

COWLES FOUNDATION  
COWLES COMMISSION

*Research Report*  
1954–1956



*Yale University: 30 Hillhouse Avenue, New Haven  
Offices of the Cowles Foundation and the Econometric Society*

REPORT *of*  
RESEARCH ACTIVITIES

*July 1, 1954—June 30, 1956*

COWLES FOUNDATION  
FOR RESEARCH IN ECONOMICS  
AT YALE UNIVERSITY

COWLES COMMISSION  
FOR RESEARCH IN ECONOMICS

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FOR RESEARCH IN ECONOMICS AT YALE UNIVERSITY

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## PURPOSE

**T**HE COWLES FOUNDATION FOR RESEARCH IN ECONOMICS AT YALE UNIVERSITY, *established as an activity of the Department of Economics in 1955, has as its purpose the conduct and encouragement of research in economics, finance, commerce, industry, and technology, including problems of the organization of these activities. The Cowles Foundation seeks to foster the development of logical, mathematical, and statistical methods of analysis for application in economics and related social sciences. The professional research staff are faculty members with appointments and teaching responsibilities in the Department of Economics and other departments.*

The COWLES COMMISSION FOR RESEARCH IN ECONOMICS *is a not-for-profit corporation, founded in Colorado in 1932 and, since 1939, chartered under the laws of the state of Illinois. The Commission moved from Colorado Springs to Chicago in 1939 and was affiliated in academic matters with the University of Chicago until 1955. Since July 1, 1955 the Commission has sought to accomplish its objectives through the activities of the Cowles Foundation at Yale. At that time, the members of the research staff of the Commission accepted appointments at Yale and, along with other members of the Yale Department of Economics, formed the staff of the newly established Foundation.*

*The Econometric Society, an international society for the advancement of economic theory in its relation to statistics and mathematics, is an independent organization which has been closely associated with the Cowles Commission since its inception. The headquarters of the Society were moved from Chicago to Yale in 1955.*

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## NOTE ON REFERENCES TO PUBLICATIONS

The following abbreviations are used throughout this report in referring to publications of the Cowles Commission and Cowles Foundation:

CCNS: Cowles Commission New Series Papers (see p. 48)

CFP: Cowles Foundation Papers (see p. 48)

CCDP: Cowles Commission Discussion Papers (see p. 57)

CFDP: Cowles Foundation Discussion Papers (see p. 57)

*Monographs* (see p. 45) are referred to by number, and *Special Publications* (see p. 46) by title.

The *other publications* of each staff member are designated by letter in the list on pp. 60–62, and are referred to by author and letter in the text.



## INTRODUCTION

THE progress of economics as a science depends on three related kinds of research: (1) the accumulation of observations—frequently, but by no means always, numerical data—of economic processes and institutions; (2) the development of analytical tools to facilitate both the formulation and the testing of possible generalizations; (3) the application of the tools and the observations to the task of enlarging the body of established generalizations about economic affairs. Although scarcely any research worker can fail to be concerned with all three of these activities, each must decide for himself what emphasis will enable him to make the greatest contribution to the general progress of economic science. In economics, as in economic life itself, productivity requires a certain degree of specialization and division of labor.

The development of tools is a natural emphasis for a small community of university teachers and scholars, like the group now organized as the Cowles Foundation for Research in Economics at Yale University. The Cowles Commission made contributions of all three types during its twenty-three years of research at Colorado Springs and Chicago. But, especially in the last decade, its greatest and most characteristic contributions were in the development and refinement of tools of analysis, both theoretical concepts and models and statistical methods for deriving inferences from economic observations. The profession at large—in governments and businesses as well as in universities and research institutions—has been hungry for such tools, and there has been no lack of problems and data to which to apply them. In helping to satisfy this hunger, the Cowles Commission had an impact far out of proportion to the size of its staff or its budget. Neither large scale data collection nor comprehensive substantive research is a feasible focus of effort of a university faculty research group. These important activities are better left to large non-academic research institutions, governmental and private.

Tools for an empirical science cannot, however, be built in a vacuum. Methods of theoretical analysis and techniques of statistical inference

must be relevant to the substantive problems of the science. Their utility must be proved not just for ideally conceivable observations of economic institutions and behavior but for observations that are within the limited capacities of known instruments of data collection. Specific substantive investigations have time and again revealed the need for new methods which, once developed, had a quite general range of applicability. As the social sciences progress in methods of making and processing observations, our data become less exclusively the by-products of government and business administration and more frequently the integral parts of a research design. Thus the building of tools of analysis may be intimately connected with the design and testing of new methods of collecting data, e.g., in experimental situations or sample surveys. For these reasons, the Cowles Foundation seeks to maintain a balanced research program, in which tools of wide applicability are developed in response to the needs of substantive research in economics and are tested on accessible empirical observations. Experience both in theoretical economics and in statistical induction has shown the power of mathematical methods in empirical science. Experience has also shown the considerable aesthetic appeal and challenge offered by mathematical economics and statistics as subjects pursued for their own sake. The power of these methods must not be wasted on irrelevant problems but harnessed in the service of the substantive problems of the empirical science of economics.

There is another kind of balance that must be maintained in the work of an organization dedicated, like the Cowles Foundation, to fundamental research. It is the balance between description and prescription, between the general quest for predictable regularities in economic affairs, and advice to specific economic agents on the decisions and policies that best serve their interests. The evolution of modern economics from nineteenth-century "political economy" reminds us that the historic purpose of economics is ultimately prescription—helping peoples and their governments better to satisfy their own economic and social aspirations. But this ultimate prescriptive goal is a diffuse one, taking many forms and ranging from the specific detail of administrative regulations to national determination of the whole structure of society. Consequently it is best served by a descriptive science that provides an understanding of the regularities of economic life, applicable to a wide variety of specific purposes, useful in

situations that have not yet arisen as well as in the familiar contexts of the past. The quest for this kind of a science of economics must not be relaxed. Ultimately economics will be judged more by how well it describes the way people *do* behave than by how much it tells people the way they *should* behave. In recent years economics has tended towards a greater prescriptive emphasis, as the potentialities of the tools of economic analysis and statistical method for improvement of business practice have come to be appreciated. To a great extent, this emphasis also serves the more fundamental goal of economic science. If it is to continue to do so, we must not concern ourselves with specific applications for their own sake. And we must not be content merely to provide rules for optimization; as economists, we have also the duty to examine the consequences of the recommended behavior for the workings of the economy as a whole in response to changing circumstances.

The research reported in these pages has been made possible by a variety of sources of financial support. The nucleus of support for the organization comes from Alfred Cowles (Yale 1913) and other members of the Cowles family, and from the university, the University of Chicago until 1955, Yale University thereafter. Much of the research on the theory of organization, decision-making under uncertainty, economic equilibrium, and management economics (Sections 1-3 below) has been conducted under contracts with the Office of Naval Research. The Merrill Foundation has aided the preparation of a book on techniques of portfolio selection (Section 4 below). A grant from the Ford Foundation has financed the Yale Workshop in Quantitative Economic Research (Section 5 below) which is not part of the Cowles Foundation but overlaps it in personnel, location, and interests. To all of these donors we express our gratitude and our hope that the results of our research will justify their confidence in us.

