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FOR RESEARCH IN ECONOMICS

Rational  
Decision-Making  
*and*  
Economic Behavior

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## THE YEAR IN REVIEW\*

THE year of this report is memorable in the life of the Commission because it has seen the publication of five monographs, representing the fruits of research carried on over a period of years. A brief review of these five volumes is a good way to illustrate the problems the Commission studies, the skills it brings to bear on them, the answers it seeks, and the purposes these answers may serve.

Monograph 11, *Economic Fluctuations in the United States, 1921-1941*, was written by Lawrence R. Klein, an economist now associated with the Survey Research Center of the University of Michigan and a research consultant of the Commission. The plan of this study, which was made possible by generous grants from the Rockefeller Foundation, is to reconstruct (from the statistical records of the nation) links in the chain of events that make up business cycles. Consumers spend in accordance with their income and market prices. Incomes are determined by the spending of consumers, manufacturers, and the government. Manufacturers spend in accordance with expected sales and expected profits, which are in turn determined by prices and incomes, etc. Each of these group behavior patterns is expressed by a mathematical equation distilled from the statistics. When all is put together, the explanation one obtains does not run around in a circle, for two reasons. Some items enter only as determining factors, not as being determined: weather, population, discoveries. Also, each link takes time, and carries the explanation back to earlier periods. This year's spending is, through many links, a repercussion of last year's spending, etc. The purpose of studies of this kind is not only to explain past cycles, but also to help form judgments as to how to modify and lessen future cycles.

The methods used in distilling the equations of economic

\* The remarks in the present section of this report provide a short survey of the activities of the Commission. Additional details on many of the topics covered will be found in the remaining sections of the report.

behavior from statistical records are a subject of study in themselves. Such methods are developed in Monograph 10, *Statistical Inference in Dynamic Economic Models*. This volume had its origin in a research conference held at the Commission in 1945. It contains contributions from many authors, all mathematical statisticians or economists, both on the Commission's staff and from other institutions. Its editor is Tjalling C. Koopmans, now director of research of the Commission.

We move from the sphere of facts and the interpretation of facts to the sphere of values in Monograph 12, *Social Choice and Individual Values*, by Kenneth J. Arrow, now of Stanford University and a research consultant of the Commission. How will Jack and Jill, John and Jennifer, decide whether to play bridge, canasta, or go bowling if each of them has a different idea as to which of these is his or her first, second, and third choice? If we can find some scheme of calculation which mixes their individual preferences into a social choice, more problems than that of deciding on a satisfactory evening can be solved. The representative system of government is one device constructed to deal with the problem of social choice. Arrow reduces the problem to its barest logical elements. He starts by detailing in what way a method for determining social choices should be responsive to individual preferences. He also requires that, if one of the alternatives that was not at the top of the social preference list turns out to be impossible for some reason, this should not change the alternative that *is* at the top as long as *it* remains available. From this he goes on to prove that, if people are too much at cross purposes, you cannot find a common denominator of their wishes. A minimum of agreement in the diversity of individual preferences is necessary to allow the formation of social choices. While this result is not unexpected, the book marks a new departure in the field of politics and social valuation through the manner in which it introduces and utilizes the tools of formal logic. It is one thing to expect a conclusion, and another thing to establish it.

Both valuation, expressed by the desire for efficiency and maximum production, and facts, the innumerable details of technological know-how, enter into the content of Monograph 13, *Activity Analysis of Production and Allocation*, edited by

Koopmans. Again originating in a conference held at the Commission, this time in June, 1949, its contributing authors include economists, mathematicians, and administrators, from the staff of the Commission, from government agencies, and from various universities. The main theme of the book is how to attain efficiency in the scheduling of production in the widest sense of these words. Wide enough, for instance, to include a theoretical appraisal (and qualified confirmation) of the efficiency of the price system and competitive markets, if these are viewed as means of decentralizing production decisions among as many decision-makers as there are business firms in the country. Wide enough, also, to include the "production" of security by the military establishment, with efficiency to be sought in this case by scientific, centralized programming of the manifold activities of this very large organization. In fact, the interest of the Air Force in this problem provided the support, through a research contract with The RAND Corporation, for the Commission's research in this area, and provided the background as well for several other contributions to this volume. The book deals with theory, applications, new mathematical tools for economists, and computational methods. Applications illustrating the theory include, besides those already mentioned, the choice of a best crop rotation plan, the efficient routing of empty ships or trucks or box cars, and predicting the effects of introducing new methods of production.

*Economic Aspects of Atomic Power*, an exploratory study directed by Sam H. Schurr and Jacob Marschak, combines facts with hypotheses and theories. We do not know the future trends in the techniques of generating and using energy. But we can set reasonable limits. We can, for example, estimate the lowest conceivable cost for atomic power, and derive a general picture of the scope of economic change which would result, at best, from the use of the new energy source. To explore in this manner a reasonable range of possibilities, one has to use, on the one hand, facts about the supply and cost conditions for nonatomic power throughout the world and facts about the potential demand on the part of important energy-consuming industries (such as aluminum, chlorine and caustic soda, phosphate fertilizers, cement, brick and glass, iron and steel, railroad

transportation, and residential heating). On the other hand, one has to employ a theory on how cheap power can affect, in general, industrialized as well as underdeveloped areas of the world. Needless to say, the applicability of any estimates or predictions thus obtained depends on how future history will develop—especially how the production and use of the new energy will be affected by political factors.

The common thread that runs through these five volumes, and through all other investigations of the Commission, is the endeavor to construct abstract models of real situations. Abstraction means expressing and exploring the common elements in many situations while ignoring what is particular and incidental. It has been our experience that abstraction in this sense is powerful and economical, not impractical or remote.

An area in which the Commission is continuing and expanding its research program is decision-making under uncertainty. There is uncertainty about nature and uncertainty about people's actions. We give one example of each: Uncertainty about the weather affects production decisions on the farm. Uncertainty about future sales and prices (the result of other people's actions) enters into business decisions about inventory accumulation or purchases of equipment.

We need to develop an analysis, abstract at first, of efficient production decisions under uncertainty about nature. Only in this way can we see the common elements in such diverse problems as the choice of a crop insurance plan, of a system of flood control, of a policy for industrial research, and hope to arrive at good solutions.

Likewise, we must analyze decision-making under uncertainty about people. To some extent, human action is predictable. Business firms pursue profits and growth, executives pursue careers, workers and employees pursue income and favorable conditions of work, savers seek the returns and preservation of capital. Nevertheless, any one individual's action is taken in some uncertainty about what others may decide to do next. The problem of best organization of a business enterprise, of a government agency, of society as a whole, is a problem in the interplay of incentives and opportunities.

partment of the Air Force, and the National Bureau of Standards. Informal contact is maintained with other research groups such as the Agricultural Research Group at the University of Chicago, the Bureau of Business Research of the University of Illinois, the School of Industrial Administration of Carnegie Institute of Technology, and a research project conducted at the University of Michigan and sponsored jointly by the Survey Research Center and the National Bureau of Economic Research. In addition, various members of the Commission render consultative services to the Bureau of the Budget, to the Treasury Department, and to The RAND Corporation.

The Commission is affiliated with the Econometric Society, an international society for the advancement of economic theory in its relation to statistics and mathematics, and its offices serve as headquarters for that organization and for its quarterly journal, *Econometrica*. The Society has continued its rapid growth and now has approximately 2,435 members and nonmember subscribers, chiefly libraries, representing 73 different countries. Meetings of the Econometric Society were held in Berkeley, California; Cambridge, Massachusetts; Varese, Italy; Tokyo, Japan; and Chicago, Illinois, in 1950, and meetings are currently scheduled for Santa Monica, California; Minneapolis, Minnesota; Louvain, Belgium; Tokyo, Japan; New Delhi and Patna, India; and Boston, Massachusetts, in 1951.

The Commission has continued to benefit from the support and recognition given by the University of Chicago and the Rockefeller Foundation to its general research program, and has carried further its study of the best allocation of resources under its subcontract with The RAND Corporation. Increased support was received during the year from the Commission's founder, Mr. Alfred Cowles, and from members of the Cowles family. Starting in July, 1951, the Commission will also receive support from the Office of Naval Research through a contract to undertake research in the area of decision-making under uncertainty.

These developments have made possible a marked increase in the research effort of the Commission. What is left unresolved

Application of ideas and insights obtained by abstract analysis requires fact-finding about technology and about behavior of people, acting individually or in organizations. Most of these facts are naturally expressed in numbers and in relationships between numbers. Analysis is needed once more to decide which facts to look for, and how to distill general conclusions from the vast mass of facts collected; in short, to make the fact-finding itself efficient.

The Cowles Commission research staff is selected from individuals trained in the application of logical reasoning to theoretical analysis of the interplay of economic motives, to the collection and interpretation of facts and data, and to relationships between numbers; that is, in that order, economists, statisticians, and mathematicians. Among its research consultants it includes a political scientist. The unifying element in the cooperation of this diversity of talents is a devotion to clearly stated logical reasoning that examines particular applications in the light of general principles. The methods of cooperation include informal discussions in small groups, circulation of memoranda for discussion in staff meetings, presentation of results in seminars and at meetings of professional associations. Research fellows from other universities in the United States and abroad, as well as advanced students of the University of Chicago, participate in these activities. The frequency of joint publications of staff members and other scholars testifies to the spirit of teamwork prevalent in the group. Supporting services to the research effort are rendered by an office staff consisting of library, computational, editorial, secretarial, and administrative personnel. The publication of five monographs in one year is the result of a considerable strengthening of the supporting services against a background of a more gradually growing research effort.

The Commission cooperates with various other groups through joint appointments within the University, through appointment of staff members of other institutions as research consultants of the Commission, and through participation in conferences sponsored by organizations such as the Social Science Research Council, The RAND Corporation, the George Washington University, the Office of Naval Research, the De-

is the problem of assuring the long-term support of this effort, a prerequisite for a continuing increase in the scope of the effort at a rate in keeping with its potential usefulness. As a first step in coping with this problem the Commission is strengthening its organizational structure, with increased provision for long-term planning and development. It is recognized that a solution to the problem requires an increase in both human as well as financial resources which can be drawn upon for econometric research, a consideration which will claim the Commission's increased attention in the period ahead.

## REPORT ON RESEARCH ACTIVITIES

**I**T WAS J. R. Hicks, the Oxford economist, who said that the foundations of economic theory were, essentially, nothing but "the logic of choice." Charles Hitch, of The RAND Corporation, expressed this in another way: "Economics is about how to economize." To be economical is to choose the best use of limited opportunities and resources. Let us ask, for example, what we mean by an economical, successful business manager. The firm's own capital and its ability to borrow are limited, and so are its possibilities to determine the prices of its materials and products and to improve upon the known technology of production. A good business manager will make decisions—to borrow and build, buy and hire, produce and sell—which will result in a larger profit than that resulting from choices made by a bad manager. We apply a similar criterion when judging the efficiency of a housewife or a hospital administrator: they can make a good or a bad use of limited money. The concept of "economical" decision-making has an even wider application. Army commanders are trained to choose decisions that are likely to achieve a given objective at the smallest cost in life and materiel, or decisions that are likely to yield, at a given cost, the most desirable result. And is not our concept of an efficient party leader or diplomat similar? Finally, decisions on how to carry out a national policy are also judged by their success in achieving proclaimed goals—



be they security, prosperity, justice, or freedom, or any combination of these values—within limits set by the skills, habits, and natural resources of the people.

All these cases of “economical” decision-making have the same logical content. In mathematical language, their common problem is to “maximize, subject to given conditions.” “Rational behavior” and “optimal behavior” are still other words for economical decision-making. To study how to choose best decisions is to study norms of behavior, not actual behavior. Abstract though such a study may seem in the first stages, its ultimate ambition is to enable people to make reasonable recommendations whenever goals and opportunities are specified. These norms are, of course, suggested by and distilled from actual practice; but they are no less valid if only a small minority of practitioners has applied them in the past. For example, certain methods of inventory control were devised some years ago by Dr. Thornton Fry and Mr. R. H. Wilson, both at that time with the Bell Telephone Laboratories, Inc. These methods, and similar ones described in business literature, exemplify rational behavior since, under certain plausible assumptions, they are likely in the long run to result in a higher profit than other inventory policies. We understand that a small number of leading concerns has, rather recently, accepted these methods and successfully reduced the rate of inventories to sales. Possibly these methods can be adapted to the uses of noncommercial institutions such as schools, hospitals, and governmental depots. In other words, though few people behave rationally, people can *learn* to behave that way. And this learning process may be in the public interest.

However, for the purposes of the normative studies described, knowledge of the actual behavior of men is equally important, even if that behavior is only imperfectly rational or, indeed, very far from being rational. It is of interest for two reasons. First, because (as we have just seen) actual decision-making is full of suggestions for the study of rational decision-making. Second, because the rational decision-maker has to take into account the possible irrationalities of his fellows. For example, the limited opportunities of a businessman or an army leader are determined by the actual, possibly

nonrational habits of his employees, competitors, and clients, or by the prejudices of his enemy and the nerves of his own troops, as much as by the natural laws that underlie technology or weather.

Hence, the interest in people's actual behavior is not motivated only by our scientific curiosity: In order to make rational recommendations on human institutions and policies it is necessary to predict as well as we can people's actual, possibly irrational behavior. Therefore, staff members of the Cowles Commission have followed with great interest the recent attempts at empirical observation, and even experimentation, in the fields of psychology directly relevant to economic decisions and social organization—for example, Thurstone's work on consumers' choices, the experiments of Mosteller on betting and of Bavelas on the effects of "democratic" and "bureaucratic" communication networks, and the social surveys conducted at the University of Michigan. The Commission's own contribution to the study of actual behavior has for the most part consisted in statistical inference from nonexperimental observations on economic time series (prices, production, consumption, investment, etc.), which measure aggregative effects of similar decisions of large numbers of people.

Inasmuch as the tools for the study of actual behavior have been statistical, their thorough revision and adaptation for the particular purposes of the social sciences is necessary. Ideas and principles developed at the Cowles Commission regarding the statistical methods necessary in economic research have been found applicable also in sociology and psychology, essentially because of the difficulty of experimentation in all social sciences.

The Commission's workers on statistical methods have received much inspiration from and have participated in recent discussions on the logic and tools of inductive inference initiated by Jerzy Neyman and developed by the late Abraham Wald into a theory of "decision functions." The empirical investigator is a decision-maker—not less so than the businessman, the housewife, and the commander. The sample, the experiment, the statistical formula must be designed in such a way as to minimize the risk of damage caused by wrong in-

ferences to whoever has asked the statistician's advice. This "economic" approach to statistics, which is reflected in the analogy between, say, choosing the cheapest and most effective way of sampling a city population and the most satisfactory way of operating a factory or of allocating national resources, has proved fruitful of ideas. Naturally, this way of thinking is congenial to economists. It has been decisive in some recent work on the economics of uncertainty pursued at the Cowles Commission as part of its studies on rational and actual behavior. It is also notable that, with both economics and statistics considered as the study of "maximization under given conditions," economists and statisticians are expanding their horizons in their use of mathematical tools.

