualification to the statement in the text is warranted. The Wage and Price Boards, that have been set up to pass on proposed wage and price increases in key industries, may find that computer technology is of considerable help in determining whether, and how large, a proposed increase is permissible. Computerized interindustry models, such as those discussed earlier, should enable the Boards to estimate the broad effects of specific price and wage increases on the consumer's cost of living. It is not implausible that better decisions can be made, as a result.
In addition to the unresolved problems of economic fine-tuning, to whose resolution computers have not been able to contribute very much, there are a number of other problems, especially those relating to certain aspects of the methodology of modern economics, which have actually been intensified rather than resolved by the growth of computer use. Two examples are particularly worth citing. Both have been around for a long time, and both have been aggravated by the power and flexibility which advanced computer technology provides.

The first problem concerns the use of computers in hypothesis-testing vs. their use in hypothesis-formulation. In testing economic hypotheses postdictively, that is, against data relating to prior events (which is the economist's principal counterpart of laboratory testing in the physical sciences), the various parametric and non-parametric statistical tests, that we typically use, require that the hypothesis and the model which incorporates it precede the testing process. What the statistical tests then determine is the likelihood that the result predicted by the model would be as close to the actual results if the relationships specified in the model in fact did not apply. The precedence of the hypothesis, and a properly specified model, before the data are confronted, is essential in the proper use of computers for testing hypotheses.

On the other hand, in hypothesis-formulation, the analyst can use the computer to search the data, probe for patterns and regularities, and generate hypotheses. So, in the hypothesis-formulation process, the data precede the hypothesis. And this process has become both easier and more fruitful because of the lowered cost and increased flexibility of new computer systems and software. The
opportunities thereby opened for experimentation, learning and discovery are notable. In this mode of computer use, economic analysts have acquired a greatly enhanced capacity to sift large data bases so as to create hypotheses for subsequent verification.

However, there is an important reservation that needs to be, and is not always, recognized: standard statistical tests (of significance, confidence-levels, goodness-of-fit, etc.) do not strictly apply in the hypothesis-formulating mode. In order to test properly hypotheses that have been arrived at through this process -- a process which has been immeasurably facilitated by advances in computer technology -- it is necessary either to (a) partition the initial data base between a "search" or "fishing" sample used in hypothesis formulation, and a "test" data sample, or (b) generate new and independent data, against which to test the hypotheses resulting from the initial search process. Of course, computers can be of measurable assistance in connection with (b). Enhanced computing speed and storage permits rapid data collection and retrieval. Hence new materials can be more readily provided for testing hypotheses whose formulation has exhausted the information contained in a previously existing data base.

Integrity, as well as intelligence, are extraordinarily important in keeping these two processes -- hypothesis-testing and hypothesis-formulation -- clearly distinguished from one another. The enhanced capacity, lowered costs, and increased access provided by computer systems in recent years has abundantly complicated this problem.

A lesser, but also important, problem in the methodology of economics arises in connection with the joint role of the economic
analyst as an observer of, as well as an influence on, the phenomena that he is analyzing. The increased power and speed, as well as publicity, associated with advanced computer technology can thereby lead to two different effects on the phenomena being analyzed, both of which may be distorting. One distortion may arise in connection with the self-confirming effect of a computerized model. For example, if a particular computerized model for prediction and selection of investment portfolios gains acceptance, the model may actually look better ex post than is really warranted, because of its effect on the behavior of investors. The bullish behavior that is stimulated by a particular model may thereby validate the model.

A second type of distortion can arise through adaptive, disconfirming behavior. For example, when a computerized model forecasts, say, increased unemployment, or decreased exports, the effect of the forecast may be to generate remedial action. The result of this "distortion" may either make the forecast appear erroneous ex post or, given the interdependencies likely to exist in the system, at least make the outcome that would have ensued in the absence of the remedial action appear indeterminate.

None of these fundamental methodological problems in economics is new, or attributable to computer use in itself. But both of them have been made measurably more serious and extensive by the expanded use of computers.

Thus, there are at least some not inconsiderable debits on a balance sheet that shows an abundance of credits. Like other major advances in modern technology, from the internal combustion engine
to nuclear fission and fusion, the opportunities and accomplishments of computer use in economics also entail serious difficulties and risks of abuse.
VI. SUMMARY AND CONCLUSIONS

The main points of this survey, and their implications for the future, can be briefly summarized:

1. Computers and computer technology have played a central role in the growth of modern economics by providing an essential bridge between the accumulated body of formal theory on the one hand, and the growing availability of large data bases, on the other. The result of this crucial bridging function has been the growth of modern econometrics and, more recently, an increasing application of economics to the formulation and testing of alternative policies and programs for dealing with social and economic problems.