JAMES TOBIN  
*Director, Cowles Foundation*



# RESEARCH ACTIVITIES

*July 1, 1954—June 30, 1956*

## 1. *Theories of Organization and Decision-Making under Uncertainty*

### *Theory of teams*

A TEAM is a group of individuals with a common purpose. The organization of a team presents two important and related problems for social science. One is the maintenance of loyalty to the common organizational purpose; the members of the team must be motivated to suppress conflicting individual goals. A great deal of theoretical and empirical research has been done on this aspect of organization, particularly in application to employer-employee relations. A leading center of such research is the Yale Labor-Management Center under the leadership of E. Wight Bakke. The second problem, which is the focus of work by Marschak and Radner at the Cowles Foundation, is the optimal degree and kind of decentralization of decision in a team.

Assuming that there are no divergences of interest among the members, it is of the essence of an organization that there are differences in the information available to the different members and in the actions that they can take. A team must seek its goal by reacting to changes in its environment; each member of the team observes a part, and necessarily only a part, of the relevant environment. Further, each member of the team has a different opportunity for action in response to the environment. If each member could estimate all those opportunities and dangers presented by the environment that will influence the effect of his actions on the success of the team, and if this success were merely the sum of individual successes by team members, decisions could be left to the individual members, and communication among them would be unnecessary. But in the more typical situation, the optimal response of a member to the part of the environment that he observes depends both on what is happening in the rest of the

environment and on his partners' responses to those occurrences. The success of the team is not a simple sum of individual successes. The observations and actions of one team member are relevant to the actions of another. These interactions call for communication and centralization. But communication and centralization are not costless, and a balance must be struck between the costs of communication and centralization and the costs of possible inconsistencies and irrationalities if decisions are left decentralized and based on incomplete information.

How to strike this balance depends partly on the caliber of the incomplete information each decision-maker must substitute for exact knowledge of the whole environment and of his teammates' actions. He may count on certain regularities and constancies in the world, but he may not count on them fully. He substitutes for exact information, therefore, some notion of the probabilities of various occurrences. His optimal decision will depend both on estimates of the variability of the environment and on estimates of the consequences for the team of discrepancies between the actual state of the environment and the state assumed in taking actions.

Marschak and Radner have formalized and treated mathematically the problem of balancing decentralization and communication in a team. Many of their results have appeared in papers [CCNS 94-96, CFP 100, CCDP 386, CFDP 5].\* A monograph on *Economic Theory of Teams* is under preparation. The outline of topics is given below. A simple example taken from business economics and applied throughout the book will illustrate the concepts and results.

## ECONOMIC THEORY OF TEAMS (Outline of Topics)

1. The Single Person Decision Problem
  - Decision under certainty
  - Probabilistic uncertainty and expected utility
  - Non-probabilistic uncertainty
  - Information and strategy
2. The Team Decision Problem
  - Components of action variable

\*For the manner in which reference is made to publications in this report, see Note, p. viii.

Interaction (complementarity) in payoff function

Components of information structure

Components of decision function

Interaction in cost of information

### 3. Best Decision Functions

Optimality

“Each member shall equate the conditional expected marginal payoff to zero.”

The case of special information structures; independent information, sharing independent information

### 4. Best Information Structures

Non-sequential: examples of production and speculation

Sequential: example of the arbitrage firm

Interaction between components of the information structure

Optimal delay

### 5. The Case of Unknown Probability Distributions

Sufficient statistics for team members

The Markoff problem (minimax decisions for quadratic payoff functions)

### 6. Directions for Further Work

#### *Experimental estimation of disutility of effort*

Economists have long been interested in the strength of the incentive effects of greater rewards as a stimulus to effort and the possible disincentive effects of wealth on willingness to work hard. One aspect of the relationship of effort to reward and to wealth has been studied experimentally. John W. Atkinson, a University of Michigan psychologist, Marschak, and Radner have designed an experiment, carried out in June 1956 with the assistance of Judd Mill, a Stanford University psychologist. Each of 21 subjects was given a transparent vessel with 100 marbles, of which a certain number are black, the winning color. The proportion of black marbles can be raised by the subject through work, at a certain “wage-rate”: one black marble (replacing a white one) for each unit of work. The subject is given a fixed amount of time to work (such that a certainty of winning can never be reached) and he can work fast or slowly, as he likes. He gains a fixed prize if, at the end, he draws a black marble out of the vessel. Under one hypothesis, the subject maximizes the difference

between the expected utility of gain—the value of the prize to him weighted by his probability of winning it—and the disutility of effort. Therefore the subject would choose to spend an amount of effort such that the advantage of earning an additional black marble and thus raising by 1% his probability of winning is just offset by the disutility of additional effort. This hypothesis can be described as a “special economic hypothesis” since under a more general hypothesis of economic theory the individual tries to maximize the expected (i.e., average) value, not of a simple “balance of pleasure and pain,” but of some more complicated function of reward and effort that would allow for an interaction, a “complementarity” between them. The results obtained in the experiment just described indicated that the “special economic hypothesis” should not be rejected. As expected under this hypothesis, the initial proportion of black marbles showed no statistically significant effect on the amount of effort that the individual chose to spend. This contrasted with the expectations of some psychologists that the initial probability of success would strongly influence the amount of effort. In experiments begun after the period covered in this report, further implications of the hypotheses are being tested by experiments in which the “wage-rate” and the prize are subject to variations. So far, the results indicate a small departure from the “balance of pleasure and pain” principle but not from the general economic hypothesis.

### *Homo stochasticus*

In traditional economic theory each man is supposed to have rigidly consistent “tastes.” He acts as if all possible alternative occurrences—the results of his choice and action—were ranked in his mind as to which occurrence is better than which. This ranking is assumed to remain unchanged over a reasonable period of time. Hence the choices that are made by the “economic man” of the theory would be exactly predictable if his rankings were known. The assumption of rigid consistency is too restrictive. We are nearer to reality if we merely assume that a person will be more likely than not to choose one thing over a given alternative. Such a person is not rigidly consistent. But he is “stochastically consistent”: the word stochastic simply means “pertaining to probabilities.” This hypothesis can be made somewhat more restrictive by assuming that the probability of



choosing one thing over a specific alternative remains constant over a reasonably long period. Applying the hypothesis to a whole group of such "stochastic men" would yield, as in all econometric work, predictions that are not exact but refer to the probabilities of certain events: for example, that total expenditure on cars and total saving will lie within certain ranges with a probability .9.

The next step is to ask whether it is or is not true for a given person that, if he is more likely to choose A than to choose B, and B than C, he is also more likely to choose A rather than C. If this is true, a "utility rank" can be assigned to each of his options. A utility ranking in this probabilistic sense is more plausible than the classical economic concept of a rigid preference scale.

If individuals give consistent preference rankings to alternatives, in this stochastic sense, is it also possible to give some quantitative measure to the degree of preference? Can the size of the probability of choosing A over B be interpreted as a measure of the numerical difference in utility between A and B? If the differences in utility of a number of pairs of alternatives (A and B, B and C, C and A, A and D, B and D, etc.) are so measured, will these measures be consistent with each other? The problem is analogous to a typical situation in experimental psychology, where the investigator attempts to scale, say, the loudness of sounds. The psychologist asks subjects to judge which of two sounds is louder and he observes the proportions in which different choices are made. Psychologists have had considerable practical success in finding consistent scales for measuring the strength of sensations associated with alternative stimuli. It remains to be seen whether similar scales can be constructed for individual preferences. Presumably the proportion of the population who are consistent in this more restrictive sense is smaller than the proportion who are consistent in their ranking of alternatives. Investigation of the other distinguishing characteristics of this smaller group would not only help to understand human behavior but would also throw a light on the problem of selecting and training decision-makers and leaders.