In reporting on particular problems under research at the Cowles Commission we shall start with (1) *normative studies*—the studies of rational, or optimal, behavior. Here it will be convenient to begin with (1.a) *single-person decision problems*, typified by certain studies in the economics of business firms, and to follow up with (1.b) *multi-person decision problems*, which arise out of conflicts of interest or imperfect communication (for example, within or between firms) and which lead up to methods for the optimal allocation of society's resources. We shall then proceed to (2) *descriptive studies* of actual behavior. Finally, we will take into account studies of (3) *statistical methods* and (4) *mathematical tools*. Since there is, of course, much overlapping among these fields, the outlined order can be followed only approximately.

### 1. *Rational Behavior*

1.a. *Single-person decision problems*. The nature and practical significance of studies in the field of optimal single-person decisions is exemplified by the work on inventory policies, mentioned above. This work was done by Kenneth J. Arrow and Jacob Marschak jointly with Theodore Harris of The RAND Corporation. Although it originated and was discussed at conferences on military logistics, the study has applications in the business field as well. If the firm knows with certainty the weekly demand for its product, it can compute the optimal

storage period from the cost of handling an order, the storage cost, and the buying price. If the weekly demand is uncertain but has a known probability distribution and if the firm can set a "penalty" on any given size of unsatisfied demand (and the consequent loss of customers), then it is again possible to compute the best inventory policy, characterized in this case by the stock level at which replenishment orders should be issued and by the stock level after replenishment. If the firm does not know in advance the probability distribution of demand, it is faced with a problem in statistical decision functions, to be discussed below. Unlike the previous studies of the Cowles Commission on the demand for inventories and for cash, the recent one did not consider speculation on changing prices. A combination of the two aspects of inventory decisions would involve a joint probability distribution of future demand and future price. Such an approach would give a fuller understanding of the motivation of inventories and cash balances in a free-enterprise economy. In this connection, Karl Brunner made a critical study of a recent controversy on the logic of monetary economic theories.

A different approach to the problem of inventory control was taken by Herbert A. Simon. Assuming the optimal size of stocks to be known, Simon devised a rule of reaction to any given deviation from optimum. Simon's mathematical model is similar to that of a robot or "servomechanism"—for example, a thermostat that quickly counteracts any undesired change in temperature.

As a concrete example of single-person decision-making under uncertainty, Harry Markowitz chose to study the behavior of open-end investment companies because of their institutional simplicity and the availability of data. If rational, such a company is assumed to act as if it had certain beliefs, based on past experience, concerning the probabilities of returns from each available security. The company would therefore be able to compute, for each possible portfolio, the probability distribution of its total profit. Each such distribution can be characterized by numbers such as the expected, or actuarial, profit level (that is, the average of all possible profit levels, weighted by their respective probabilities), by the unpredict-

ability of profits, as measured by their potential spread around the actuarial level, etc. An "efficient" portfolio is one that has the lowest degree of unpredictability attainable in combination with a given level of actuarial profit. Markowitz attempted to test empirically whether the portfolios actually carried by companies were efficient in this sense (see page 18).

To prefer a high to a low predictability of profits may be characteristic of investment companies and their clients. But the gambler's "taste" is for the opposite. There is, in fact, a great variety of "tastes" among investors, insurers, and risk-takers in general. Such tastes can be expressed by describing the "utilities" (degrees of satisfaction) assigned by each person to gains and losses of various sizes or to any other outcome of his action. Certain plausible definitions of rational choice imply that the person will maximize the actuarial value of utility (called "moral expectation" by eighteenth-century theorists of probability). By assuming such behavior and by tracing a plausible functional relationship between a person's initial wealth, the wealth increment, and the resulting utility, Markowitz tried to explain various phenomena related to insurance and gambling.

In the inventory and investment studies outlined above, the decision-maker was supposed to act on the basis of probabilities that are either known (for example, from long experience) or believed. Indeed, some students of the logic of probability—for example, Ramsey and de Finetti—think that no rational decision is possible without some knowledge of, or belief about, the probabilities of the alternative "states of nature" that influence the action's outcome.

Yet, many statisticians feel that, in their own practice, they have to choose a "decision function" (i.e., they have to design a sample or an experiment and derive in advance a formula relating action to observation) without any advance knowledge as to the relative probabilities of alternative states of nature. The same is true of many practical situations. In fact, only in exceptional cases (such as life insurance, games of chance, and scientific predictions based on much past experience) does the decision-maker have good information on the relevant probabilities. In the general case, such information is not available;

hence moral expectation cannot be computed. Additional criteria become necessary. Thus a pessimist will assume the worst possible state of nature to be true and hence will maximize the lowest possible moral expectation; while, as pointed out by Franco Modigliani, the optimist will maximize the maximum moral expectation. Leonid Hurwicz formulated a certain compromise between the two attitudes. In general, the compromise may be slanted toward optimism or pessimism, the extent of the slant being part of a person's "tastes." Another criterion was suggested by L. J. Savage and, independently, by Jürg Niehans of Zurich: for any given state of nature define as "loss" (or "regret") the difference between the highest moral expectation that could be obtained if that state were known and the moral expectation obtained from a given action; then choose the action for which the highest loss is lower than for any other action.

In a long expository paper, Arrow reviewed the theories on risk and uncertainty of economists, statisticians, probability theorists, and philosophers. Marschak and Roy Radner constructed what is perhaps the simplest possible model for economic action under incomplete information. If you do not know the proportions of black and white balls in an urn and have to pay one nickel for each observation, how many drawings will you observe before you are willing to bet on the color of the next ball? How high will your bets be? The model helps to bring into relief some essential properties of what is loosely called "taking calculated risks." Decision-making is studied under the condition—so frequent in social and economic life—that the relevant probabilities are unknown and that the experience is enlarged in the course of the action itself, thus leading to a continual change in plans of action. The implications of the model show important weaknesses of the various criteria of choice suggested so far.

The following papers bear upon the problem of optimal single-person decisions. Some of them were published or presented in public meetings, including open academic lectures or seminars. (An asterisk indicates such papers by staff members, and additional information can be found in Appendix I.) Others were discussed in Cowles Commission staff meetings, usually

on the basis of a previously circulated hectographed document. Papers appear below in the same order in which the problems are described in the text. The list does not include some of the more technical papers on statistical decision functions, which will be mentioned in the section on statistical methods:

- Optimal Inventory Policy:\* *Arrow, Harris* (RAND Corporation), *and Marschak*
- Inconsistency and Indeterminacy in Classical Economics: *Brunner*
- An Exploration into the Use of Servomechanism Theory in the Study of Production Control: *Simon*
- Investment Company Behavior Equations: *Markowitz*
- A Note on Markowitz' Theory of Investment Companies: *Marschak*
- On The Certainty Equivalence and Risk-Discount Hypotheses: *Markowitz*
- The Utility of Wealth: *Markowitz*
- Why "Should" Statisticians and Businessmen Maximize "Moral Expectation":\* *Marschak*
- Note on "Measurable Utility": *Marschak*
- A Simplification of the Axiomatics of Measurable Utility: *Marschak*
- A New Theory of Probability: Degree of Confirmation and Inductive Inference: *Rudolf Carnap*, Department of Philosophy, University of Chicago
- De Finetti's Theory of Subjective Probability with Reference to the Statistical Decision Problem: *Leonard J. Savage*, Committee on Statistics, University of Chicago
- Recent Discussions on Utility and Probability, and the Late Frank Ramsey:\* *Marschak*
- Probability in the Social Sciences:\* *Marschak*
- Seminar on the Economics of Uncertainty:\* *Marschak*
- Rational Selection of Decision Functions: *Herman Chernoff*, Department of Mathematics, University of Illinois
- A Class of Criteria for Decision-Making under Ignorance: *Hurwicz*
- The Generalized Bayes-Minimax Principle: A Criterion for Decision-Making under Uncertainty: *Hurwicz*
- Alternative Approaches to the Theory of Choice in Risk-Taking Situations:\* *Arrow*
- Alternative Criteria for Economic Action under Ignorance: *Marschak and Radner*

1.b. *Multi-person decision problems.* If all persons in a group have identical goals and possess identical information, the team

can be treated, for the purposes of the theory of decision-making, as a single person. But diversity of interests and imperfect communication create the specifically *social* problem: the problem of measuring group welfare, of predicting the outcome of conflict and cooperation, and of choosing the best organizational structure. In its general form the problem is this: how to let "utility maximizing" individuals choose decisions that jointly produce the best result from the point of view of the organization as a whole. This problem exists for a large corporation in relation to its managing officers as well as to its labor force; it exists for the government in relation to its subordinate agencies. In a wider sense, the same problem exists between the government and private consumers and producers. To determine the best economic organization in this wider sense is to study the central problem of our time: the advantages and limitations of free competition and the most desirable forms and limits of governmental activity. Thus, the problems that are, in most American universities, artificially split between schools of business administration, schools of public administration, departments of political science, and departments of economics, turn out to be special applications of the same general problem, that of optimal organization.

Is it possible to rank the community's preferences, to draw its list of "priorities" on the basis of conflicting desires of individual citizens? The degrees of satisfaction of various individuals are not comparable. Bentham's "greatest happiness of the greatest number" hardly stands a logical scrutiny. Arrow's book, *Social Choice and Individual Values* (Cowles Commission Monograph 12), deals with these problems, and Clifford Hildreth, Markowitz, and Leo A. Goodman studied conditions which may make it possible to compute a meaningful "social welfare index."

Gerard Debreu defined a measure of inefficiency of an economic system. This measure is the maximum saving of primary resources which could be made within the existing technology without preventing any consumer from enjoying his current level of satisfaction. With the help of this measure we can assess the effect of a given technological change upon the production



potential or evaluate the economic loss resulting from a given system of taxes and subsidies.

Debreu's index of inefficiency of an economic system, or its complement, the index of resource utilization, is an offshoot of his more general work on efficiency. An economic system is said to be efficient if limited resources and technical knowledge are used in such a way that no consumer's satisfaction can be further increased without hurting some fellow consumer. If production decisions are made not by a central authority but by individual firms, it can be proved that there exists a set of "efficiency prices" with the following property: if every firm chooses its inputs and outputs so as to maximize its profit computed on the basis of those prices, then the system is efficient in the sense defined above. (Edmond Malinvaud extended the concept of efficiency prices to interest rates.) Efficiency prices may be identical with those arrived at under free competition between firms. But one could also think of applying the principle to the case in which the "firms" are agencies of the government—for example, branches or units of the armed forces. Decisions on production are thus decentralized and use the initiative and knowledge of local or specialized people who strive to maximize the "efficiency profits" of the agencies in their charge, computed on the basis of "efficiency prices"; the central body is left to decide only on "prices"—that is, on the relative importance of various objectives and sacrifices.

The principle of efficiency prices as a guide for decentralized policy-making in the interest of the community goes back to earlier studies, by Tjalling C. Koopmans and others. Those studies excluded from consideration the conflict of individual interests and defined as efficient an allocation of resources under which the output of a good cannot be increased further without decreasing the output of some other good. The organizational device of decentralizing decisions through efficiency prices is assumed here also. With the specific difficulty of the diversity of individual interests removed, it is in principle a simple matter to test the efficiency of an economic decision, whether it is made by one person or decentralized among many. The volume on *Activity Analysis of Production and Allocation* (Cowles Commission Monograph 13) was written in this spirit.

In 1950–1951 conditions for efficiency were studied in a few concrete fields, mainly those related to location and transportation. George H. Borts continued his statistical study of the production technology of railroads. His preliminary results indicated constant or increasing returns to scale for the production of line-haul services, and constant or slightly decreasing returns to scale for the production of switching services. Kirk Fox and Koopmans began to collect and study data on the movement patterns for empty railroad cars. Martin J. Beckmann used hydrodynamic theorems to discuss the optimal transport flows through a closed region with a given geographic distribution of demand and supply conditions for each commodity. Koopmans studied also the efficiency aspects of dispersal of population and industry.

It takes time to make and carry out a decision. This fact is neglected in the simple, “static” model of decentralized decision-making discussed so far. Arrow and Hurwicz made a step toward greater realism. Both the organization leader who determines efficiency prices and the subordinate who determines the in- and outputs for his agency proceed by alternate steps: each reacts to the preceding move of the other. Optimal rules of action are rules that make for the quickest convergence to the optimal use of the organization’s resources. The problem reduces to the mathematical one of finding the fastest iterative method for a computation. Exploratory computations were made by James G. C. Templeton.

Another realistic step was made by Simon, who introduced into organization theory the important element of uncertainty. He pointed out, for example, that the difference between a news publisher’s contract with a salaried staff member and one with a free-lance contributor lies in the greater predictability of services obtained in the former case. This difference may be reflected in the relative prices of the two kinds of services.

A Difficulty in the Concept of Social Welfare:\* *Arrow*  
Derivation of Social Welfare Functions from Individual Utility  
Functions:\* *Hildreth*  
Social Welfare Functions Based on Rankings: *Leo A. Goodman*,

\* Listed in Appendix I.

Department of Sociology, University of Chicago, and *Markowitz*  
 The Coefficient of Resource Utilization:\* *Debreu*  
 Effect of Technological Change on Production Potential:\* *Debreu*  
 Efficiency Prices as Guides for Decentralized Decisions:\* *Debreu*  
 The Mathematics of Welfare Economics: An Introduction:\* *Hur-*  
*wicz*  
 Resource Allocation and Statistical Decision Functions: *Debreu*  
 An Extension of the Basic Theorems of Classical Welfare Eco-  
 nomics:\* *Arrow*  
 Recent Developments in the Theory of Production:\* *Koopmans*  
 Generalizations of Leontief's Input-Output Model:\* *Koopmans*  
 A Continuous Transportation Model: *Beckmann*  
 Efficiency Aspects of Dispersal of Population and Industry:\*  
*Koopmans*  
 A Gradient Method for the Lagrangian Problem: *Arrow, Hur-*  
*wicz, Templeton*  
 Theory of Economic Organization:\* *Hurwicz*  
 A Formal Theory of the Employment Relationship: *Simon*  
 A Comparison of Organization Theories: *Simon*  
 The Bargaining Problem: *John F. Nash*, Princeton University  
 Theory of Cooperative and Noncooperative Games: *Nash*  
 On Some Problems in Logistics: *C. B. Tompkins*, George Washing-  
 ton University  
 Organization Theory in Miniature: *A. Newell*, RAND Corpora-  
 tion, and *J. Kruskal*, Logistics Project of the Office of Naval Re-  
 search, George Washington University

## 2. *Actual Behavior*

Some of the descriptive work done during the report period is directly related to models of optimal behavior. It aims at establishing some concrete, possibly numerical, properties of the model, and measuring its deviation from reality. The work on railroad transport by Borts and by Fox and Koopmans, mentioned above, is along these lines. Markowitz' discussion of the utility function of wealth, also mentioned above, is of the same type, although it has not so far involved any statistical study. However, Markowitz' model for the optimal portfolios of investment is being submitted to elaborate statistical measurements. Taking into account a few of the more important variables usually recognized in security analysis, Markowitz derives the "belief formation equations" assumed to be used by a company in estimating the probability distribution of future returns from various securities. On this basis the

set of efficient portfolios (as defined on page 12 of this report) is constructed and compared with actual portfolios.