2. The tremendous growth of computing capacity and flexibility, combined with the enhancement of software capabilities, have permitted applications to be made pervading the entire field of economics and of economic problems. The pervasiveness of this growth in applications is suggested by the problems and fields in which computer use has been concentrated: a) interindustry and activity analysis; b) regional economics; c) development planning in less developed countries; d) microeconomic decisionmaking, bordering on operations research applications; e) public finance and government decisionmaking; f) quantitative economic history. In turn, applications of computers to existing problems in these fields have opened up opportunities for dealing with new problems. Often these applications have led to the development of new theoretical concepts as well.

3. Probably the most substantial applications of computers in economic analysis (from the standpoint of the financial and human
resources involved, though less assuredly from the standpoint of the results obtained) lie in the area of large scale macro-econometric modeling. Dozens of such models have been developed in the U.S. and in other countries. They vary in scale from models embodying several equations, to the massive and complex Brookings quarterly model, which contains over 300 equations and more than 100 exogenous variables.

Such models have been useful for both forecasting and simulation purposes. The record of accuracy of the forecasts has been positive, though certainly not overwhelming, as suggested by the crude test we have made of forecasts by the Council of Economic Advisers over the last ten years. The simulation uses have been helpful in understanding cyclical movements of the economy, as well as in illuminating, rather than resolving, the dispute between advocates of fiscal and monetary policy. Models that combine useful features of both fiscal and monetarist approaches remain to be developed, in order to arrive at more satisfactory specification from a theoretical standpoint, as well as more accurate forecasts.

4. In the past five or six years, there has been a major new development in the use of computers in economics. The innovation has occurred in connection with a growing interest among economists in the analysis of public policy issues, especially in such fields as education, health, and poverty. Economic issues are prominent in all of these fields because in these, as in other public policy issues, it is of crucial importance to ask and to investigate four key questions, all of which have a predominant economic component: How much does each proposed policy alternative cost? Who will pay? How large are the benefits? And who will receive them?
In education, computerized analysis has helped us to understand how little we really understand of the precise relationships between inputs (costs) and outputs (learning), at virtually all levels of the educational process.

The results obtained in the analysis of health care have been more positive: for example, in connection with investigation of the pricing and supply of physician services; the costs and pricing of hospital services; and the effects of different current and prospective insurance plans on the demand for health services.

In analytical work on poverty, computers have been helpful in uncovering a number of results relating to the anticipated effects on labor supply of a guaranteed annual income, or negative income tax. This work has also improved our understanding of the major changes that have occurred in race differences in income at different parts of the income distributions for blacks and whites.

Work in all of these fields has involved a typical and crucial role for computer hardware and software in providing the necessary bridge between initial theory, and a large and growing assortment of data bases relating to these problem areas. In the future, it seems increasingly clear that computer use will be directed more and more toward experimentation and toward evaluation of program alternatives. It also seems clear that the choice between one policy or another is likely to depend in most cases on a wider range of considerations than those for which economists and computers can provide quantitative estimates.
5. Notwithstanding the dramatic growth of computer applications to economic problems, and the significant results that have already been obtained -- either in uncovering improved solutions or in increasing general understanding -- we should avoid euphoric expectations of what computers and advances in computer technology can do to solve economic problems. Some major economic problems remain unresolved; nor is their resolution likely to be greatly accelerated by wider computer use. And there are other problems, relating especially to methodological issues in economic analysis, which have in fact been aggravated by the growth of computer use.

Perhaps the principal example of an important unresolved problem is the problem of economic "fine-tuning": how to improve the set of choices between price stability on the one hand, and employment and growth, on the other? Fine-tuning solutions are less likely to lie in more extensive use of computers, and more likely to lie in the field of anti-trust policy, or liberalized commercial policy, or a selective incomes policy.

Two examples can be provided of problems that have actually been intensified by the power and flexibility of advanced computer technology. One problem concerns the use of computers in hypothesis-testing versus their use in hypothesis-formulation. Failure to distinguish between the two processes can drastically obscure the results obtained. Such failure can also mislead in the interpretation of results and in drawing inferences for public policy. Although the problem has been around for a long time, the enhanced capacity, lowered costs, and increased access provided by computer systems has
abundantly complicated this problem in recent years, and no doubt will do so in the future. However, if used with ingenuity and prudence, computers can also provide an antidote for remedying this problem.

A second problem arises in connection with the joint role of the economic analyst as observer, as well as influence, on the phenomena that he is analyzing. The added speed and power provided by computerized models can lead to seriously distorting effects on the behavior being analyzed, thereby seeming to confirm or disconfirm hypotheses, when neither is actually warranted.

None of these fundamental methodological problems in economics is new, nor attributable to computer use in itself. But both of them have been made more serious by the expanded use of computers in economics. That there are thus some risks and debits connected with the use of computers in economics is not really surprising. Like other major advances in modern technology, the impressive record of computer accomplishments in economics thus far, as well as the abundant opportunities for further applications in the future, also entail some not inconsiderable difficulties and risks. Minimizing them require integrity as well as intelligence in the case of computer use, no less than in the case of nuclear energy.
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