The necessary experiments and statistical tests are under way, but there are some special difficulties that do not arise in scaling physical sensations. In the case of preferences, the experimenter must rely as little as possible on replicating the same pair of alternatives.

Otherwise the subject may distort his preferences by remembering his past choices and endeavoring to remain "consistent." Fortunately, the testing of some of the hypotheses mentioned does not require repetitions, and the independence of successive trials can be safeguarded. For example, to test whether there is a stochastic ranking for utilities, it is not necessary to let the subject face the same three pairs (A, B), (B, C), (A, C) more than once. Instead, the experimenter presents him with a whole battery of different triples of this kind. A statistical test appropriate for such experiments has been devised, with the computational help of Professor Joseph Carter, Electronic Research Laboratory, Stanford University. Experiments designed by Marschak jointly with Donald Davidson, (Department of Philosophy, Stanford University) were begun at the end of June. The results were summarized in CFDP 22.

## 2. *Theory of Economic Equilibrium*

At least since Adam Smith's *Wealth of Nations* economists have been fascinated with the mechanism of the competitive market economy. Somehow a private enterprise society makes its important economic choices without any over-all guidance, without any conscious coordination of the actions of multitudes of consumers, business men, and workers. The independent decisions of these economic agents interact in markets and determine the amounts produced of various commodities, the manner in which labor, land, and other resources are allocated among alternative uses, the prices of commodities, wages of labor, yields of assets. Economists have been concerned with two aspects of this process: its *determinacy*, and its *efficiency*. It is not obvious that the decentralized decisions of economic agents can be made to mesh into determinate values of economic variables—outputs, inputs, prices—or that, if so, competitive markets can accomplish the task. Three quarters of a century ago the French economist Leon Walras applied mathematical reasoning to the question of determinacy. He endeavored to show that a system of competitive markets can be described by a set of simultaneous equations, in which there are as many equations as unknowns. By formulating more rigorously what previous observers had described intuitively and impressionistically, Walras provided what the great economist Joseph Schumpeter has

called the *magna charta* of economic theory. Similarly, around the turn of the century, Vilfredo Pareto gave systematic expression to the view that the competitive market process reaches not just a determinate solution but an optimal solution—no other way of using productive resources can more *efficiently* satisfy the wants and preferences of individuals.

Debreu has been engaged in a fundamental reformulation of these theories of economic equilibrium. To prove determinacy it is not enough to count equations and unknowns; even if they are equal in number, the system may have no solution. Building on the work of Abraham Wald and John von Neumann, Debreu has shown (in CFP 87, written in collaboration with Kenneth Arrow, and CFDP 10) the assumptions on which a determinate and efficient solution is assured. The objectives of Debreu's reformulation are to give an entirely rigorous treatment to the theory, using modern mathematical tools in closer agreement with economic intuition and freeing the theory from unnecessary assumptions, particularly those imposed by the older mathematical techniques. Debreu also seeks to relax one of the most unrealistic assumptions—that each economic agent knows the relevant future with certainty.

One of the components of Debreu's model of the competitive economy is the set of production possibilities: the combinations of various outputs that are attainable from any given set of inputs of productive resources. The *activity analysis* model of production developed at the Cowles Commission by Koopmans and others (see Monograph 13 or, for a simplified treatment, [Koopmans, A]) implies a special kind of set of production possibilities. Although somewhat restricted in generality, this model of production leads to some interesting specific implications for the theory of equilibrium. These are the subject of a study by McKenzie, who is applying the tool of activity analysis to a number of aspects of economic equilibrium, among them optimal taxation and inter-industrial, interregional, and international specialization in production.

The theory of international specialization and trade has long been one of the most fruitful applications of the theory of economic equilibrium. This is no less true of the new developments in equilibrium theory. McKenzie has used activity analysis to illuminate, and to state with rigor for more than two trading countries, the

time-honored principle of comparative advantage. (Each nation should—and will if free trade is permitted—specialize in producing those commodities in which its superiority over other countries is relatively the greatest, or its inferiority the least.) Beckmann and Thomas Marschak of the RAND Corporation have [CFP 99] applied the same analytical tools to the problem of determining the optimal direction and degree of specialization among diverse economic regions, taking account both of their differences in endowments of productive resources and of the costs of transportation between regions. The principle of comparative advantage also applies to specialization of jobs as between individuals. Beckmann has [CFDP 8] shown how the principle, as stated in the linear programming solution to the assignment of personnel to tasks, applies to the division of labor among members of teams.

Certain results reported in the next section are also relevant to the theory of economic equilibrium: in particular, the contributions to the theory of location there summarized.

### 3. *Management Economics*

The rapid growth of “operations research” and “management science” in recent years has demonstrated that quantitative analytical techniques can fruitfully be applied in business management and in the administration of the economic activities of governments. Concepts and methods developed in economics and statistics have proved useful in management’s quest for optimal policies. Their value has become apparent in a variety of applications: inventory and production planning, location of plants, minimization of transportation costs, personnel assignment, investment decisions. Economic science itself has in turn been considerably enriched, both in its substance and in its tools, by a closer acquaintance with the nature of the actual policy choices that confront private and public decision-makers and of the information on which choices must be based.

Research at the Cowles Commission played an important part in these developments. Fundamental exposition of the related techniques of linear programming and activity analysis was presented in Monograph 13. During the two years under report, members of the staff have continued to contribute to management science.

These contributions are closely related to development of the theory of economic equilibrium (Section 2 above). This relationship arises from the fundamental theorem of activity analysis. Suppose a problem can be cast in the following form: There are a number of activities or processes; each activity produces some things of value, outputs, in proportion to its inputs of certain resources; the resources are limited in quantity, and the problem is to allocate them among the activities. An *optimal* allocation is one in which there is no waste in the sense that it would be possible by reshuffling inputs to obtain more of one kind of output without having less of any other kind. There are many such optimal allocations, and *the* optimal allocation will depend on the values, or weights, attached to the different outputs. Corresponding to any optimum, there is a set of prices of outputs and imputed prices of inputs that measure both the terms on which one output may be "traded" for another and the values of additions to the limited supplies of resources. Moreover, these prices would be reached by competition and would sustain the optimal allocation if the decision process were decentralized by giving each activity one or more managers who expand whenever their process is profitable and abandon operations whenever it shows a loss. This duality between optimal allocations and competitive price systems makes much of the research in management science also relevant to the theory of general equilibrium, and vice versa.