The study on expectations and business fluctuations, conducted by Modigliani at the University of Illinois, is not related to the Cowles Commission formally, but the subject matter indicates a strong mutual interest, fostered by visits and discussions. Modigliani's group is interested in the formation of expectations in industry, and has completed the analysis of the quarterly shippers' forecasts of carload requirements. As part of this project Jean Bronfenbrenner and A. Kisselgoff studied the formation and realization of capital outlay plans.

In cooperation with the Agricultural Economics Research Group of the University of Chicago and the Bureau of Agricultural Economics of the U.S. Department of Agriculture, Hildreth is conducting a study of supply and demand for livestock products in the United States. A model has been developed to explain annual fluctuations in the amounts of all livestock products (treated as a group) produced and consumed in the United States, in the price of livestock products, and in selected economic variables. Available time series for the period 1920-1949 are being processed to obtain measurements of variables that most nearly correspond to those appearing in the model. When these are obtained, a statistical analysis of the model will be undertaken. This will include estimation of equations by alternative methods and a comparison of the results. Frank Jarrett, research associate in economics, University of Chicago, is participating in the study.

The following list, which includes contributions by guests, gives an account of work on actual behavior not listed previously in this report:

Statistical Problems and Computational Programs Suggested  
by the Theory of Investment Behavior: *Markowitz*

Interim Report of Progress of Project on Expectations and Business  
Fluctuations: *Modigliani*

Discrepancies between Actual and Anticipated Plant and Equip-  
ment for Individual Firms: *Jean Bronfenbrenner*

A Model of Farm Production:\* *Hildreth*

A Tentative Model of the Livestock Economy: *Jarrett and Hildreth*

\* Listed in Appendix I.

- A Report on a Two Week Visit at the Chrysler Corporation: *Christ*  
A Statistical Analysis of the Demand for Liquor in Sweden:  
*Sten Malmquist*, Uppsala, Sweden  
A Measurement of Money Utility and of Functional Values of the  
Cost of Living Index: *Isamu Yamada*, Hitotsubashi University,  
Tokyo, Japan

### 3. *Statistical Methods*

Work was continued on Cowles Commission Monograph 14, *Econometric Methods*, a statement of earlier and new work on the statistical measurement of economic relationships, with emphasis on exposition. We shall mention here only contributions to this volume not described in the Commission's *Report for 1949-1950*. In an introductory article Marschak discusses economic measurements for policy and prediction by elaborating in detail the program outlined in "Economic Structure, Path, Policy, and Prediction," pages 2-6 of the Commission's *Five-Year Report for 1942-1946*.

Simon extended the distinction between endogenous and exogenous variables into a discussion of causal ordering of variables connected by a system of relationships. In this (partial) ordering a variable lower in the hierarchy is affected by, but does not itself affect, a variable placed higher up. He then noticed and analyzed connections between the analysis of a causal hierarchy and criteria for identifiability of the relationships explaining the formation of these variables. It is worth noting that the study was inspired by Simon's interest in servomechanisms, mentioned on page 11.

Hurwicz discussed both model construction and the choice of a method of estimation as a problem in decision-making under uncertainty, balancing the effects of specification errors on the usefulness of the model against the complications arising from too detailed or refined models.

Herman Chernoff and Nathan J. Divinsky completed a detailed expository description of computational procedures followed in maximum-likelihood estimation of systems of behavior equations and of subsystems or single equations thereof.

Many gaps in the statistical theory of structural equation systems are still to be filled. T. W. Anderson completed his

study of exact confidence regions for coefficients of a certain type of incomplete set of linear structural equations. A similar problem was attacked by Gurland for the case, called "dynamic" by economists, in which lagged dependent variables appear. An econometric problem induced Gurland to study also the distribution of ratios of quadratic forms; this may lead to applications in other fields as well. Anderson continued his joint study with Hurwicz on models involving disturbances in equations as well as errors in observations. Hildreth revived an earlier suggestion of Wald's to base estimates on means of subsets of observations, and studied its application to models involving disturbances. He also discussed the application of statistical decision functions to the estimation of economic structure. Arnold C. Harberger examined the effect of empirical or a priori limits to the variance of disturbances upon the bias of the least-squares method; this attempt is motivated by the relative cheapness of the latter method.

It is notable how statistical problems studied in connection with the measurement of economic structure have also arisen in other fields. Koopmans applied the concept of identifiability to the "latent structures" postulated by Paul Lazarsfeld, of Columbia University, to analyze and explain responses to public opinion surveys. Anderson developed models for the analysis of data reflecting changes in responses by a panel of respondents to repeated surveys.

Economists often face the peculiar statistical problem of aggregating or summarizing numerous data into a few index numbers, such as price level and total output. Debreu's coefficient of resource utilization (see above, page 15) may prove, for certain problems, more useful than some conventional aggregates such as the gross national product. In fact, as in other statistical methods, the choice of the best method of aggregation depends on its relative cost and usefulness. A set of items (prices, for example) can be partitioned into mutually exclusive subsets in a variety of ways, with a certain operation to be performed subsequently on each subset. The problem of finding, for a given cost, the most useful partition and operation is a problem in decision-making. This point of view was taken by Hurwicz, who treated the general case of uncertainty,

and by Marschak, who used the inventory problem as an illustration for the case of certainty.

The following list excludes those contributions to Monograph 14 which were listed in the previous Annual Report. For a table of contents of that monograph, see page 29 of this report.

Some Specification Problems and Applications to Econometric Problems:\* *Hurwicz*

“Possibilities” and Statistical Analysis:\* *Hildreth*

Some Remarks on Admissible Minimax Solutions of Statistical Decision Problems: *Sverdrup*

Bayes and Minimax Interpretations of the Maximum-Likelihood Estimation Criterion: *Hurwicz*

Distribution of Ratios of Quadratic Forms: *Gurland*

A Reconsideration of Least-Squares and Simultaneous-Equations Estimates: *Harberger*

Probability Models for Analyzing Time Changes in Attitudes: *Anderson*

Identification Problems in Latent Structure Analysis: *Koopmans*  
Introduction to Econometrics (Course Lectures):\* *Hildreth*

Statistical Problems of Model Construction (Course Lectures):\* *Koopmans*

Testing Linear Hypotheses (Course Lectures):\* *Gurland*

Theory of Statistical Estimation (Course Lectures):\* *Gurland*

The Causal Principle and the Identification Problem: *Simon*

Aggregation as a Problem in Decision-Making under Ignorance or Uncertainty: *Hurwicz*

Aggregation Problems Exemplified in Optimal Inventory Policy: *Marschak*

#### 4. *Mathematical Tools*

As mentioned in the previous report, a process of widening the horizons of economists in regard to mathematical tools used in their theories can be observed. In particular, the work on resource allocation has led away from differential calculus, called “marginal analysis” by economists and appropriated from mechanics and physics, toward the methods of point set theory, which are more abstract, more general, logically simpler, and better adapted to many problems of social science. Convex point sets have been particularly useful in expressing a more general form of the traditional assumption of increasing

\* Listed in Appendix I.

marginal rates of substitution in consumption, and in expressing the simplifying assumptions of constant returns to scale and additivity of production processes. More general point sets need to be studied in order to revise these assumptions to obtain greater realism. The abandonment of differentiability assumptions permits inclusion, in the analysis, of limits to physical resources or plant capacities and other technical indivisibilities, as well as consumption patterns in which the price-and-income situation induces some consumers to exclude some commodities altogether from their consumption.

Morton L. Slater studied the mathematical content of the problem of economic choice, that is, the problem of maximization under constraint. He provided mathematical advice and criticism with regard to the work of many staff members and provided expository presentations of mathematical results to economists. Visiting mathematicians addressed the staff on problems of maximization under linear inequalities. John Chipman, Debreu, and Slater explored mathematical theorems providing criteria of stability in models of international, interregional, or interindustrial economics. Templeton gave direction to the computing staff of the Commission.

Lagrange Multipliers Revisited: *Slater*

A Note on Motzkin's Transposition Theorem:\* *Slater*

Optimization under Constraints: A Central Economic Problem and the Mathematical Tools for Its Solution:\* *Slater*

Mathematical Methods in the Study of Efficiency in Production:\* *Slater*

Convex Cones and the Economic Theory of Production:\* *Koopmans*

Solutions of Linear Inequalities: *Theodore S. Motzkin*, National Bureau of Standards at Los Angeles

Some Problems in Linear Programming: *E. Barankin*, University of California, Berkeley

Admissible Points of Convex Sets: *Arrow and D. Blackwell*, Stanford University

The Stability of Systems with Nonnegative Coefficients: *Chipman*

Characteristic Roots of Nonnegative Matrices: *Debreu*

A Theorem on Characteristic Roots: *Slater*

\* Listed in Appendix I.



## STAFF MEETINGS AND SEMINARS

THE Cowles Commission has developed its research procedures with a view to benefiting from the cooperative efforts of research workers with a variety of backgrounds and training: economists who specialize either in theory, the analysis of policies, or empirical work; statisticians; mathematicians; and (among research consultants) one who specializes in political science and administrative behavior. An essential feature of this cooperation is the informal discussion which takes place among staff members at various stages of the research. Staff meetings are scheduled when an individual's research reaches a point at which criticism by the group as a whole would prove of particular value. Research memoranda are circulated in advance of such meetings to economize on the time required for presentation and to facilitate constructive criticism and appraisal of the work. At such staff meetings the resident staff is often joined by research consultants of the Commission and by advanced students and research fellows from the University of Chicago and other American or foreign academic centers. There were 42 such staff meetings held at the Cowles Commission during the period of the present report.

Of a more expository and somewhat less technical nature are the seminars which the Cowles Commission conducts throughout the year devoted to varying topics within the broad area of quantitative method. Papers are presented by research workers from this and other centers of learning and are followed by critical discussions of the material by seminar participants. The seminars have proved to be of particular value in suggesting new associations of ideas and in developing a more receptive attitude toward quantitative techniques. To facilitate this, invitations to seminars are extended to research personnel in a wide variety of fields as well as to the public and to interested graduate students.

It was possible to arrange most of the seminar sessions of the 1950-1951 period into two sequences: "Utility and Probability"

(papers by Carnap, Savage, Marschak, Arrow, Chernoff, van Dantzig, and Thurstone) and "Economics of Welfare" (papers by Hurwicz, Koopmans, Slater, Debreu, and Hildreth). During the period covered by this report the following Cowles Commission seminars were held:

1950

October 12. JOHN F. NASH, Princeton University, "The Extended Bargaining Problem."

October 26. RUDOLPH CARNAP, Department of Philosophy, University of Chicago, "A New Theory of Probability: Degree of Confirmation and Inductive Inference."

November 9. LEONARD J. SAVAGE, Committee on Statistics, University of Chicago, "De Finetti's Theory of Subjective Probability with Reference to the Statistical Decision Problem."

November 16. LLOYD A. METZLER, Department of Economics, University of Chicago, "The Pigou Effect and the Rate of Interest."

November 30. JACOB MARSCHAK, "Recent Discussions on Utility and Probability, and the Late Frank Ramsey."

December 21. KENNETH J. ARROW, "Alternative Approaches to the Theory of Choice in Risk-Taking Situations."

1951

January 11. HAROLD T. DAVIS, "Some Implications of the Curve of Income Distribution."

January 25. HERMAN CHERNOFF, Department of Mathematics, University of Illinois, "Rational Selection of Decision Functions."

February 1. D. VAN DANTZIG, Department of Mathematics, University of Amsterdam, "On the Linking up of Probability Theory to Empirical Sciences."

February 15. LOUIS L. THURSTONE, Department of Psychology, University of Chicago, "Consumer Preferences and the Prediction of Choices."

March 1. LEONID HURWICZ, "The Mathematics of Welfare Economics: An Introduction."

March 15. T. C. KOOPMANS, "Generalizations of Leontief's Input-Output Model."

March 29. LEONID HURWICZ, "Optimization Rules in a Decentralized Economy."

April 12. MORTON L. SLATER, "Optimization under Constraints: A Central Economic Problem and the Mathematical Tools for Its Solution."

April 26. LOUIS GUTTMAN, Israel Institute of Applied Social Research, "Qualitative Data and the Theory of Scaling." (Jointly with Committee on Statistics, University of Chicago.)

May 3. GERARD DEBREU, "The Efficiency of an Economic System."

May 10. CLIFFORD HILDRETH, "Derivation of Social Welfare Functions from Individual Utility Functions."

May 24. JOHN CHIPMAN, University of Chicago, "Oscillations in a Multi-Sector Economy."

June 12. M. G. KENDALL, London School of Economics, "Testing Significance in Cases Where There Is Autocorrelation in Residuals of a Time Series."

## COOPERATION WITH OTHER GROUPS

THE Cowles Commission and its staff members have continued to cooperate in various ways with other parts of the University of Chicago and other institutions in research of common interest.

In view of the interdisciplinary nature of the Commission's interests, close ties with other departments within the University are important for the success of its work. The Commission has several joint appointments with the Department of Economics (Hildreth, Koopmans, Marschak). It also has joint appointments with the Committee on Statistics (Gurland), with the Agricultural Economics Research Group (Hildreth), and with the Department of Mathematics (Herstein). The research results and experience of the Commission have been and are being utilized by the Agricultural Economics Group, in particular in a study conference on efficiency held in the summer of 1950. They also play an important role in the study of supply and demand for livestock products in the United States which Hildreth is conducting for the Agricultural Economics Group with the cooperation of the Bureau of Agricultural Economics of the U.S. Department of Agriculture.

Informal contact has been continued with various centers of empirical work. Through Modigliani the Commission remains in touch with the study on expectations and business fluctuations conducted at the Bureau of Business Research of the University of Illinois. Through Klein and others the Commission similarly maintains contact with the collection and analysis of survey data on consumer behavior conducted at the University of Michigan under the auspices of the Survey Research Center and the National Bureau of Economic Research. Further insight into problems of empirical research

has been gained through the continued consultative activities of Hildreth with agricultural research workers in other institutions.

A number of research conferences during the year were the occasion of particularly fruitful cooperation between the Commission and other groups. Several staff members (Arrow, Hurwicz, Koopmans, Marschak, Slater) took part in a conference on logistics at The RAND Corporation in Santa Monica, California, in the summer of 1950. Marschak participated in a second conference on logistics held in Washington, D.C., in January, 1951, under the joint auspices of The George Washington University and the Logistics Branch of the Office of Naval Research. In April the Social Science Research Council sponsored a conference in Princeton on the measurement of technological change. Debreu, Hurwicz, and Koopmans took part in that conference, as well as in a symposium on linear inequalities and programming held in Washington, D.C., in June. The latter conference was organized jointly by the Department of the Air Force and the National Bureau of Standards. Integration of the research being undertaken at the Cowles Commission with that of Carnegie Institute of Technology in their Air Force project on intra-firm behavior and their Controllershship Foundation project on decentralization of accounting organization was the subject of another June conference. This was held at Pittsburgh and was attended by Hurwicz, Koopmans, Marschak, and Simpson, and by Simon and other members of the Carnegie staff.

Certain staff members (Anderson, Arrow, Marschak) served as consultants to The RAND Corporation during the year in addition to Hurwicz and Simon who, as consultants of the Commission, are engaged in research being undertaken by the Commission under contract with The RAND Corporation. Hurwicz provided consultative services to the U.S. Bureau of the Budget on problems connected with inter-industry studies. Hildreth was a consultant to the Office of the Technical Staff of the U.S. Treasury on estimating the effects of excise taxes on demand, supply, and revenue.

Links are established with various institutions through members of their staffs acting as research consultants of the

Cowles Commission. The number in this category increased during the year and now includes Carnegie Institute of Technology, Columbia University and its Bureau of Applied Social Research, The Johns Hopkins University, Northwestern University, Stanford University, the University of Illinois, the University of Michigan and its Survey Research Center, the University of Oslo, and the University of Toronto.

## PAPERS AND MONOGRAPHS

THE results of research by members of the Commission's staff are published in two series, Cowles Commission Papers and Cowles Commission Monographs, as well as in occasional separate form.

The policy was adopted at the end of 1943 of having reprints of papers by members of the Commission's research staff bound in special covers as Cowles Commission Papers, New Series (for econometric research), and Cowles Commission Special Papers. A list of these papers is given in Appendix III. Two papers (Nos. 36 and 39) were issued during the period covered by this report. Nos. 32, 33, and 34 are in preparation and will be issued in the latter part of 1951, along with ten papers to be published shortly after the period of this report. A limited supply is available of those papers which are marked by an asterisk, and copies will be furnished to individuals who request particular items.

A complete list of the monographs published by the Cowles Commission is included in Appendix IV. Published at the beginning of the report period were Monograph 10, *Statistical Inference in Dynamic Economic Models*, edited by Tjalling C. Koopmans; Monograph 11, *Economic Fluctuations in the United States, 1921-1941*, by Lawrence R. Klein; and an unnumbered monograph, *Economic Aspects of Atomic Power*, by Sam H. Schurr, Jacob Marschak, *et al.* During the latter part of the report period two further monographs were published: Monograph 12, *Social Choice and Individual Values*, by Kenneth J. Arrow, and Monograph 13, *Activity Analysis of Production and Allocation*, edited by Tjalling C. Koopmans.

Two monographs are in manuscript stage: Monograph 14, *Econometric Methods*, edited by Hood and Koopmans, a less technical presentation of some of the contents of Monograph 10, together with results of further research in methods; and a monograph on introductory econometrics being prepared by Marschak and Christ on the basis of a lecture series presented earlier. The latter monograph will be of interest to a broader readership than the other, recently published monographs. The tables of contents of the five monographs published during the report period are given in Appendix IV. The tentative table of contents of Monograph 14 is as follows:

I. Economic Measurements for Policy and Prediction, *J. Marschak*; II. Identification Problems in Economic Model Construction, *T. C. Koopmans*; III. Causal Ordering and Identifiability, *Herbert A. Simon*; IV. Methods of Measuring the Marginal Propensity to Consume, *T. Haavelmo*; V. The Estimation of Simultaneous Linear Economic Relations, *T. C. Koopmans and Wm. C. Hood*; VI. Statistical Analysis of the Demand for Food: Examples of Simultaneous Estimation of Structural Equations, *M. A. Girshick and T. Haavelmo*; VII. Asymptotic Properties of Limited-Information Estimates under Generalized Conditions, *H. Rubin and H. Chernoff*; VIII. An Example of Loss of Efficiency in Structural Estimation, *S. G. Allen*; IX. On Specification Errors in Model Construction, *L. Hurwicz*; X. Source and Size of Least-Squares Bias in a Two-Equation Model, *J. Bronfenbrenner*; XI. The Computation of Maximum-Likelihood Estimates of Linear Structural Equations, *H. Chernoff and N. J. Divinsky*.

## RELATED TEACHING

THE University of Chicago offers a wide variety of courses in econometrics, mathematical economics, economic theory, and statistics. Staff members of the Cowles Commission participate in the teaching activities of the University, especially in these fields. The courses offered by the Department of Economics or by the Committee on Statistics (not all given every year) that are particularly relevant to the area of interest of the Commission are listed in Appendix II.

## STAFF NEWS

THE current period has again been one of considerable research activity, travel, and publication for members of the Commission's staff. Some indication of these activities has been given in the section on cooperation with other groups and by the lists of papers cited in the text of the report on research. Information about papers and lectures published or presented outside of staff meetings during the period is given in Appendix I. Other items of staff news are given in the present section, which brings up to date the biographical sketches of staff members in earlier reports of the Cowles Commission.

The terms "research associate" and "research assistant" are used to denote staff members who are resident and devote part or all of their time to the research work of the Cowles Commission. The term "research consultant" is used to designate staff members who are generally nonresident and cooperate in the work of the Commission by participating in staff meetings, by correspondence, or in other ways. Only active members are retained on the list of the staff of the Commission.

Gerard Debreu continued as a research associate of the Commission throughout the period in connection with the study of the theory of resource allocation conducted for The RAND Corporation. In June, 1951, he was appointed assistant professor in the Cowles Commission.

Nathan J. Divinsky left the Commission in July, 1950, to become assistant professor of mathematics at Ripon College, and was succeeded by James G. C. Templeton as supervisor of the computational work of the Commission. Templeton obtained his B.A. in applied mathematics at the University of Toronto in 1947 and his A.M. in mathematics at Princeton University in 1949. Prior to joining the Cowles Commission as a research associate he spent three years at Princeton University as a graduate student in mathematical physics and mathematical statistics and as an assistant in instruction and

research. In the summer of 1949 he attended the Institute for Numerical Analysis at Los Angeles.

John Gurland continued under his joint appointment as assistant professor in the Cowles Commission and assistant professor of statistics in the Committee on Statistics.

Clifford Hildreth, associate professor in the Cowles Commission and research associate (associate professor) in the Department of Economics, carried forward his research for the Commission, presented an introductory course in econometrics, and directed the study of livestock products mentioned on page 26. In addition, Hildreth served as chairman of the program committee for the meeting of the Econometric Society in Chicago in December, 1950. In June of this year he consulted with the Treasury Department on estimating effects of excise taxes.

William C. Hood, a consultant to the Commission, returned for a short period as research associate. He took leave from his position as assistant professor at the University of Toronto to spend May and June of 1951 in Chicago in connection with the writing and co-editing (with Koopmans) of Monograph 14. At Toronto he taught mathematical economics in the Department of Economics, presented a course in statistical analysis in the Institute of Business Administration, and participated in a Mathematics Department seminar on the theory of games.

Leonid Hurwicz joined the Commission on a full-time basis in October, 1950, as research associate and visiting professor and remained through January, 1951. He provided the research leadership for the project on the theory of resources allocation during Koopmans' absence, and temporarily assumed Koopmans' teaching duties in the Department of Economics of the University of Chicago. He is now research professor of economics and mathematical statistics at the University of Illinois but, effective in September, he will become professor of economics and mathematics in the School of Business Administration at the University of Minnesota. He continues his association with the Cowles Commission as a research consultant.

Of major interest was the visit of the director of research, Tjalling C. Koopmans, to leading European centers of research



and instruction in econometrics, from August, 1950, to January, 1951. This trip was made possible by a grant from the Rockefeller Foundation to the University of Chicago, and occurred during Koopmans' tenure as president of the Econometric Society. The contacts made can be judged from the groups sponsoring his various lectures (see Appendix I). Upon returning from Europe, Koopmans again engaged in teaching at the University of Chicago, where he is professor of economics, and in co-editing and writing for Cowles Commission Monograph 14, described elsewhere in this report. He served as a member of the Social Science Research Council committee on the social implications of atomic energy and technological change. He is a member of the Council of the Econometric Society for 1951, and participated in arranging the program for the Minneapolis meeting of the Society. Also during the year he was appointed correspondent member of the Royal Dutch Academy of Sciences in Amsterdam.

Harry Markowitz continued as a research fellow of the Cowles Commission and as a fellow of the Social Science Research Council.

Jacob Marschak, who is a research associate of the Commission and professor of economics at the University of Chicago, took part in various outside activities during the period. He cooperates in the editing of the *Journal of Political Economy*, is a member of the editorial board of the *Journal of Human Relations*, and, starting in 1951, has been a member of the board of editors of *Metroeconomica*. Marschak served on the program committee for the Harvard meeting of the Econometric Society in September, 1950. Together with Hurwicz he represented the Econometric Society on the intersociety committee on the mathematical training of social scientists. He is a consultant for The RAND Corporation.

William B. Simpson, the assistant director of research of the Commission, served as acting research director during Koopmans' absence. He was appointed executive director of the Commission as of July 1, 1951. He was re-elected secretary of the Econometric Society by the Council of the Society. He continued as managing editor of *Econometrica*, and in June, 1951, was designated co-editor of that journal. An account of

the work of the Econometric Society during the period is given in a later section of this report.

Morton L. Slater was actively engaged in mathematical research on the study of resource allocation as a research associate of the Cowles Commission (with the rank of assistant professor).

Erling Sverdrup, a fellow of the Rockefeller Foundation and a research fellow of the Cowles Commission, continued his association with the group through November, 1950. He has since been acting professor of actuarial mathematics and mathematical statistics at the University of Oslo, Norway.

Several changes occurred among research assistants of the Cowles Commission. Gerhard Stoltz completed his work as a research assistant on the resources allocation study in the summer of 1950, moved to Stanford University, and has now returned to the University of Oslo, Norway. Kirk Fox was appointed research assistant in November, 1950, and Roy Radner in March, 1951. Fox was in the United States Navy submarine service from 1943 to 1946, after which he attended the University of Chicago, where he received a B.S. in mathematics in June, 1948. Just before joining the Commission, Fox held the position of economic research assistant at the Northern Trust Company Bank of Chicago. He will be engaged in the application of linear programming techniques to the transportation industry, as well as in the performance of various administrative and editorial duties for the Commission. Concurrently he is teaching introductory and intermediate statistics at the Northwestern University School of Commerce. Radner studied at the University of Chicago from 1944 to 1945 under a William Cook scholarship, receiving his Ph.B. with honors. After three years with the army he returned to the University and undertook graduate work in mathematics, obtaining an M.S. degree in 1951. He continues his preparation in statistics concurrently with his work for the Commission.

The research consultant staff was increased during the year by the addition of Carl Christ in September, 1950, Stephen G. Allen in December, and Lawrence R. Klein in May. Christ was with the Commission as a research associate and as a fellow of the Social Science Research Council until mid-September, at which time he became an assistant professor of political

economy at the Johns Hopkins University. He is currently collaborating with Marschak on the preparation of a Cowles Commission monograph on introductory econometrics. Allen and Klein were both members of the Commission's research staff in previous periods. Allen is currently a research associate of the Applied Mathematics and Statistics Laboratory at Stanford University. Klein is on the staff of the Survey Research Center at the University of Michigan and is a research associate of the National Bureau of Economic Research.

Various research consultants of the Cowles Commission, in addition to those mentioned above, were active during the year. T. W. Anderson, who is associate professor of mathematical statistics at Columbia University, continued his teaching and acted as executive officer for the Department of Mathematical Statistics at Columbia from November, 1950. He was appointed to the Board of Governors of the Bureau of Applied Social Research of Columbia University. He was elected a fellow of the Econometric Society in 1950. Anderson continued as editor of the *Annals of Mathematical Statistics* and was a member of the Executive Committee and Council of the Institute of Mathematical Statistics, and of a number of committees. He served as a representative of the Institute on the committee on mathematical training of social scientists. He is a consultant to The RAND Corporation.

Kenneth J. Arrow, a research consultant both to the Cowles Commission and to The RAND Corporation, is associate professor of economics and statistics at Stanford University. He was program chairman for the Berkeley meeting of the Econometric Society in 1950 and currently is on the program committee for the meeting in Santa Monica.

Harold T. Davis, professor of mathematics at Northwestern University, continued as chairman of the department at that institution. He is an associate editor of *Econometrica* and was a member of the program committee for the Chicago meeting of the Econometric Society.

Trygve Haavelmo is professor of economics at the University of Oslo, where he presented courses in econometric methods, statistics, and economic theory during the year. He is a con-

sultant to the University Institute of Economics, Oslo, as well as to the Cowles Commission.

Franco Modigliani continued to devote the major portion of his time to the study on expectations and business fluctuations, of which he is director, at the University of Illinois. He is associate professor at the Bureau of Economics and Business Research. His other activities during the period included presentation of a course on the methods of mathematical economics, membership on the executive committee of the Conference on Research in Income and Wealth, National Bureau of Economic Research, and on the committee organizing the conference on short term projections to be held under the auspices of the National Bureau of Economic Research at the University of Michigan in September.

Herbert A. Simon continued as professor of administration and head of the Department of Industrial Management at Carnegie Institute of Technology. He is engaged in research as a consultant of the Cowles Commission on its study on resource allocation, and in projects at Carnegie Institute, one sponsored by the U.S. Air Force on intra-firm behavior and the other by the Controllership Foundation on the centralization and decentralization of accounting organization. Simon is currently a member of the program committee for the Boston meeting of the Econometric Society in December, 1951.

## GUESTS

As in other years, the Cowles Commission has benefited from the presence of advanced students and research fellows from this and other research centers. This has both stimulated the work of the Commission and aided in spreading the results of its research.

To the extent that its resources permit, the Commission has accorded office, library, and other research facilities to its guests, a fact which has intensified the advantages gained from these periods of resident cooperation. The following are among those who were associated with the Commission in this manner during the year.

Martin J. Beckmann, formerly of the University of Freiburg, Germany, and currently a post-doctoral fellow in political economy at the University of Chicago, participated actively in the research program of the Commission during the year. He joins the Commission as a research associate as of July, 1951, to undertake research on the theory of best locational distribution of industry in connection with the study on resource allocation. George H. Borts, a Fellow of the Social Science Research Council for 1949-1950, continued as a guest of the Commission until the late summer of 1950, at which time he became assistant professor of economics at Brown University. The Commission has continued to provide computational facilities for the research he initiated while at Chicago. Karl Brunner, of the Handelshochschule, St. Gallen, Switzerland, was with the Commission under a grant from the Rockefeller Foundation throughout most of the period from January, 1950, through June, 1951. He will join the economics faculty of the University of California at Los Angeles. John Chipman, a Canadian holder of a post-doctoral fellowship in the department of economics at the University of Chicago, also participated with the staff of the Commission in its research activities. In September he will assume teaching duties at Harvard University. The Fulbright fellowship program and the Institute of International Education cooperated in bringing Siro Lombardini to the University of Chicago. He maintained contact with the work of the Commission from his arrival in October, 1950, until June, 1951, at which time he returned to Italy to join the faculty of the University of Milan. Edmond Malinvaud, of the Institut National de la Statistique et des Etudes Economiques, Paris, was with the Commission as a Rockefeller Fellow from July, 1950, through June, 1951, and was an active participant in the research group. Sten Malmquist, Statistical Institute of the University of Uppsala, Sweden, was in residence at the Commission as a guest from November, 1950, through March, 1951. Isamu Yamada visited the Commission in March and April, 1951, under the auspices of the Ministry of Education of the Japanese government. He returns to his post as professor of econometrics at Hitotsubashi University, Tokyo.

The Cowles Commission also benefited from the occasional contributions of numerous other research workers and from the brief visits of a number of distinguished guests in addition to those mentioned above. Reference to some of these visits can be found in the report on research activities and in the list of seminars on pages 25-26.