Koopmans and Beckmann have taken up the problem of assigning a number of plants of given types to a set of locations so as to maximize their joint profitability [CFDP 4; revised version to be published in *Econometrica*]. The indivisibility of the plant creates no special complications so long as the profitability of a given plant in a particular location is independent of the locational assignments of the other plants. In that case, the problem is a straightforward application of linear programming. But if there is interaction between locational decisions, arising from the costs of transporting intermediate commodities between plants, explicit computation of the best locational patterns is as yet beyond the capacity of computing equipment and technique. There is a corollary finding of great interest also for the theory of economic equilibrium (Section 2 above). In the absence of interaction, an optimal assignment can be achieved and sustained by market rents established in competition among plant managers and

owners of locations, each seeking the maximum profit or rent. But no such competitive price system can do this job if interaction exists. This finding suggests that the price system may not be an ideal technique for making locational assignments. A locational problem of a conceptually simpler type was investigated by Beckmann and Thomas Marschak in an article already cited [CFP 99]. If a concern has branch plants of given locations and capacities, the optimal allocation of production among the branches can be determined by their differential distances from markets and raw materials. The same allocation would result if each plant were separately managed and competed with the others for sales and materials.

Inventory policy has proved a fertile area for the application of quantitative techniques to business decision problems. The optimal size of inventories depends on a balance between, on the one hand, the costs of holding large stocks—warehousing costs, interest on investment—and, on the other hand, the advantages of ample stocks—avoiding the costs of frequent deliveries or the costs of instability in production. Since there is considerable variety in the situation for which inventory policy must be designed, the optimal balance has been worked out for a number of different models. In studying the inventory problems of a manufacturing firm one of whose plants was in Chicago, Muth noticed two institutional features that previous inventory models had not adequately allowed for. First, repair parts were stocked in two places, both at the plant using them and at the plant producing them. Second, there was a significant lag in delivery of repair parts to the central warehouse. Muth and Beckmann worked out a model allowing for lagged delivery [CFP 102]. Manne has shown how the optimal balance between the holding of inventories of finished product and the costs of instability in rates of output can be treated as a linear programming problem [CFDP 16]. He is also seeking a solution to this production-smoothing problem when allowance is made for the uncertainty of future sales.

Uncertainty about future requirements also complicates a second problem on which Manne is working, the calculation of the optimal degree of excess capacity to be built in a new facility, such as a superhighway or a pipeline. These cases also exemplify the phenomenon of economies of scale—it is cheaper to build one big line than two small ones. The activity analysis model of production does not help





*Computing Room*



here, because it assumes that every process uses inputs and produces outputs in the same proportions, regardless of how small or large the scale. Analysis of inventory and investment programming problems involving these two phenomena,—uncertainty and economies of scale,—separately or in combination, is the major focus of the Cowles Foundation's continuing theoretical and empirical research in management science. One approach to the complication of indivisibilities is given in a forthcoming paper by Manne and Markowitz [Manne and Markowitz, A].

#### 4. *Portfolio Selection*

The problem of portfolio selection confronts every individual or institution with funds to invest: in what assets should investments be made, and in what proportions? The investor must strike some kind of balance between probable income and appreciation, on the one hand, and risks of loss, on the other. The way he strikes this balance between yield and security will depend on his needs, preferences, and responsibilities. The selection of a portfolio which gives the desired balance will depend on his estimates of the most probable yields and the risks of individual securities, and of the correlations among them. The correlations are important in order to avoid "putting all your eggs in one basket"; risk can be reduced by choosing securities which will not always move together. These estimates of risks and correlations are based on the past history of the various securities and on study of the factors that are likely to influence them in the future.

The basic idea of Markowitz's forthcoming monograph *Techniques of Portfolio Selection* is that the process of portfolio selection can be divided into three stages. (1) *Estimation of expected yields (including both income and capital gain or loss) and risks of individual securities, and of correlations between securities.* (2) *Weeding out of inefficient portfolios.* By combining the estimates of stage 1, it is possible to compute the over-all expected yield and risk of any portfolio. An inefficient portfolio is one that gives less expected yield but the same risk (or the same expected yield but more risk), compared to some other combination of securities. The book develops the mathematics for distinguishing inefficient from efficient portfolios, and presents practical computational methods for doing so. These techniques are illus-

trated by numerical examples using estimates based on past history of yields, risks, and correlations of actual securities. (3) *Choice among efficient portfolios*. Efficient portfolios differ in that some promise a low but safe income and others a high but insecure yield. Which of the available combinations is optimal depends on the preferences and responsibilities of the investing individual or institution.

The research of the Cowles Foundation in this field has a double objective: (1) To assist portfolio managers and their advisers to make more explicitly rational selections, consistent with their own judgments of individual securities and preferences between yield and risk. (2) To contribute to understanding the determination of prices and yields in the capital markets, on the assumption that the process of portfolio selection described in the book formalizes what portfolio managers already seek to do. Markowitz's monograph is primarily oriented towards the first objective, prescription. An application of portfolio selection theory aimed at the second objective, description, is Tobin's work on the theory of liquidity preference, where interest rate differentials between monetary assets are explained by investors' choices among efficient portfolios [CFDP 14]. A related application is Houthakker's theory of the pricing of commodity futures (See Section 7).

### 5. *Household Economic Behavior*

In 1954, prior to the establishment of the Cowles Foundation at Yale, the Yale Workshop in Quantitative Economic Research was organized to facilitate empirical econometric research by faculty members and graduate students, focussing on the economic behavior of households. Tobin and Guthrie, the directors of the Workshop, became members of the staff of the Cowles Foundation on July 1, 1955. Although the Workshop is still a separate organization, its activities are naturally closely meshed with those of the Cowles Foundation, both intellectually and administratively. Therefore some of the research of the Workshop can appropriately be reported here.

The Yale Workshop in Quantitative Economic Research has undertaken three major types of projects: (1) a research training seminar, (2) doctoral dissertations, and (3) faculty research.

### *Research training seminars*

In the research training seminar, graduate students work as a group in designing and executing projects in quantitative economic research. The subject of the project undertaken during the first year, 1954-55, was consumer interdependence. The phenomenon of interdependence among consumers has long been recognized by sociologists and economists; Thorstein Veblen made the point dramatically and perceptively a half century ago. But explicit allowance for the phenomenon in the theory of consumer behavior has been a difficult task. Duesenberry, and Brady and Friedman, have sought to allow for interdependence by relating the propensity to save of consumers not to their absolute incomes but to their incomes relative to those of other consumers in their social group.\* Tests of relative-income models have been made only for large aggregates of consumers and have not led to conclusive results; consequently the dynamics of consumer interdependence offers important and challenging research problems.

Formulating hypotheses of consumer interdependence in a manner capable of empirical test proved surprisingly difficult, and for this very reason was exceedingly instructive. The group eventually decided upon a research project designed to investigate interdependence among Yale undergraduates. The objective was to disentangle the effects, on the student's consumption behavior and his satisfaction with his scale of consumption, of his absolute economic status and his economic status relative to his reference and membership groups. The concepts "reference group" and "membership group," borrowed from sociology, were used to define the areas within which interdependence might be expected to operate. These groups were ascertained by asking the student questions about his secondary school, residence college, fraternity affiliation, and extra curricular activities. The commodities investigated were sport coats and automobiles. These were chosen because they are both visible foci of prestige and important items in student budgets.