## OFFICE AND LIBRARY

THE activities of the Cowles Commission, and of the Econometric Society which shares its offices, are carried out with the aid of a supporting staff of approximately ten full-time and several part-time persons. Miss Helen Docekal, who joined the staff in January, 1949, is Administrative Secretary and as such is responsible for various administrative matters as well as the supervision of the office. The publication programs of the Commission and of the Econometric Society are the concern of Mrs. Jane Novick, Editorial Secretary. J. Myron Jacobstein became Librarian of the Cowles Commission early in 1951. A Financial Secretary, Miss Marilyn Holmes, was also added to the staff during the year. The balance of the group includes mathematical technicians, editorial assistants, book-keepers, secretaries, and technical typists.

The offices and library of the Cowles Commission are located in the Social Science Research Building on the quadrangles of the University of Chicago, overlooking the Midway Plaisance. The Commission has a working library specializing in material pertinent to its investigations, particularly in the fields of quantitative economics, statistics, mathematics, economic theory, and descriptive data. Additions to the library during the period covered by this report total 279 books, 311 pamphlets, and 150 bound volumes of journals. The total collection consists of 2,728 books, 5,547 pamphlets, and 744 bound journal volumes representing 162 different journals, of which 139 are currently received. In addition, the library of the late Professor Henry Schultz, which contains 950 books and 1,750 pamphlets, is kept in the Commission's offices. The library is open to

members of the Department of Economics as well as to advanced students by arrangement.

## ORGANIZATIONAL STRUCTURE

**A**N IMPORTANT development of the recent period has been the emergence of the faculty of the Cowles Commission as a self-governing body. More general supervision over the academic affairs of the Commission lies with the executive committee. This consisted, during the report period, of the Dean of the Division of the Social Sciences (Ralph W. Tyler), the Chairman of the Department of Economics (Theodore W. Schultz), the President of the Cowles Commission for Research in Economics, the Director of Research (as Chairman), and the Assistant Director of Research. The administrative affairs of the Commission were under the supervision of a committee consisting of the last three mentioned above.

New bylaws and statutes of the Commission, as well as amendments to the articles of incorporation, were formulated during the year to provide for organizational changes made desirable by the recent growth of the Commission and to better prepare the organization to meet the problems of the future. The new provisions will go into effect in the latter part of 1951 and will be published in full in the twentieth-year report of the Commission. Among other things, these provide for increased lay and professional representation on the board of directors of the Cowles Commission, for integration of the executive committee into the formal corporate structure, for appointment of a committee on investments and a committee on development, for realignment of responsibilities among the principal officers, and for statutes relating to the research staff, faculty, academic advisory committees, and the supporting staff. The executive committee as reconstituted will include the Chairman of the Board, the Executive Director, the Director of Research, the Treasurer, the Chairman of the Department of Economics, and the Dean of the Division of the Social Sciences of the University, and two directors not affiliated with the University who shall be elected by the board of directors.

While strengthening its own independent corporate structure and continuing its activities on both a national and international scale, the Cowles Commission also retains its valued association with the University of Chicago. The Commission is affiliated with the University in that the research activities of the Commission are integrated with other research and teaching activities of the University in the following ways: through participation of academic officials of the Division of the Social Sciences of the University in the ruling bodies of the Commission, through representation of the Commission on the executive committee of the Division of the Social Sciences of the University, through adherence to University procedures in the appraisal and appointment of members of the Commission's staff to the faculty and staff of the University, and through support provided by the University in the form of office facilities, salaries, and provision of tenure for academic appointees.

## FINANCIAL SUPPORT

**A**CKNOWLEDGMENT is made to the Rockefeller Foundation and the University of Chicago for financial assistance in the Commission's research on the econometric foundations of rational economic policy. The study on the theory of allocation of resources is conducted on a cost basis under a subcontract with The RAND Corporation. Starting in July, 1951, the Commission's research in the area of decision-making under uncertainty will receive support through a contract with the Office of Naval Research.

As in previous years, a substantial contribution toward the support of the Commission has been made by its founder, Mr. Alfred Cowles, and by members of the Cowles family. The extent of this contribution was significantly increased in amount during the period of this report.

Several guests and members of the research staff have held fellowships from the Rockefeller Foundation, the Social Science Research Council, or the University of Chicago.



## PRESENT NEEDS AND FUTURE PROSPECTS

OF MAJOR concern to the Cowles Commission is the problem of building up the human as well as the financial resources which must be drawn upon if the research effort of the group is to keep pace with the potential usefulness of econometric research.

For the immediate future the limitation is mainly financial, namely, that of providing additional long-term support which can form the basis for the commitments involved in adding major staff members from the existing pool of research workers.

Taking a longer view, the problem is one of developing additional human resources which can be utilized for research and teaching in this and related areas. This requires an increase in mathematical and statistical ability and interest in the economics profession and in the social sciences generally, and the removal of barriers to the exchange of information within the profession, between professions, and internationally.

The Cowles Commission is seeking support to attack this long-range problem through a fellowship program, a conference program, an extended publication program, and a study program aiming at recommendations for the improvement of communication referred to above.

Apart from the needs and prospects mentioned above there is the long-run objective of securing an endowment which would assure to the Commission a permanent source of income. There is also a pressing need for additional space, both for the rapidly growing research group and supporting staff of the Commission and for the interested group of advanced students and research fellows which is attracted to the Commission from centers of learning throughout the world.

## THE ECONOMETRIC SOCIETY

THE Cowles Commission offices have continued to serve as headquarters of the Econometric Society, an international society for the advancement of economic theory in its relation to statistics and mathematics.

Several members of the Cowles Commission staff hold offices in the Society. Tjalling C. Koopmans was president of the Econometric Society during 1950, after which he continued as a member of the Council. William B. Simpson was re-elected secretary of the Econometric Society and continued as managing editor of *Econometrica*. In June, 1951, he was designated co-editor of the journal. He has been active in organizing the various meetings of the Society. Alfred Cowles continued as treasurer of the Society and also as business counsel for *Econometrica*. Harold T. Davis is an associate editor of the Journal.

Various members of the staff served on program committees or presented papers or discussion in connection with the meetings of the Society. Others are members of an intersociety committee on the mathematical training of social scientists, which was an outgrowth of a symposium arranged by the Econometric Society in 1949. One member of the Commission, T. W. Anderson, was elected a Fellow of the Econometric Society during the year.

The practice of holding a regional meeting of the Econometric Society on the West Coast was initiated in 1950 with sessions on the Berkeley campus of the University of California, August 1-5, in conjunction with the second Berkeley Symposium on Mathematical Statistics and Probability and the meeting of the Institute of Mathematical Statistics. In 1951 the West Coast meeting will be held at The RAND Corporation in Santa Monica, August 2-4.

Starting in September, 1948, the practice was adopted of holding the American summer meeting of the Econometric Society in conjunction with the meetings of the American Mathematical Society, Mathematical Association of America,

and Institute of Mathematical Statistics, with emphasis being placed upon papers of a mathematical and technical nature. These meetings were held at the University of Wisconsin in 1948 and at the University of Colorado in 1949. In 1950 the Econometric Society met at Harvard University concurrently with the International Congress of Mathematicians. This year the meeting is scheduled for the University of Minnesota, in Minneapolis, September 4-7.

The American winter meeting of the Society is usually held at the same time and place as the meetings of the American Economic Association, American Statistical Association, Institute of Mathematical Statistics, and other components of the Allied Social Science Associations, and some joint sessions are arranged. This was held in Cleveland in 1948, in New York City in 1949, and in Chicago in 1950. On occasion sessions are also held jointly with Section K of the American Association for the Advancement of Science, with which section the Econometric Society is affiliated. Sessions of the Econometric Society are open to all its members as well as to the members of the other organizations and the general public. Attendance at particular sessions ranges from 25 to over 300. The 1951 meeting with the social science organizations will be held in Boston, December 26-29.

The European meeting of the Econometric Society was held at Colmar, France, in 1949 and at Varese, Italy, in 1950. It is planned this year for Louvain, Belgium, September 12-14.

The first Japanese meeting of the Econometric Society was held October 8-9, 1950, at the Tokyo University of Commerce, at which time a Japanese branch of the Society was organized. Sessions are again planned for 1951, possibly in conjunction with the meetings of the Japanese Economic Association and Japanese Statistical Association.

A preliminary meeting of persons interested in econometrics took place in India in December for purposes of planning meetings of the Society in that country. Present plans call for a joint session with the International Statistical Institute in New Delhi, December 10, 1951, and a meeting in Patna, India, within the period December 24-30, 1951, in conjunction with the meeting of the Indian Economic Association.

The representation of South American countries in the Econometric Society increased markedly during the period of this report, and consideration is being given to inaugurating annual meetings in South America.

The Econometric Society continued its affiliation with the International Statistical Institute during the year. The Council of the Society also approved entering into an informal cooperative relationship with the newly organized International Economic Association. The Society was represented by observers at the first meeting of that organization in Monaco in September, 1950, at which a round-table on the problem of long-term international economic balance was also held. It will also be represented at a forthcoming round-table conference on the teaching of economics. The Society is on the consultative register of the Economic and Social Council of the United Nations, and is undertaking steps to complete a consultative relationship to UNESCO. In response to an invitation from the National Research Council the Society has become associated with that organization through nomination of a representative to its division of mathematics.

During 1950, Volume 18 of *Econometrica* was published, consisting of four quarterly issues totaling 464 pages. Effective with the April, 1951, issue a book review editor was appointed, and the number of associate editors was increased to assist in arranging for the refereeing of materials submitted for publication.

Other activities of the Society during the year included amendment of the constitution to provide henceforth for ex-officio Council membership for one year for the retiring president, revision of the rules for the election of fellows of the Society, cooperation with the intersociety study committee on the mathematical training mentioned above, establishment of a project for the collation of definitions of econometrics and preparation of encyclopedia and dictionary entries, and the formulation of a proposed international survey of facilities related to the quantitative approach to economics.

The active mailing list of the Econometric Society as of September 30, 1951, the end of the current fiscal year for the Society, will include approximately 1,554 members and 881

nonmember subscribers, chiefly libraries. About 800 of the membership joined the Society since June, 1949, a fact which is indicative of the rapid growth which the Society has recently experienced. About one half of the members and subscribers are in the United States and the remainder are in 72 other countries.

## APPENDIX I

### STAFF PUBLICATIONS AND ADDRESSES

JULY 1, 1950-JUNE 30, 1951

STEPHEN G. ALLEN

"Minimax Solutions for Two-Valued Decision Problems when the Size of Sample is Fixed," presented June 16, 1951, before the Institute of Mathematical Statistics.

T. W. ANDERSON

"The Asymptotic Distribution of Certain Characteristic Roots and Vectors," presented August 3, 1950, at the Second Berkeley Symposium on Mathematical Statistics and Probability, University of California, Berkeley, California.

"Multivariate Analysis," A Half Century of Progress address, presented December 27, 1950, before the American Statistical Association, Econometric Society, and Institute of Mathematical Statistics, Chicago, Illinois.

Discussion of Problems of Incorrect and Incomplete Specification, presented December 29, 1950, before the Econometric Society and Institute of Mathematical Statistics, Chicago, Illinois.

"Asymptotic Theory of Certain 'Goodness of Fit' Criteria Based on Stochastic Processes" (with D. A. Darling), presented December 29, 1950, before the Institute of Mathematical Statistics, Chicago, Illinois. (Abstract in *Annals of Mathematical Statistics*, Vol. 22, March, 1951, p. 143.)

"The Asymptotic Properties of Estimates of the Parameters of a Single Equation in a Complete System of Stochastic Equations" (with Herman Rubin), *Annals of Mathematical Statistics*, Vol. 21, December, 1950, pp. 570-582. (Included in Cowles Commission Papers, New Series, No. 36.)

"Errors and Shocks in Economic Relationships" (with Leonid Hurwicz), *Proceedings of the International Statistical Conferences*, held in Washington, D.C., September 6-18, 1947, Vol. 5, 1950. (Reprinted in Supplement to *Econometrica*, Vol. 17, July, 1949, pp. 23-25.)

"Theory of Multivariate Statistical Analysis" and "Time Series Analysis," Course Lectures, Winter, 1950-51, Columbia University.

"Correlation Theory and Elementary Multivariate Analysis" and "Seminar in Advanced Mathematical Statistics," Course Lectures, Spring, 1951, Columbia University.

"Classification by Multivariate Analysis," *Psychometrika*, Vol. 16, March, 1951, pp. 31-50.

"Probability Models for Analyzing Time Changes in Attitudes" (mimeographed), Columbia University and The RAND Corporation Project.

For contribution to *Statistical Inference in Dynamic Economic Models*, Cowles Commission Monograph 10, see Appendix IV.

KENNETH J. ARROW

Review of "A Correction to 'Note on a Problem of Ragnar Frisch'" by C. Radhakrishna Rao, *Mathematical Reviews*, Vol. 11, April, 1950, p. 259 (not included in previous report).

"An Extension of the Basic Theorems of Classical Welfare Economics," presented August 4, 1950, at a joint session of the Econometric Society and the Second Berkeley Symposium on Mathematical Statistics and Probability, Berkeley, California. (Abstract in *Econometrica*, Vol. 19, January, 1951, p. 53.)

"A Difficulty in the Concept of Social Welfare," *Journal of Political Economy*, Vol. 58, August, 1950, pp. 328-346.

"Optimal Inventory Policy" [with T. Harris and J. Marschak (hctographed)], *George Washington University Logistics Papers*, Issue No. 4, Appendix I to Quarterly Progress Report No. 5, 16 November, 1950-15 February, 1951 (to be published in *Econometrica*).

"Alternative Approaches to the Theory of Choice in Risk-Taking Situations," presented December 21, 1950, at a Cowles Commission Seminar, and December 27, before the American Economic Association, American Statistical Association, Econometric Society, and Institute of Mathematical Statistics, Chicago, Illinois (to be published in *Econometrica*).

Review of *Income, Savings, and the Theory of Consumer Behavior* by James S. Duesenberry, *American Economic Review*, Vol. 40, December, 1950, pp. 906-911.

Review of "The Bargaining Problem" by John F. Nash, Jr., *Mathematical Reviews*, Vol. 12, January, 1951, p. 40.

"Admissible Points of Convex Sets" (with D. Blackwell), presented February 13, 1951, at a joint Stanford University and University of California Statistics Seminar, Berkeley, California.

Course Lectures on Statistical Analysis, Elementary Statistical Analysis, Time Series Analysis, Theory of Games, and Special Topics in Dynamic Economics, 1950-51, Stanford University.

*Social Choice and Individual Values*, Cowles Commission Monograph 12 (see Appendix IV).

For contribution to *Activity Analysis of Production and Allocation*, Cowles Commission Monograph 13, see Appendix IV.

CARL CHRIST

Discussion of "Productivity in the Airframe Industry," presented December 27, 1950, before the Econometric Society, Chicago, Illinois.

Course Lectures on Elementary Statistics, Economic Statistics, Elements of Economics, and Econometrics, 1950-51, Johns Hopkins University.

#### HAROLD T. DAVIS

Review of "Formulas for Complex Cartesian Interpolation of Higher Degree" by Herbert E. Salzer, *Mathematical Tables and Other Aids to Computation*, Vol. 4, July, 1950, pp. 147-148.

"Pareto: His Significance to Modern Economics," presented December 27, 1950, before the American Economic Association and the Econometric Society, Chicago, Illinois.

"Some Implications of the Curve of Income Distribution," presented January 11, 1951, at a Cowles Commission Seminar.

*Quantitative Aspects of the Action of Carcinogenic Substances* (mimeographed), 1951, vii + 147 pp.

*The Theory of Nonlinear Operators* (mimeographed), 120 pp.

#### GERARD DEBREU

"The Coefficient of Resource Utilization," presented August 31, 1950, at the Harvard meeting of the Econometric Society, Cambridge, Massachusetts (to be published in *Econometrica*).

Discussion of "A Mathematical Model Illustrating Some Problems in the Theory of Investment Decisions" by David Durand, presented December 27, 1950, before the Econometric Society, Chicago, Illinois.

"Effect of Technological Change on Production Potential," presented April 7, 1951, at the Conference on Quantitative Description of Technological Change, Princeton University.

"The Efficiency of an Economic System," presented May 3, 1951, at a Cowles Commission Seminar.

"Socialist Economics," presented May 8, 1951, before the Political Economy Club, University of Chicago.

"Efficiency Prices as Guides for Decentralized Decisions," presented June 15, 1951, at the Symposium on Linear Inequalities and Programming, Washington, D.C.

#### NATHAN J. DIVINSKY

Course Lectures on Elementary Mathematics, Statistics, Theory of Equations, Solid Analytic Geometry, and Modern Algebra, Ripon College, Wisconsin.

#### KIRK FOX

Course Lectures on Introductory and Intermediate Statistics, Spring, 1951, Northwestern University School of Commerce.

#### JOHN GURLAND

"Testing Linear Hypotheses," Course Lectures, Winter, 1951, University of Chicago.

"Theory of Statistical Estimation," Course Lectures, Spring, 1951, University of Chicago.



"On Asymptotically Normal Efficient Estimators: I" (with E. W. Barankin), *University of California Publications in Statistics*, Vol. 1, No. 6, Berkeley and Los Angeles: University of California Press, 1951, pp. 89-130.

#### TRYGVE HAAVELMO

Lectures on Econometric Methods at the Universities of Lund and Stockholm, Sweden, October 30-November 3, 1950.

"Theories on Productive Efforts" (mimeographed lecture notes, in Norwegian), Oslo, 1950.

"The Notion of Price Homogeneity," in a special volume in honor of Professor Jørgen Pedersen, Aarhus: Aarhus University Printing Office, 1951.

"Statistical Theory" (mimeographed lecture notes, in Norwegian), Oslo, 1951.

Course Lectures in Econometric Methods, Statistics, and Economic Theory, 1950-51, University of Oslo.

For contribution to *Statistical Inference in Dynamic Economic Models*, Cowles Commission Monograph 10, see Appendix IV.

#### CLIFFORD HILDRETH

"'Possibilities' and Statistical Analysis," presented July 13, 1950, at the Economic Efficiency Seminar, Social Science Research Council Project in Agricultural Economics, University of Chicago.

"A Model of Farm Production," presented August 9, 1950, at the above seminar.

Discussion of "Economic Theory, Statistics, and Economic Policy," presented December 27, 1950, before the American Economic Association, American Statistical Association, and Econometric Society, Chicago, Illinois.

"Introduction to Econometrics," Course Lectures, Winter, 1951, University of Chicago.

"Derivation of Social Welfare Functions from Individual Utility Functions," presented May 10, 1951, at a Cowles Commission Seminar.

For contribution to *Activity Analysis of Production and Allocation*, Cowles Commission Monograph 13, see Appendix IV.

#### WILLIAM C. HOOD

Abstract of discussion of "Analysis of the Multi-Part Economy," *Econometrica*, Vol. 18, July, 1950, pp. 287-288.

"The Treatment of Certain Economic Research Problems Mathematically and Statistically," presented January 31 and February 7, 1951, at the Seminar in Applied Mathematics and Physics, Department of Applied Mathematics, University of Toronto.

Course Lectures in Mathematical Economics, 1950-51, University of Toronto.

Course Lectures in Statistical Analysis, 1950-51, University of Toronto.  
Discussion at Seminar on Theory of Games, Department of Mathematics, University of Toronto.

LEONID HURWICZ

"A Theory of Stabilizing Business Fluctuations" (abstract), *Econometrica*, Vol. 18, July, 1950, pp. 278-279.

"Theory of Economic Organization," presented August 5, 1950, before the Econometric Society, Berkeley, California. (Abstract in *Econometrica*, Vol. 19, January, 1951, p. 54.)

"Some Specification Problems and Applications to Econometric Models," presented December 29, 1950, before the Econometric Society and Institute of Mathematical Statistics, Chicago, Illinois.

"Errors and Shocks in Economic Relationships" (with T. W. Anderson), *Proceedings of the International Statistical Conferences*, held in Washington, D.C., September 6-18, 1947, Vol. 5, 1950. (Reprinted in Supplement to *Econometrica*, Vol. 17, July, 1949, pp. 23-25.)

"Mathematics of Welfare Economics: An Introduction," presented March 1, 1951, at a Cowles Commission Seminar.

"Optimization Rules in a Decentralized Economy," presented March 29, 1951, at a Cowles Commission Seminar.

"Decentralized Optimization," presented April 9, 1951, at a joint seminar on Econometrics and Theory of Games, Princeton University.

"Statistical Treatment of Time Series," presented April 17, 1951, before the University of Illinois Chapter of the American Statistical Association.

"Generalized Minimax-Bayes Solutions," presented May 22, 1951, at the Mathematical Statistics Seminar, University of Illinois.

"Discussion of paper by Wassily Leontief on Structural Change, presented April 7, 1951, at the Conference on Quantitative Description of Technological Change, Princeton, University.

"Gradient Methods in Lagrangian Problems and their Game-Theoretic Interpretation," presented June 15, 1951, at the Symposium on Linear Inequalities and Programming, Washington, D.C.

"Uncertainty in Organization Theory," presented June 19, 1951, at the Carnegie Institute of Technology.

For contributions to *Statistical Inference in Dynamic Economic Models*, Cowles Commission Monograph 10, see Appendix IV.

LAWRENCE R. KLEIN

"Stock and Flow Analysis in Economics" and "Further Comment," *Econometrica*, Vol. 18, July, 1950, pp. 236-241, 246.

"The Integration of Cross-Section and Time-Series Data" (abstract), *Econometrica*, Vol. 18, July, 1950, pp. 280-281.

"The Dynamics of Price Flexibility: A Comment," *American Economic Review*, Vol. 40, September, 1950, pp. 605-609.

"Sample Surveys of Households: A New Tool in Econometrics," pre-

sented December 29, 1950, before the American Economic Association, Econometric Society, and Institute of Mathematical Statistics, Chicago, Illinois.

"Estimating Patterns of Consumer Behavior from Sample Surveys," presented March 14, 1951, before the Detroit Chapter of the American Statistical Association.

*Economic Fluctuations in the United States, 1921-1941*, Cowles Commission Monograph 11 (see Appendix IV).

#### TJALLING C. KOOPMANS

"Efficiency Aspects of Dispersal of Population and Industry," presented July 7, 1950, at the Logistics Conference of The RAND Corporation, Santa Monica, California.

"Recent Developments in the Theory of Production," presented September 6, 1950, before the Econometric Society, Varese, Italy.

"Maximization and Substitution in Linear Models of Production," presented September 28, 1950, at a Conference on Input-Output Analysis, Driebergen, The Netherlands.

"Convex Cones and the Economic Theory of Production," presented November 25, 1950, before the Mathematical Society, Amsterdam, The Netherlands.

Lectures, under various titles, on the Theory of Production and Allocation, presented October 5, 1950, at the Seminar on Production Theory, University Economic Institute, Oslo; October 14, at the Economics Seminar, University of Uppsala, Sweden; October 31-November 23, for the Department of Economics, University of Amsterdam; November 25, before the Mathematical Society, Amsterdam; December 7, at a Seminar of the Department of Applied Economics, Cambridge University; December 15, at the Institute of Applied Economics, Paris.

Lectures on the Theory of Transportation, presented October 16, 1950, at the Economics Seminar, University of Stockholm; October 19, at the Economics Seminar, University of Copenhagen; November 20, at the Mathematical Seminar, Technological Institute, Delft, The Netherlands; November 29, at the Economics Seminar, London School of Economics; December 19, at the Economics Seminar, Ecole des Mines, Paris.

Lectures dealing with Problems of Specification, Identification, and Estimation in Statistical Model Construction in Econometrics, presented October 11, 1950, before the Statistical Institute, University of Uppsala; October 18, at the Institute of Statistics, University of Stockholm; October 20, at the Statistical Seminar, University of Copenhagen; October 27-November 21, at the Netherlands Economic University, Rotterdam; November 11, for the Netherlands Statistical Association and the Mathematical Center, Amsterdam; November 28, at the Seminar on Econometrics, London School of Economics; December 22, at the Institut Henri Poincaré, Paris.

Lectures on the Dynamic Theory of Consumers' Choice, presented December 4, 1950, at the Economics Seminar, Oxford University; December 21, at the Economics Seminar, Ecole des Ponts et Chaussées, Paris.

"Optimum Utilization of the Transportation System," *Proceedings of the International Statistical Conferences*, held in Washington, D.C., September 6-18, 1947, Vol. 5, 1950. (Reprinted in Supplement to *Econometrica*, Vol. 17, July, 1949, pp. 136-146; to be reprinted as Cowles Commission Paper, New Series, No. 34.)

"Generalizations of Leontief's Input-Output Model," presented March 15, 1951, at a Cowles Commission Seminar.

"Allocation of Resources in Production," Course Lectures, Winter, 1951, University of Chicago.

"Statistical Problems of Model Construction," Course Lectures, Spring, 1951, University of Chicago.

Discussion of "Efficiency Prices as Guides for Decentralized Decisions" by Gerard Debreu, presented June 15, 1951, at the Symposium on Linear Inequalities and Programming, Washington, D.C.

For contributions to *Statistical Inference in Dynamic Economic Models*, Cowles Commission Monograph 10 (Tjalling C. Koopmans, ed.), see Appendix IV.

For contributions to *Activity Analysis of Production and Allocation*, Cowles Commission Monograph 13 (Tjalling C. Koopmans, ed.), see Appendix IV.

#### HARRY MARKOWITZ

"Theories of Uncertainty and Financial Behavior," presented December 27, 1950, before the Econometric Society, Chicago, Illinois.

#### JACOB MARSCHAK

"Review of 'Revisione della teoria matematica dell'interesse' by Luigi Amoroso, *Mathematical Reviews*, Vol. 11, July-August, 1950, p. 531.

"Why 'Should' Statisticians and Businessmen Maximize Moral Expectation?" presented August 4, 1950, at a joint session of the Econometric Society and the Second Berkeley Symposium on Mathematical Statistics and Probability, Berkeley, California. (Abstract in *Econometrica*, Vol. 19, January, 1951, pp. 52-53.)

"Demand for Cash and for Inventories under Certainty," presented August 7, 1950, before the Department of Economics, Stanford University.

"The Rationale of the Demand for Money and of 'Money Illusion,'" *Metroeconomica*, Vol. 2, August, 1950, pp. 71-100. (Abstract in *Econometrica*, Vol. 18, July, 1950, pp. 272-274.)

"Rational Inventories: A Study in Uncertainty," presented November 20, 1950, before the Political Economy Club, University of Chicago.

"Recent Discussions on Utility and Probability, and the Late Frank Ramsey," presented November 30, 1950, at a Cowles Commission Seminar.

"Optimal Inventory Policy" [with Kenneth J. Arrow and T. Harris

(hctographed)], *George Washington University Logistics Papers*, Issue No. 4, Appendix I to Quarterly Progress Report No. 5, 16 November, 1950-15 February, 1951 (to be published in *Econometrica*).

"Probability in the Social Sciences," three lectures presented December 6, 7, 8, 1950, before the Department of Sociology, Columbia University.

Discussion of "Progress in the Analysis of Demand," presented December 29, 1950, before the American Economic Association, American Statistical Association, and Econometric Society, Chicago, Illinois.

Course Lectures on Income, Employment, and the Price Level, Autumn, 1950, University of Chicago.

"Models for Inventory Policy, Static and Dynamic," presented January 3, 1951, at the Office of Naval Research Conference on Logistics, George Washington University, Washington, D.C.

Seminar on Economics of Uncertainty, Winter, 1951, University of Chicago.

For contribution to *Statistical Inference in Dynamic Economic Models*, Cowles Commission Monograph 10, see Appendix IV.

*Economic Aspects of Atomic Power* (with Sam H. Schurr *et al.*), Princeton: Princeton University Press, 1950, 289 pp. (For Table of Contents see Appendix IV.)

*Income, Employment, and the Price Level*, Notes on lectures given at the University of Chicago, Autumn, 1948 and 1949, New York: Augustus M. Kelley, 1951, 95 pp.

#### FRANCO MODIGLIANI

Discussion of Analysis of Choices Involving Risk, presented December 27, 1950, before the American Economic Association, American Statistical Association, Econometric Society, and Institute of Mathematical Statistics, Chicago, Illinois.

"Use of Sample Surveys of Business Expectations," presented December 29, 1950, before the American Economic Association, Econometric Society, and Institute of Mathematical Statistics, Chicago, Illinois.

"An Introduction to the Method of Mathematical Economics," Course Lectures, Autumn, 1950, University of Illinois.

#### HERBERT A. SIMON

Discussion of Theory of Automata, presented September 5, 1950, at the Harvard meeting of the Econometric Society, Cambridge, Massachusetts. (Abstract in *Econometrica*, Vol. 19, January, 1951, p. 72.)

"Modern Organizational Theories," *Advanced Management*, Vol. 15, October, 1950, pp. 2-4.

"The Use of Theoretical Models in Political Science," presented December 28, 1950, before the American Political Science Association, Washington D.C.

"The Analysis of Promotional Opportunities," *Personnel*, Vol. 27, January, 1951, pp. 282-285.

"The Ingredients of Organization Theory," presented March 1, 1951, before the Sloan Fellows, Massachusetts Institute of Technology.

"Alternatives to Economic Man," presented March 2, 1951, at the Economics Seminar, Massachusetts Institute of Technology.

"Formal Aspects of Organization as Related to Communication," presented April 10, 1951, at the Seminar on Communication Theory, Columbia University.

Chapters XIII and XIV in *Economic Aspects of Atomic Power*. (See Appendix IV.)

For contribution to *Activity Analysis of Production and Allocation*, Cowles Commission Monograph 13, see Appendix IV.

#### MORTON SLATER

"Mathematical Methods in the Study of Efficiency in Production Models," presented September 4, 1950, at the Harvard meeting of the Econometric Society, Cambridge, Massachusetts. (Abstract in *Econometrica*, Vol. 19, January, 1951, pp. 68-69.)

"Some Generalizations of a Real Variable Lemma due to Cesari," presented January 17, 1951, at the Analysis Seminar, Department of Mathematics, University of Chicago.

"A Note on Motzkin's Transposition Theorem," *Econometrica*, Vol. 19, April, 1951, pp. 185-187.