The students in the seminar designed the project, formulated the questions, pre-tested the questionnaire at Wesleyan University, administered the questionnaire to a sample of 380 Yale undergraduates,

\*James S. Duesenberry, *Income, Saving, and the Theory of Consumer Behavior*, Cambridge: Harvard, 1949. Dorothy S. Brady and Rose D. Friedman, "Savings and the Income Distribution," *Studies in Income and Wealth*, X (New York: National Bureau of Economic Research, 1947), pp. 247-265.

IBM cards, designed the statistical calculations, and executed the processing of the data on IBM machines. Thus the students gained edited the completed schedules, arranged for punching the results on experience with every phase of the research process, beginning with the formulation of concepts and hypotheses based on previous theoretical and empirical results, and ending with the making of calculations to test the original hypotheses and to estimate the hypothesized relationships.

The statistical analyses which have been completed to date do not substantiate the proposition that conformity to norms among groups of students is a powerful and pervading influence on the consumption patterns of Yale undergraduates. However crucial cases—e.g., undergraduates of low economic status whose reference groups were predominantly of high status—were not numerous enough to permit conclusive tests.

#### *Determinants of consumer saving*

During the 1955–56 academic year the seminar shifted its attention to the national population of consumers and to the overall problem of determinants of consumer saving, using data from past Surveys of Consumer Finances conducted by the Survey Research Center of the University of Michigan for the Board of Governors of the Federal Reserve System. The Workshop is grateful to the Survey Research Center and to the Board of Governors for making these data available.

The major line of inquiry followed in the 1955–56 Seminar was to measure the effects on current saving of differences in long-run income anticipations. The subject is related to that of Milton Friedman's forthcoming book *A Theory of the Consumption Function*, but the hypotheses developed by the seminar were somewhat different from Friedman's. The data of the Surveys of Consumer Finances do not contain direct measurements of long-run income anticipations. Consequently the method of analysis is to subdivide 8,000 spending units from four Surveys—pooled for the purpose of this analysis—into 57 socio-economic groups, according to education, occupation, and location. These groups are believed to be fairly homogeneous with respect to income profiles over the life cycle. Dividing the sample into these groups and taking account of age differences is one method of taking account of differences in long-run income anticipations. The

relation of saving to income *within* the groups can then be analyzed and compared to the relationship of saving to income *between* the groups.

This investigation involves multivariate statistical techniques requiring considerable computation, which has been programmed for the IBM Data-Processing Machine, Type 650, at the Watson Laboratory, New York, which has kindly donated some time on this machine. One of the students in the Seminar, Harold Watts, is pursuing this project for his Ph.D. dissertation.

### *Doctoral dissertations*

Ralph Bristol completed a dissertation on *Quality v. Quantity Variation in Consumer Expenditure*. The variation of a given category of expenditure as consumer income varies over a cross-section of households in a survey or budget study can be decomposed into three components: (1) the percentage of people reporting any purchases at all will vary as income changes; (2) the number of articles purchased per buyer will vary with income; (3) the average price paid per item will change. The first and last components of expenditure elasticity are generally overlooked in budget study analyses, and expenditure elasticities are mistakenly identified as quantity elasticities.

The main purpose of Bristol's project was to examine the variation of quality, as measured by price paid per article, and to estimate its importance in variations of expenditure. The data analyzed came from the three United States budget studies of 1918, 1935-36, and 1941. Quality elasticity was found to account for 30-50 per cent of the expenditure elasticity for most categories of clothing. The first component, the elasticity of the percentage of people reporting non-zero expenditures, is much more variable and is often negative for "inferior" commodities. As income increases, price elasticity becomes a larger and larger proportion of expenditure elasticity; both quantity purchased and percentage purchasing become less and less important. High-income groups seem to be quality-adjusters rather than quantity-adjusters. For clothing items, both men's and women's, the rate at which price paid for articles increases with income is proportional to the over-all average price paid for the commodity. In other words, the price or quality elasticity is approximately the same for all clothing categories. This uniformity was also true of food items, although

the price elasticities were generally much lower than for clothing, reflecting the greater homogeneity of commodity categories in the case of food. For household furnishing and equipment, on the other hand, there was much more variability among commodities.

A dissertation on *Working Wives: Determinants and Effects* is under preparation by Richard Rosett. He is analyzing the circumstances and characteristics of households that lead to the entry of the wife into the labor force, and also the effects on saving and spending patterns of the wife's earning of income. Recent Surveys of Consumer Finances have, partly because of the Workshop's interest in these problems, collected and coded useful data on this subject. We are grateful to the Survey Research Center and to the Board of Governors of the Federal Reserve System both for sharpening the Survey income schedule in this direction and for making the data available for analysis. Rosett's project involves the use of high-speed computing equipment. He intends to apply the "limited variable" statistical model suggested by Tobin (see Section 6 below) and he has developed a program for making the necessary iterative calculations on the IBM Type 650 Data Processing Machine. For allowing Rosett machine time, the Workshop is once again indebted to the Watson Laboratory.

The Workshop has also assisted a research project on *Patterns of Estate Distribution*, the dissertation of William McKinstry. The Workshop has made it possible for him to collect and process estate records made available to him by the administration of the Connecticut Successions Tax. Transfers of wealth between generations must surely play an important role in determining the propensity to save. Alfred Marshall found the chief motive for saving to be man's desire to leave "his family to start from a higher round of the social ladder than that on which he began." More recent theories of consumer behavior also point up the importance of the strength of bequest motivation in determining saving behavior. McKinstry's research will attempt to determine the relationship between the size of estates and their distribution among heirs and to examine the effects of the Federal Estate Tax on the pattern of bequests. His data, which may also be of value for other research, consist of 1,053 records; they are distributed among the years 1931, 1938, and 1944 in order to observe the effects of changes in the Federal Estate Tax.

A dissertation studying the *Pattern of Introduction of a New*

*Commodity: the Case of Television*, has been undertaken with the help of the Workshop by Thomas Dernburg. The importance of acceptance of new commodities in maintaining the propensity to consume has long been recognized and has recently been stressed in connection with theories of economic growth. But there have been few empirical studies of the factors determining the response of the consumers to new products. Dernburg's data are from the 1950 Census of Population, which shows for large cities and their suburbs the proportion of dwelling units with television sets in each census tract in 1950. Because television broadcasting began at different times in different cities, it is possible for Dernburg to examine the effects of the length of time of availability of television on ownership of television in 1950. According to his hypotheses, these effects will depend on such other variables as income, age, educational attainment, urban or suburban residence and so on.

#### *Faculty research*

Guthrie has attempted an analysis of the relative strength of the precautionary motive for holding liquid assets among various kinds of consumers. The model used in this analysis contrasts the ratio of liquid assets to income in 1947, for consumers defined by given variables, with the same ratio in 1953 for the same kinds of consumers. 1947 is assumed to be a year in which some people still held balances accumulated by forced saving during World War II, and 1953 is assumed to be a year in which balances of liquid assets were in equilibrium relative to the consumer's choice between liquid assets and other assets or consumption. The process of adjustment from a disequilibrium in 1947 to equilibrium in 1953 may be expected to indicate, approximately, the tenacity with which given kinds of consumers hold liquid assets. This analysis of liquid asset holdings is based primarily on data from the Survey of Consumer Finances.