"Optimization under Constraints: A Central Economic Problem and the Mathematical Tools for Its Solution," presented April 12, 1951, at a Cowles Commission Seminar.

#### ERLING SVERDRUP

"Prediction Problems and the Theory of Statistical Decision Functions," presented September 1, 1950, at the Harvard meeting of the Econometric Society, Cambridge, Massachusetts. (Abstract in *Econometrica*, Vol. 19, January, 1951, p. 61.)

"Probability Theory and Mathematical Statistics" and "Life Insurance Mathematics," Course Lectures, January 15-June 15, 1951, University of Oslo, Norway.

"Recent Ideas in Mathematical Statistics," presented in April, 1951, before the Norwegian Society of Actuaries.

## APPENDIX II

### LIST OF COURSES AT THE UNIVERSITY OF CHICAGO IN ECONOMETRICS, MATHEMATICAL ECONOMICS, ECONOMIC THEORY, AND STATISTICS

**USE OF ELEMENTARY MATHEMATICS IN ECONOMICS.** Discussion of students' solutions of problems pertaining to the dimensionality of economic magnitudes; to the presentation of economic theories as systems of quantitative relations; to the use of the maximization principle; to the aggregation over individuals and over commodities; to the formulation of dynamic theories; to the use of random variables in economics; and to the comparison of policy results.

**PROBLEMS IN MATHEMATICAL ECONOMICS.** Elements of set theory and of advanced calculus and algebra, applied to fundamental economic problems. The material is arranged in the order of increasing mathematical difficulty.

**NATIONAL INCOME AND RELATED AGGREGATES.** Survey of the sources and methods involved in estimating the economic structure. National income, capital formation, balance of payments, and the components of the input-output analysis. Formulation of national economic programs. Aggregates are related to the data and methods of both business and government accounting. Attention is given to students' practical work.

**PRICE THEORY.** A systematic study of the pricing of final products and factors of production under essentially stationary conditions. Covers both perfect competition and such imperfectly competitive conditions as monopolistic competition, oligopoly, and monopoly.

**WELFARE ECONOMICS.** Description of conditions defining production and utility "possibilities." Implications of these conditions for appraising economic policies affecting resource allocation, income distribution, and the level of employment. Special applications are made in the appraisal of imperfect competition, various government fiscal policies, and alternative economic systems.

**ALLOCATION OF RESOURCES IN PRODUCTION.** Criteria for optimal resource allocation. Prices are introduced as marginal rates of substitution under efficient allocation of resources. The use of prices as guides to allocative decisions. Applications to a variety of production and pricing problems, including those of the transportation industry, and problems of industrial location.

**CHOICE AND POSSIBILITIES IN ECONOMIC ORGANIZATION** (with particular application to agriculture). Economic development. Economic fluctuations.

lying the probability distribution of observed variables. Problems of identification of structural characteristics in a given model, of estimation of identifiable parameters, of estimation bias arising from incorrectly specified models, and of testing the specifications that define a model. Examples are drawn from econometrics, factor analysis, latent attribute analysis, and from the study of errors of observation.

**TIME SERIES.** Stochastic difference equations, trends, moving averages, tests for randomness, correlograms, periodograms.

**SAMPLE SURVEYS.** Theory of sampling from finite populations and especially its application to human populations.

**MATHEMATICAL STATISTICS.** An introduction, including discussions of point estimation, set estimation, and the testing of hypotheses.

**MARKOV PROCESSES.** Three types of Markov process: discrete in space and time; discrete in space and continuous in time; continuous in both space and time. Use of certain of these processes as models in, e.g., genetics, evolution, diffusion, and communication.

**ANALYSIS OF VARIANCE AND REGRESSION.** Algebra and geometry of vector spaces systematically applied to theory and application of subjects known variously as linear hypotheses, regression, analysis of variance, and least squares.

**ESTIMATION AND TESTS OF HYPOTHESES.** General methods, especially the theories of Neyman, Pearson, and Fisher.

**SEQUENTIAL ANALYSIS.** The sequential probability ratio test and its operating characteristics and average sample number functions; application to standard distributions; double dichotomies; sequential estimation; special problems.

**STATISTICAL THEORY OF DECISION-MAKING.** Critical review of modern statistical viewpoints, emphasizing general ideas as opposed to techniques. Interpretations of probability; the probabilistic utility theory; critique of Bayes' theorem; methods proposed for avoiding Bayes' theorem, especially Wald's theory of minimum risk and the Neyman-Pearson theory; randomization; sufficient statistics and likelihood ratios; de Finetti's theory of personal probability.

**THEORY OF MINIMUM RISK.** Where practical, illustrations are drawn from standard statistical tests and estimates, but the treatment is for the most part on an abstract level. Existence theorems; general techniques of solution; simple dichotomies; asymptotic point estimation; symmetrical problems; sequential decisions.

**MULTIVARIATE ANALYSIS.** The multivariate normal distribution. Related distributions such as the Wishart distribution and its noncentral analogue, and the distribution of the roots of determinantal equations. Hotelling's



**THE THEORY OF INCOME, EMPLOYMENT, AND PRICE LEVEL.** Government policies and other factors determining the employment of resources, the national income and its use, and the levels of prices, wage rates, and interest rates. These problems are linked with the behavior of individual firms and households.

**ECONOMICS OF UNCERTAINTY.** Probabilistic vs. deterministic social science, normative and descriptive. Optimal strategies under complete and incomplete information. Applications to private and public policy; choice of assets (liquidity, inventories, diversification); versatility.

**MONETARY ASPECTS OF INTERNATIONAL TRADE.** Foreign payments and receipts. Classical and modern theories of adjustment of the balance of payments. Theories of exchange rates. Capital movements in the balance of payments. Postwar monetary plans.

**ECONOMIC ASPECTS OF INTERNATIONAL RELATIONS.** Price theory and international trade; the gains from international specialization. International trade and the distribution of income. Historical and theoretical discussion of the theory of tariffs. Commercial policies of particular countries, including the United States, the United Kingdom, and France. Commodity agreements and cartels. The growth of state trading. The new mercantilism.

**SEMINAR ON MODERN DEVELOPMENTS IN ECONOMIC THEORY.** Discussion of selected topics from recent literature.

**SEMINAR IN MONETARY DYNAMICS.** The dynamic adjustment of the economy as a whole, with special emphasis on the role of the monetary and banking system. Student discussion of theoretical issues and empirical studies in this general field.

**SCOPE AND METHOD OF THE SOCIAL SCIENCES.** The first of this sequence of three courses is an introduction to statistical methods as used in the social sciences.

**STATISTICAL INFERENCE** (sequence of three courses). The first two courses survey the principles of statistical inference. Among the subjects treated are: elements of probability; concepts of population, sample, and sampling distribution; choice of estimates in the light of their sampling properties; testing hypotheses with reference to specific alternatives; principles of sampling and sample design; analysis of proportions, means, and standard deviations; simple, partial, and multiple regression and correlation. In the third course of the sequence students may carry out a statistical investigation; published statistical studies may be analyzed in detail; or some special field of application may be studied.

**INTRODUCTION TO ECONOMETRICS.** Some properties of vectors, matrices, systems of linear equations. Analysis of simple economic models.

**STATISTICAL PROBLEMS OF MODEL CONSTRUCTION.** Discussion of problems arising when inference processes are directed to a postulated structure under-

## APPENDIX III

### COWLES COMMISSION PAPERS, 1943-1951

#### NEW SERIES

No. 1. OSCAR LANGE, "The Theory of the Multiplier," *Econometrica*, Vol. 11, July-October, 1943, pp. 227-245.

No. 2. GEORGE KATONA, "The Role of the Frame of Reference in War and Post-War Economy," *American Journal of Sociology*, Vol. 49, January, 1944, pp. 340-347.

No. 3. LEONID HURWICZ, "Stochastic Models of Economic Fluctuations," *Econometrica*, Vol. 12, April, 1944, pp. 114-124.

No. 4. TRYGVE HAAVELMO, "The Probability Approach in Econometrics," *Econometrica*, Vol. 12, Supplement, July, 1944, viii + 118 pp.

No. 5. JACOB MARSCHAK AND WILLIAM H. ANDREWS, JR., "Random Simultaneous Equations and the Theory of Production," *Econometrica*, Vol. 12, July-October, 1944, pp. 143-205.

\*No. 6. ALFRED COWLES, "Stock Market Forecasting," *Econometrica*, Vol. 12, July-October, 1944, pp. 206-214.

No. 7. GEORGE KATONA AND DICKSON H. LEAVENS, "Price Increases and Uptrading," *Journal of Business*, Vol. 17, October, 1944, pp. 231-243.

No. 8. OSCAR LANGE, "The Stability of Economic Equilibrium," Appendix from Cowles Commission Monograph 8, *Price Flexibility and Employment*, pp. 91-109.

No. 9. JACOB MARSCHAK, "A Cross Section of Business Cycle Discussion," *American Economic Review*, Vol. 35, June, 1945, pp. 368-381.

No. 10. HERMAN RUBIN, "On the Distribution of the Serial Correlation Coefficient," *Annals of Mathematical Statistics*, Vol. 16, June, 1945, pp. 211-215.

No. 11. TJALLING C. KOOPMANS, "Statistical Estimation of Simultaneous Economic Relations," *Journal of the American Statistical Association*, Vol. 40, December, 1945, pp. 448-466.

No. 12. TRYGVE HAAVELMO, "Multiplier Effects of a Balanced Budget," *Econometrica*, Vol. 13, October, 1945, pp. 311-318.

No. 13. LEONID HURWICZ AND JACOB MARSCHAK, "Games and Economic Behavior, Two Review Articles," *American Economic Review*, Vol. 35, December, 1945, pp. 909-925, and *Journal of Political Economy*, Vol. 54, April, 1946, pp. 97-115.

\* Single copies available on request. (Of the papers not marked with an asterisk, those which are reprinted from *Econometrica* may be obtained by purchasing the back issues in which they appear from the Econometric Society, University of Chicago, Chicago 37, Illinois. Price \$2.50 per issue.)

canonical correlations. Associated tests and estimation functions and the problem of classification.

**THE DESIGN OF EXPERIMENTS.** Design of experiments with special reference to the analysis of variance. Interaction and its exploitation in design, and the analysis of covariance. Numerical methods, analysis in the case of missing observations, and the effects of departure from the underlying assumptions of the analysis of variance are touched upon.

**STATISTICS SEMINAR.** Reports by staff members, students, and visitors.

No. 14. LAWRENCE R. KLEIN, "Macroeconomics and the Theory of Rational Behavior," *Econometrica*, Vol. 14, April, 1946, pp. 93-108.

No. 15. G. HABERLER, R. M. GOODWIN, EVERETT E. HAGEN, AND TRYGVE HAAVELMO, "Multiplier Effects of a Balanced Budget, Notes Supplementary to Cowles Commission Paper, New Series, No. 12," *Econometrica*, Vol. 14, April, 1946, pp. 148-158.

No. 16. LEONID HURWICZ, "Theory of the Firm and of Investment," *Econometrica*, Vol. 14, April, 1946, pp. 109-136.

No. 17. JACOB MARSCHAK, LEONID HURWICZ, TJALLING C. KOOPMANS, AND ROY BERGH LEIPNIK, "Estimating Relations from Nonexperimental Observations" (abstracts of papers presented at Cleveland, January 25, 1946), *Econometrica*, Vol. 14, April, 1946, pp. 165-172.

No. 18. LAWRENCE R. KLEIN, "A Post-Mortem on Transition Predictions of National Product," *Journal of Political Economy*, Vol. 54, August, 1946, pp. 289-308.

No. 19. KENNETH MAY, SHOU SHAN PU, AND LAWRENCE R. KLEIN, "The Problem of Aggregation," *Econometrica*, Vol. 14, October, 1946, pp. 285-312; Vol. 15, January, 1947, pp. 51-63.

\* No. 20. NANCY BRUNER AND DICKSON H. LEAVENS, "Notes on the Doolittle Solution," *Econometrica*, Vol. 15, January, 1947, pp. 43-50.

No. 21. R. B. LEIPNIK AND T. W. ANDERSON, "Three Papers on Serial-Correlation Coefficients and Oscillatory Time Series," *Annals of Mathematical Statistics*, Vol. 18, March, 1947, pp. 80-87; *Journal of the American Statistical Association*, Vol. 42, March, 1947, pp. 187-188; *Econometrica*, Vol. 15, July, 1947, pp. 105-122.

No. 22. TRYGVE HAAVELMO, "Methods of Measuring the Marginal Propensity to Consume," *Journal of the American Statistical Association*, Vol. 42, March, 1947, pp. 105-122.

No. 23. LAWRENCE R. KLEIN, "The Use of Econometric Models as a Guide to Economic Policy," *Econometrica*, Vol. 15, April, 1947, pp. 111-151.

No. 24. M. A. GIRSHICK AND TRYGVE HAAVELMO, "Statistical Analysis of the Demand for Food: Examples of Simultaneous Estimation of Structural Equations," *Econometrica*, Vol. 15, April, 1947, pp. 79-110.

No. 25. Two Review Articles: TJALLING C. KOOPMANS, "Measurement without Theory," and JACOB MARSCHAK, "On Mathematics for Economists," *Review of Economic Statistics*, Vol. 29, August, 1947, pp. 161-172; November, 1947, pp. 279-273.

No. 26. Three Papers on Econometrics of Consumption: LAWRENCE R. KLEIN AND HERMAN RUBIN, "A Constant-Utility Index of the Cost of Living," *Review of Economic Studies*, Vol. 15, 1948, pp. 84-87; PAUL A. SAMUELSON, "Some Implications of Linearity," *Review of Economic Studies*, Vol. 15, 1948, pp. 88-90; TRYGVE HAAVELMO, "Family Expenditures and the Marginal Propensity to Consume," *Econometrica*, Vol. 15, October, 1947, pp. 335-341.

No. 27. Two Papers on Econometric Models: TRYGVE HAAVELMO, "Quantitative Research in Agricultural Economics: The Interdependence between

Agriculture and the National Economy," and GERSHON COOPER, "The Role of Econometric Models in Economic Research," *Journal of Farm Economics*, Vol. 29, November, 1947, pp. 910-924; Vol. 30, February, 1948, pp. 101-116.

No. 28. DON PATINKIN, "Relative Prices, Say's Law, and the Demand for Money" and "The Indeterminacy of Absolute Prices in Classical Economic Theory," *Econometrica*, Vol. 16, April, 1948, pp. 135-154; Vol. 17, January, 1949, pp. 1-27.

\*No. 29. RUTLEDGE VINING AND TJALLING C. KOOPMANS, "Methodological Issues in Quantitative Economics," "A Reply," and "A Rejoinder," *Review of Economics and Statistics*, Vol. 31, May, 1949, pp. 77-94.

No. 30. T. W. ANDERSON, "On the Theory of Testing Serial Correlation," *Skandinavisk Aktuarietidskrift*, Vol. 31, 1948, pp. 88-115.

\*No. 31. TJALLING C. KOOPMANS, "Identification Problems in Economic Model Construction," *Econometrica*, Vol. 17, April, 1949, pp. 125-144.