The Surveys of Consumer Finances are also the principal source of data for another project in which Guthrie is engaged, an investigation of the effects of absolute income and relative income on expenditures for durable goods. The "Duesenberry hypothesis" relating saving to relative income has been submitted to several tests with inconclusive results. This investigation will be a more comprehensive micro-analysis than others reported to date. The design adopted will allow the test-

ing of another aspect of consumer interdependence. It is generally assumed that interdependence works to increase consumption, that a consumer who observes his associates enjoying commodities or services which he lacks seeks to move toward higher consumption levels. Researchers in marketing have recently found scattered evidence that interdependence sometimes works the other way. There has been no econometric research on "keeping down with the Joneses," and Guthrie's model will allow the testing of this hypothesis.

Tobin has continued an analysis of the reinterview portion of the 1953 Survey of Consumer Finances. The reinterview sample consisted of about 1,000 spending units who had also been interviewed in the 1952 Survey. This sample is somewhat unrepresentative of the entire population of spending units, because it omits households who were not in the same dwelling unit both years. But it has a number of important advantages for statistical testing and estimation of behavior relationships: (1) Previous levels of income, assets, and debts, and changes in these quantities, can be estimated without relying so heavily on respondents' memories. (2) Since behavior during 1952 is reported in the 1953 interview, it can be compared with answers to questions in the 1952 interview. Thus the predictive value of information available at the beginning of the year—in particular, expectations, intentions to buy, and attitudes of optimism or pessimism—can be tested.

Tobin's analysis endeavors to exploit both these advantages of the reinterview sample. The household behavior studied is represented by three dependent variables: expenditure on cars and other durable goods during 1952, change in liquid asset holding during 1952, change in personal debt (debt other than business or real estate debt) during 1952. The relationships of these three variables to a common set of independent variables are estimated. These determining variables include income, income change, initial asset holding, initial debt, and age and marital status of head of household. The form of the estimated relationships allows for interactions among these variables as well as additive main effects. The relationships have been estimated by multiple regression, but alternative estimates following the "limited variable" model described in Section 6 below are also being computed. Residuals from the estimated regressions have been computed for all the cases in the sample, and the residuals are the material for further analysis.



By means of analysis of variance of the residuals, possible influences of other variables can be tested. Tests have been computed for a variety of demographic and geographic variables, including education, occupation, region, city size, and number of income-earners in the household. Tests have also been computed for the battery of questions on attitudes, intentions, and expectations. The tentative general impression given by these tests is that intentions to buy have highly significant predictive value, but that other attitudinal data contain little information not already included in the regression variables. These conclusions will be reported in a paper under preparation on the predictive value of attitudinal data.

The residuals are also useful for examining the pattern of correlation among the three dependent variables. Purchases of durable goods and additions to debt are very significantly associated, as might be expected. But it is perhaps surprising to find that neither of these variables has any significant correlation with liquid asset change after the effects of their regressions on a common set of variables have been removed.

Some of the results of these analyses were reported in CFDP 24.

## 6. *Research Tools and Methods*

In the past ten years, new statistical tools for estimating economic relationships have been developed. The Cowles Commission played an important role in these developments (Monographs 10 and 14), and the Cowles Foundation is continuing this concern for the improvement of estimating techniques.

Economic theory endeavors to represent the essential interdependence of many economic phenomena by systems of simultaneous equations. Classical statistical procedures provide methods of estimating from empirical data the parameters of a single equation when all variables but one are predetermined. Largely because of the work of the Cowles Commission, econometricians have come to realize that these procedures cannot be applied directly, one at a time, to each member of a system of equations. When a system of equations,  $k$  in number, simultaneously determine the values of  $k$  variables, these variables must all be regarded as dependent rather than predetermined. Consequently, classical procedures are not applicable to any equation that contains,

in addition to predetermined variables, more than one of the jointly dependent variables.

New procedures have been developed for estimating the parameters of the equations of a simultaneous system. It can be shown that statistical estimators based upon these procedures have desirable properties if they are applied to very large samples. Almost nothing is known, however, about the properties of estimates computed from small samples. Neither is it known at what size of sample large-sample formulae give reasonable approximations of the distributions of the estimates. The properties for small or medium-size samples are far more important than for larger samples in economic applications because the need for simultaneous equation estimation usually arises in connection with time-series data covering a relatively small number of time periods or sample survey data containing a limited number of independent observations. Econometricians have often had to work with as few as twenty annual observations, applying these procedures because no more satisfactory methods were available. The implicit assumption that the large-sample properties applied to such samples cannot be justified in our present state of knowledge.

There are two parallel lines of research that could increase our knowledge of the properties of simultaneous-equations estimators. One is explicit mathematical analysis, to which the Cowles Foundation will return when resources and personnel permit. The other approach, which has been adopted in research begun by Summers, is numerical and experimental. The advent of the high-speed electronic calculator makes it feasible to attack the problem numerically by performing a series of sampling experiments. The sampling experiment approach, known as distribution sampling, is a variation of the so-called Monte Carlo technique. Its use dates back to the beginning of this century when the English statistician Gossett reproduced the "t" distribution using an urn and a set of tags. Large-scale application of the method to complicated problems depended upon the availability of a rapid calculating device and a method of sampling that avoids physical handling of a population.

Summers is investigating the distributions of small-sample estimates given by a number of alternative procedures: single-equation least squares; full information maximum likelihood; full information diagonal covariance matrix maximum likelihood; limited information

maximum likelihood; reduced least squares—Theil's method. His investigation concerns (1) the bias and efficiency of the various estimates, (2) their differences in computation costs, (3) their sensitivity to failure of some of the assumed specifications of the statistical model.

As the attention of empirical research in economics turns increasingly to cross-section data, there will be need for development of new statistical tools appropriate for economic survey statistics. The next ten years may witness a methodological development in this area comparable to the developments of the past decade in the analysis of economic time series. The techniques of multiple regression and analysis of variance, which have been so popular and so useful in much econometric work both on survey data and on time series, are powerful tools and allow for the effects of many variables. However, surveys frequently confront us with variables to which regression and analysis-of-variance models obviously fail to apply.

One such situation arises when the dependent variable under study is dichotomous. For example, a household either buys a car or does not buy a car during the survey year, and the problem is to analyze the factors associated with buying or not buying. Regression analysis and variance analysis cannot properly be applied to a variable of this kind, but applicable statistical techniques have been developed in biometrics. One of these is *probit analysis*, which fits a cumulative normal curve relating the percentage of cases "responding" to the strength of the "stimulus." If this model is to be applied in economics, the stimulus must be multivariate rather than univariate, as is generally assumed in biometric situations. Tobin has pointed out the applicability of multivariate probit analysis to economic survey data, and has illustrated the technique with an example calculated from data of the 1953 Survey of Consumer Finances [CFDP 1]. Probit analysis is, however, not the only model for handling dichotomous dependent variables, and it is interesting to compare its results with the results of applying other models to the same data. Calculations have been made using, in addition to probit analysis: (1) ordinary multiple regression, (2) discriminatory analysis, (3) "logit analysis."