No. 32. JACOB MARSCHAK, "Statistical Inference from Nonexperimental Observations: Economic Example," *Proceedings of the International Statistical Conferences*, Vol. 3.

No. 33. EVSEY DOMAR, "Capital Accumulation and the End of Prosperity," *Proceedings of the International Statistical Conferences*, Vol. 5 (reprinted as a Supplement to *Econometrica*, Vol. 17, July, 1949).

No. 34. TJALLING C. KOOPMANS, "Optimum Utilization of the Transportation System," *Proceedings of the International Statistical Conferences*, Vol. 5 (reprinted as a Supplement to *Econometrica*, Vol. 17, July, 1949).

\*No. 35. Approaches to Business Cycle Analysis: ROBERT A. GORDON, "Business Cycles in the Interwar Periods: The Quantitative-Historical Approach"; TJALLING C. KOOPMANS, "The Econometric Approach to Business Fluctuations"; and discussion by J. W. ANGELL, A. F. BURNS, AND G. HABERLER, *Proceedings Supplement of the American Economic Review*, Vol. 39, May, 1949, pp. 47-88.

\*No. 36. T. W. ANDERSON AND HERMAN RUBIN, "Estimation of the Parameters of a Single Equation in a Complete System of Stochastic Equations" and "The Asymptotic Properties of Estimates of the Parameters of a Single Equation in a Complete System of Stochastic Equations," *Annals of Mathematical Statistics*, Vol. 20, March, 1949, pp. 46-63; Vol. 21, December, 1950, pp. 570-582.

No. 37. JACOB MARSCHAK, "Role of Liquidity under Complete and Incomplete Information," *Proceedings Supplement of the American Economic Review*, Vol. 39, May, 1949, pp. 182-195.

\*No. 38. Two Papers on Involuntary Economic Decisions: TRYGVE HAAVELMO, "The Notion of Involuntary Economic Decisions," *Econometrica*, Vol. 18, January, 1950, pp. 1-8; DON PATINKIN, "Involuntary Unemploy-

\* Single copies available on request. (Of the papers not marked with an asterisk, those which are reprinted from *Econometrica* may be obtained by purchasing the back issues in which they appear from the Econometric Society, University of Chicago, Chicago 37, Illinois. Price \$2.50 per issue.)

ment and the Keynesian Supply Function," *Economic Journal*, Vol. 59, September, 1949, pp. 360-383.

\*No. 39. Three Papers on Identification Problems: OLAV REIERSØL, "On the Identifiability of Parameters in Thurstone's Multiple Factor Analysis," *Psychometrika*, Vol. 15, June, 1950, pp. 121-149; OLAV REIERSØL AND TJALLING C. KOOPMANS, "The Identification of Structural Characteristics," *Annals of Mathematical Statistics*, Vol. 21, June, 1950, pp. 165-181; OLAV REIERSØL, "The Identifiability of Linear Relations between Variables Which Are Subject to Error," *Econometrica*, Vol. 18, October, 1950, pp. 375-389.

\*No. 40. K. J. ARROW, D. BLACKWELL, AND M. A. GIRSHICK, "Bayes and Minimax Solutions of Sequential Decision Problems," *Econometrica*, Vol. 17, July-October, 1949, pp. 213-244.

\*No. 41. ARNOLD C. HARBERGER, "Currency Depreciation, Income, and the Balance of Trade," *Journal of Political Economy*, Vol. 58, February, 1950, pp. 47-60.

\*No. 42. R. L. ANDERSON AND T. W. ANDERSON, "Distribution of the Circular Serial Correlation Coefficient for Residuals from a Fitted Fourier Series," *Annals of Mathematical Statistics*, Vol. 21, March, 1950, pp. 59-81.

\*No. 43. Papers on the Theory of Choice: JACOB MARSCHAK, "Rational Behavior, Uncertain Prospects, and Measurable Utility," and abstracts of papers presented at Boulder by TJALLING C. KOOPMANS AND JACOB MARSCHAK, *Econometrica*, Vol. 18, April, 1950, pp. 111-141; pp. 174-175.

#### SPECIAL PAPERS

\*No. 1. JOHN R. MENKE, "Nuclear Fission as a Source of Power," *Econometrica*, Vol. 15, October, 1947, pp. 314-333.

\*No. 2. JACOB MARSCHAK, SAM H. SCHURR, AND PHILIP SPORN, "The Economic Aspects of Atomic Power," *Bulletin of the Atomic Scientists*, Vol. 2, Nos. 5 and 6, September, 1946, pp. 1-4; *Proceedings Supplement of American Economic Review* Vol. 37, No. 2, May, 1947, pp. 98-117.

## APPENDIX IV

### COWLES COMMISSION MONOGRAPHS, 1934-1951\*

No. 1. *Dynamic Economics*, by CHARLES F. ROOS. 1934. Bloomington, Ind.: Principia Press. 275 pages. (Out of print.)

No. 2. *NRA Economic Planning*, by CHARLES F. ROOS. 1937. Bloomington, Ind.: Principia Press. 596 pages. (Out of print.)

No. 3. *Common-Stock Indexes*, by ALFRED COWLES AND ASSOCIATES. Second Edition, 1939. 499 pages. Price \$6.00. New monthly indexes of stock prices, stock prices adjusted for reinvestment of cash dividends, and yield expectations; and annual indexes of yields, dividend payments, earnings-price ratios, and earnings; for 69 industry groups, 1871-1938.

No. 4. *Silver Money*, by DICKSON H. LEAVENS. 1939. Bloomington, Ind.: Principia Press. 439 pages. Price \$4.00. A sketch of the history of the monetary use of silver, followed by more detailed consideration of recent developments.

No. 5. *The Variate Difference Method*, by GERHARD TINTNER. 1940. Bloomington, Ind.: Principia Press. 175 pages. Price \$2.50. The history and use of this method for the analysis of time series, with new devices of treatment and extensive tables to aid calculations.

No. 6. *The Analysis of Economic Time Series*, by HAROLD T. DAVIS. 1941. Bloomington, Ind.: Principia Press. 620 pages. Price \$5.00. The historical development of the subject is reviewed, methods are described, and applications made to economic phenomena.

No. 7. *General-Equilibrium Theory in International Trade*, by JACOB L. MOSAK. 1944. Bloomington, Ind.: Principia Press. 187 pages. Price \$2.50. The modern theory of economic equilibrium (as stated by J. R. Hicks and others) applied to an important field.

\* Orders for Monographs 3-9 (1 and 2 are out of print) should be sent to The Principia Press, Bloomington, Indiana. Orders for subsequent monographs should be sent to John Wiley and Sons, 440 Fourth Avenue, New York. Orders for *Economic Aspects of Atomic Power* should be sent to Princeton University Press, Princeton, New Jersey.

No. 8. *Price Flexibility and Employment*, by OSCAR LANGE. 1944. Bloomington, Ind.: Principia Press. 114 pages. Price \$2.00. A clarification of important concepts that have had much currency in the practical discussion of depressions and wars but remained too vague to allow of useful treatment.

No. 9. *Price Control and Business*, by GEORGE KATONA. 1945. Bloomington, Ind.: Principia Press. 246 pages. Price \$3.00. A study of the working of price control based on field studies among producers and distributors of consumers' goods in the Chicago area, 1942-1944.

No. 10. *Statistical Inference in Dynamic Economic Models*, edited by T. JALLING C. KOOPMANS, with Introduction by JACOB MARSCHAK. 1950. New York: John Wiley and Sons. 438 pages. Price \$6.00. Original contributions from many authors concerning statistical problems encountered in economic model construction. *Contents:*

I. Statistical Inference in Economics: An Introduction, *J. Marschak*.

PART ONE. SIMULTANEOUS EQUATION SYSTEMS: II. Measuring the Equation Systems of Dynamic Economics, *T. C. Koopmans, H. Rubin, and R. B. Leipnik*.

*Problems of Identification:* III. Note on the Identification of Economic Relations, *A. Wald*; IV. Generalization of the Concept of Identification, *L. Hurwicz*; V. Remarks on Frisch's Confluence Analysis and Its Use in Econometrics, *T. Haavelmo*.

*Problems of Structural and Predictive Estimation:* VI. Prediction and Least Squares, *L. Hurwicz*; VII. The Equivalence of Maximum-Likelihood and Least-Squares Estimates of the Regression Coefficients, *T. C. Koopmans*; VIII. Remarks on the Estimation of Unknown Parameters in Incomplete Systems of Equations, *A. Wald*; IX. Estimation of the Parameters of a Single Equation by the Limited-Information Maximum-Likelihood Method, *T. W. Anderson, Jr.*

*Problems of Computation:* X. Some Computational Devices, *H. Hotelling*.

PART TWO. PROBLEMS SPECIFIC TO TIME SERIES: *Trend and Seasonality:* XI. Variable Parameters in Stochastic Processes: Trend and Seasonality, *L. Hurwicz*; XII. Nonparametric Tests against Trend, *H. B. Mann*; XIII. Tests of Significance in Time-Series Analysis, *R. L. Anderson*.

*Estimation Problems:* XIV. Consistency of Maximum-Likelihood Estimates in the Explosive Case, *H. Rubin*; XV. Least-Squares Bias in Time Series, *L. Hurwicz*.

*Continuous Stochastic Processes:* XVI. Models Involving a Continuous Time Variable, *T. C. Koopmans*.

PART THREE. SPECIFICATION OF HYPOTHESES: XVII. When Is an Equation System Complete for Statistical Purposes? *T. C. Koopmans*; XVIII. Systems with Nonadditive Disturbances, *L. Hurwicz*; XIX. Note on Random Coefficients, *H. Rubin*. (Principles of Notation, References, Index.)

No. 11. *Economic Fluctuations in the United States, 1921-1941*, by LAWRENCE R. KLEIN. 1950. New York: John Wiley and Sons. 174 pages.



Price \$4.00. The methodology of econometric model construction is applied to business cycle analysis with possible implications for prediction and policy making. *Contents:*

I. Model Building—General Principles; II. Economic Theory; III. Statistical Model; IV. Adequacy of the Available Data. (Appendix, Index.)

No. 12. *Social Choice and Individual Values*, by KENNETH J. ARROW. 1951. New York: John Wiley and Sons. 99 pages. Price \$2.50. Methods of symbolic logic are applied to the question whether a social valuation of alternatives can be consistently derived from given, partly conflicting, individual valuations. *Contents:*

I. Introduction; II. The Nature of Preference and Choice; III. The Social Welfare Function; IV. The Compensation Principle; V. The General Possibility Theorem for Social Welfare Functions; VI. The Individualistic Assumptions; VII. Similarity as the Basis of Social Welfare Judgments.

No. 13. *Activity Analysis of Production and Allocation*, edited by Tjalling C. KOOPMANS. 1951. New York: John Wiley and Sons. 404 pages. Price \$4.50. Contributions from economists and mathematicians on the theory and techniques of efficient allocation of resources and programming of activities. *Contents:*

Introduction, *Tjalling C. Koopmans*.

PART ONE. THEORY OF PROGRAMMING AND ALLOCATION: I. The Programming of Interdependent Activities: General Discussion, *Marshall K. Wood and George B. Dantzig*; II. The Programming of Interdependent Activities: Mathematical Model, *George B. Dantzig*; III. Analysis of Production as an Efficient Combination of Activities, *Tjalling C. Koopmans*; IV. The Aggregate Linear Production Function and Its Applications to von Neumann's Economic Model, *Nicholas Georgescu-Roegen*; V. Relaxation Phenomena in Linear Dynamic Models, *Nicholas Georgescu-Roegen*; VI. Uses of Leontief's Open Input-Output Models, *Harlan M. Smith*; VII. Abstract of a Theorem Concerning Substitutability in Open Leontief Models, *Paul A. Samuelson*; VIII. Alternative Proof of the Substitution Theorem for Leontief Models in the Case of Three Industries, *Tjalling C. Koopmans*; IX. Alternative Proof of the Substitution Theorem for Leontief Models in the General Case, *Kenneth J. Arrow*; X. Some Properties of a Generalized Leontief Model, *Nicholas Georgescu-Roegen*.

PART TWO. APPLICATIONS OF ALLOCATION MODELS: XI. On the Choice of a Crop Rotation Plan, *Clifford Hildreth and Stanley Reiter*; XII. Development of Dynamic Models for Program Planning, *Marshall K. Wood and Murray A. Geisler*; XIII. Representation in a Linear Model of Nonlinear Growth Curves in the Aircraft Industry, *Marshall K. Wood*; XIV. A Model of Transportation, *Tjalling C. Koopmans and Stanley Reiter*; XV. Effects of Technological Change in a Linear Model, *Herbert A. Simon*; Comments by *Ansley Coale and Yale Brozen*; XVI. The Accuracy of Economic Observations, *Oskar Morgenstern*.

PART THREE. MATHEMATICAL PROPERTIES OF CONVEX SETS: XVII. Convex Polyhedral Cones and Linear Inequalities, *David Gale*; XVIII. Theory of Convex Polyhedral Cones, *Murray Gerstenhaber*; XIX. Linear Programming

and the Theory of Games, *David Gale, Harold W. Kuhn, and Albert W. Tucker*; XX. A Proof of the Equivalence of the Programming Problem and the Game Problem, *George B. Dantzig*.

PART FOUR. PROBLEMS OF COMPUTATION: XXI. Maximization of a Linear Function of Variables Subject to Linear Inequalities, *George B. Dantzig*; XXII. Application of the Simplex Method to a Game Theory Problem, *Robert Dorfman*; XXIII. Application of the Simplex Method to a Transportation Problem, *George B. Dantzig*; XXIV. Iterative Solution of Games by Fictitious Play, *George W. Brown*; XXV. Computational Suggestions for Maximizing a Linear Function Subject to Linear Inequalities, *George W. Brown and Tjalling C. Koopmans*. (References, Index of Names, Subject Index.)

No. 14. *Econometric Methods*, by COWLES COMMISSION RESEARCH STAFF, edited by WM. C. HOOD AND T. C. KOOPMANS. Forthcoming. Presents and extends methods developed in Monograph 10 in an expository style addressed primarily to the user of methodology. (For the tentative table of contents, see page 29.)

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*Economic Aspects of Atomic Power*, An Exploratory Study under the direction of SAM H. SCHURR AND JACOB MARSCHAK. Princeton: Princeton University Press. 1950. 289 pages. Price \$6.00. An analysis of the potential applicability of atomic power in selected industries and its economic effects in both industrialized and underdeveloped areas. *Contents*:

Preface.

PART ONE. ECONOMIC COMPARISONS OF ATOMIC AND CONVENTIONAL POWER: I. Economic Characteristics of Atomic Power; II. The Cost of Electricity from Conventional Energy Sources.

PART TWO. ATOMIC POWER IN SELECTED INDUSTRIES: III. The Industry Analyses: A Summary View; IV. Aluminum; V. Chlorine and Caustic Soda; VI. Phosphate Fertilizers; VII. Cement; VIII. Brick; IX. Flat Glass; X. Iron and Steel; XI. Railroad Transportation; XII. Residential Heating.

PART THREE. ATOMIC POWER AND ECONOMIC DEVELOPMENT: XIII. The Effects of Atomic Power on National or Regional Economies; XIV. Atomic Power and the Industrialization of Backward Areas. (Tables, Maps, Graphs, References, Index.)