A more frequent problem in economic survey data concerns what may be called a "limited dependent variable." Such a variable is constrained by some lower limit: for example, a household cannot spend less than nothing on durable goods, nor can it repay more debt than it already

owes. In a survey of households a substantial number of cases will be found at the limit. Above the limit the variable may take on a wide range of values, and to treat it as dichotomous would throw away useful information. A hybrid of probit analysis and regression would appear to be appropriate to this situation. Such a model has been worked out and illustrated in CFDP 3. Rosett has programmed the iterative calculations required for estimation under this model for the IBM Type 650 Data-Processing Machine.

During his leave in 1954-55, Koopmans examined the general state of economic science and of the methods available for advancement of economic knowledge. His reflections are set forth in the second and third essays of his forthcoming book [Koopmans, A]. The second essay is a plea for a more explicit regard for logical rigor in economic theory. The "postulational method" it recommends involves clear distinction among three steps in the construction of economic knowledge: (1) the embodiment of observed facts in suitable postulates, (2) the reasoning that derives implications from these postulates, and (3) the verification of these implications by additional observations. The essay further examines the range of applicability of the postulates that have been used most extensively, and explores the postulational requirements of problems that lie beyond their reach, such as those concerned with indivisible resources and those arising from uncertainty about future actions of economic agents.

The third essay considers four important developments in the tools of economic research, and discusses how they have influenced research in progress and how they may help future research ventures. The four tool developments are: (1) the increased use of a growing number of mathematical concepts and theories, (2) the revolutionary increase in the speed and capacity of computing equipment, (3) the increasing use of methods of statistical inference, and (4) the development of the survey method of observation.

### *7. Other Research*

Short-term forecasting of general business conditions is a continuing challenge to econometrics. One approach is to build a statistical model of the economy, estimating a set of simultaneous equations that represent the dependence of the key economic variables on determining variables (e.g., the government budget) that can be estimated in

advance. The pioneering work of Lawrence Klein, begun at the Cowles Commission, has resulted in an invaluable body of experience with this approach to forecasting. Although a model of economic interdependence is an indispensable element in a forecasting scheme, the practical results suggest that it cannot be estimated with enough precision to do the job alone. A second approach to short-term forecasting is the use of explicit expectations and spending plans of business firms and consumers, obtained by periodic sample surveys. The Surveys of Consumer Finances obtain data on the anticipations of households; some analysis of their predictive value is reported in Section 5 above. The Department of Commerce and the McGraw-Hill Publishing Co. have collected plans for investment expenditure from business corporations. These data on anticipations are frequently used as direct and self-sufficient forecasters. But how these data may best be used and how useful they are in prediction—these are matters for inquiry. It seems probable that it will be most useful to employ anticipations data as supplements to a statistical model of economic interdependence, rather than to take them by themselves at face value. This is the conclusion to which the research on consumer anticipations (Section 5 above) points. It is also the conclusion indicated by Robert A. Levine's doctoral dissertation studying the McGraw-Hill business investment expenditure surveys, [CFDP 17] a research project assisted by the Cowles Foundation. The possibilities of integrating these two, and other, approaches to short-term forecasting will be further investigated during the next three years in a project led by Okun, made possible by a grant from the Rockefeller Foundation.

The incomes that people receive in any given year differ for a variety of reasons: differences in inherited wealth; differences in occupation due to talent, training or taste; differences in ability; differences in age; differences in accidental circumstances that vary from year to year. Some of these differences contribute to persistent inequalities of income; others produce temporary inequalities that "wash out" if lifetime rather than annual incomes are considered. The last two kinds of differences listed are of this transient nature. Middle-aged people have generally higher incomes than young and old people, but middle age happens to nearly everyone. In some occupations and lines of business, good years and bad years are to be expected, and they offset each other. Summers, in his thesis for Stanford University,

completed at the Cowles Foundation, investigated the importance of these transient factors as a source of inequality of annual incomes. Using data from Surveys of Consumer Finances, he estimated a model of life-time income generation in which an individual's income any year depends upon his occupation, his age, his previous income, and chance [CFDP 9].

The studies of transportation systems described in the 1952-54 report of the Cowles Commission (pp. 12-15) were published in book form early in 1956.

Hendrik Houthakker's study of commodity futures, also described in the 1952-54 report (pp. 4-7), will shortly be published as a monograph.

COURSES IN MATHEMATICAL ECONOMICS AND  
ECONOMETRICS AND RELATED SUBJECTS OFFERED  
IN THE YALE UNIVERSITY GRADUATE SCHOOL

*Not all of the courses listed are given every year.*

ECON. 107b — Topics in Mathematical Economics. Mr. Summers.

Relatively simple mathematical tools, primarily the calculus, are applied to economic theory. Some mathematics is taught, but only a little and only when particular problems in economic theory require it. One semester of calculus or its equivalent is a prerequisite. Each student is required to work out a set of problems in R. G. D. Allen's *Mathematical Analysis for Economists* and W. Baumol's *Economic Dynamics*.

ECON. 108a — Allocation of Resources in Production. Mr. Koopmans and Mr. Manne.

This course is intended to provide students of economics with an introduction to "activity analysis" and other models for the study of programming and productive efficiency. Particular emphasis is laid upon the welfare economics theorems that are derivable from this approach—theorems concerned with the efficiency of decentralized decision-making. As one way to check the reasonableness of the assumptions from which these theorems are derived, the course also includes a number of concrete applications of linear programming to managerial problems.

No previous knowledge of matrix algebra or of set theory is assumed. The student, however, should have at least some understanding of the concept of a system of simultaneous linear equations, and its solution.

The course has three distinguishable successive parts: (1) expository examples (Koopmans); (2) analysis of relations between productive efficiency and the price system (Koopmans); (3) examples of applications to government and business problems, including some discussion of their computational aspects (Manne).

ECON. 112a — Economic Dynamics. Mr. Koopmans or Mr. Tobin.

The course is concerned with (1) analysis of the behavior of individual economic units where planning for a certain or uncertain future is an essential element of the situation facing the decision-maker, and (2) analysis of the course of the economy as a whole over time.

ECON. 114a — Mathematical Theory of Competitive Equilibrium. Mr. Debreu.

This course formulates and solves traditional problems of producers' and consumers' behavior, of general equilibrium, of Pareto optimum, with

the help of vector spaces and topological concepts (rather than with the usual calculus tools). Certain aspects of uncertainty are also studied.

Although this course requires no knowledge of mathematics or of economics (the instructor makes a complete review of the mathematical concepts he will use), a certain mathematical maturity is necessary and a good acquaintance with economic theory is of great help.

ECON. 115a — Economic Theory of Decision. Mr. Marschak.

Topics covered include: norms and habits of behavior; scaling of utilities and probabilities; the logic of business planning under uncertainty.

ECON. 116b — Economic Theory of Information and Organization. Mr. Marschak.

Topics covered include: amount, value, and cost of information; organizational structure (i.e., rules of communication and action); conditions determining the performance and choice of organizational structure; divergent goals (some results from the theory of games); decentralization in business and in national economy.

ECON. 120a — Economic Statistics I: Introduction. Mr. Bruton.

A survey of elementary principles of statistical theory and methods useful in economics. Topics covered include sources and nature of economic data, probability theory, statistical inference, interval estimation and hypothesis testing, simple and multiple regression, time series analysis.

ECON. 121b — Economic Statistics II: Statistical Inference. Mr. Tobin or Mr. Summers.

Principles of statistical inference: estimation, testing of hypotheses. Multiple regression and analysis of variance. Particular problems of application to economic data.

ECON. 122a — Economic Statistics III: Statistical Methods in Econometrics. Mr. Radner or Mr. Summers.

Statistical techniques primarily designed for application to economic data are the basic subject matter of this course. About half of the semester is spent on simultaneous equation estimation and the rest of the time on econometric techniques applicable to the study of income distributions and the theory of consumer behavior.

ECON. 123b — Survey of Econometric Results. Mr. Koopmans and others.

This seminar examines a number of representative articles and books containing econometric results. Reports are made by the instructors and by the students, followed by discussion. Emphasis is on the contribution to knowledge rather than on the methodology.



ECON. 124 — Survey of Economic Accounting and Statistics. Mr. Guthrie and Mr. West.

The purposes of Economics 124 are to familiarize students with (a) the standard types, sources, and reliability of statistical information; (b) the concepts of economic accounting and the uses of these concepts in developing measures of economic activity; and (c) some statistical methods, with emphasis on the tools currently used in the interpretation of economic data and the analysis of economic policies.

The syllabus of the course includes the following topics: construction and analysis of economic accounts; construction and use of economic indices; techniques of time series analysis; analysis and interpretation of statistical data, including inferences from sample data and analysis of distributions; collection and processing of economic data; methods of presenting data.

ECON. 128 — Workshop in Quantitative Economic Research. Mr. Tobin and Mr. Guthrie.

The Workshop is conducted as a seminar in which the group decides upon a problem to be investigated, formulates hypotheses to be tested, develops a research design, and executes the research. The problem is to fall in the general area of consumer or household behavior and to be amenable to statistical and econometric techniques of investigation. The objective of the Workshop is to teach students by way of experience how to conduct quantitative economic research.

There are no examinations. Students are expected to participate in all phases of the research process, to make oral and written reports from time to time on parts of the research project for which they are responsible, and to participate in writing the final report. Seminar meetings are usually discussions of the progress of the workshop project; occasionally, however, a faculty member or graduate student at the thesis stage is invited to describe to the group his own research project when it is of substantive or methodological interest.

INTERDEPARTMENTAL SEMINAR — Mathematical Applications in the Social Sciences. Messrs. Abelson (Psychology), Anderson (Sociology), and Beckmann (Economics).

The seminar has the dual purpose of training students in the use of mathematics in the social sciences and of establishing communication on this topic among social scientists and between them and mathematicians. It operates mainly by the presentation of relevant papers by social scientists or by mathematicians working on social science problems. The speakers include both local faculty and students, and visitors to Yale.

MATH. 29 — Mathematics for Students of the Social Sciences. Mr. Begle.

This course covers the basic concepts of those parts of mathematics, excluding calculus, which are currently of interest in the social sciences.

More specifically, the topics studied include the following, in the order listed: basic concepts of logic and set theory; relations, including order relations; axiomatic systems; probability; and matrices and determinants. Examples and problems are drawn from the social sciences.

MATH. 42 — Statistics. Mr. Radner.

Frequency distributions, computation of statistical parameters, normal curve, least squares, curve fitting, testing of goodness of fit, sampling theory for large and small samples, correlation theory in two and several variables, testing of statistical hypotheses, design of experiments.

## RESEARCH CONSULTANTS

A RESEARCH CONSULTANT to the Cowles Foundation is a scholar at some other institution who maintains an active interest in the research program of the Foundation, manifested in exchanges of ideas and results with members of the Foundation's staff. Some Consultants are previous members of the staff, and some are completing research begun at the Cowles Commission or Foundation or pursuing further investigations stimulated by such research. Where a real relationship exists between the work of a Consultant and the program of the Cowles Foundation, the Foundation welcomes the opportunity to include the results in its publications.

The following were Research Consultants June 30, 1956:

THEODORE W. ANDERSON  
Dept. of Mathematical Statistics  
Columbia University  
New York, New York

KENNETH J. ARROW  
Dept. of Economics  
Stanford University  
Stanford, California

CARL F. CHRIST  
Dept. of Economics  
University of Chicago  
Chicago, Illinois

H. T. DAVIS  
Dept. of Mathematics  
Northwestern University  
Evanston, Illinois

TRYGVE HAAVELMO  
University Institute of Economics  
Oslo, Norway

CLIFFORD G. HILDRETH  
Dept. of Agricultural Economics  
Michigan State University  
East Lansing, Michigan

WILLIAM C. HOOD  
Department of Political Economy  
University of Toronto  
Toronto, Canada

HENDRIK S. HOUTHAKKER  
Dept. of Economics  
Stanford University  
Stanford, California

LEONID HURWICZ  
School of Business Administration  
University of Minnesota  
Minneapolis, Minnesota

LAWRENCE R. KLEIN  
Institute of Statistics  
Oxford University  
Oxford, England

HARRY MARKOWITZ  
The RAND Corporation  
Santa Monica, California

HERBERT A. SIMON  
Graduate School of Industrial  
Administration  
Carnegie Institute of Technology  
Pittsburgh, Pennsylvania

## GUESTS

FOLLOWING the tradition of the Cowles Commission, the Cowles Foundation is pleased to have as guests advanced students and scholars from other research centers in this country and abroad. Their presence both stimulates the work of the staff and aids in spreading the results of its research. To the extent that its resources permit, the Foundation has accorded office, library, and other research facilities to guests who are in residence for an extended period. The following were associated with the organization in this manner during the past two years.

NICHOLAS KYRIAZIDIS (Greece). July 1954—December 1954. Research grant from Conference Board of Associated Research Councils (Exchange Program). Returned to position as Director, Foreign Trade and Payments Division, Ministry of Coordination, Greece.

GIOVANNI MANCINI (Italy). March 1954—June 1955. Scholarship from Bank of Italy.

MARC NERLOVE (U.S.A.). June 1954—June 1955. Scholarship from Social Science Research Council.

RUDOLF RICHTER (Germany). September 1954. Rockefeller Foundation Fellow. Returned to University of Frankfort, Germany.

CIRO TOGNETTI (Italy). January 1955—June 1955. Sponsored by the Rockefeller Foundation.

ERALDO FOSSATI (Italy). July 1955. Fellowship from Rockefeller Foundation.

LESLIE KISH (U.S.A.). June 1956. Survey Research Center, University of Michigan.

HERMOD SKANLAND (Norway). September 1955—January 1956. Sponsored by the Rockefeller Foundation. Returned to position at the Ministry of Finances, Oslo, Norway.

## COWLES COMMISSION SEMINARS

*July 1, 1954—June 30, 1955*

1954

- October 7.* SIDNEY ALEXANDER, Columbia Broadcasting System, "The Ethics of Competition a Generation Later."
- October 19.* GERHARD TINTNER, Iowa State College, "Linear Programming Under Uncertainty."
- October 21.* GERARD DEBREU, Cowles Commission, "An Economic Theory of Uncertainty."
- November 4.* ROBERT SOLOW, Massachusetts Institute of Technology, "The Economics of Economic Growth."
- November 18.* STEFAN VALAVANIS-VAIL, University of Michigan, "An Econometric Model of Growth in the United States."
- December 7.* MARGARET G. REID, University of Chicago, "Income Elasticity of Consumption: An Analysis of Family Data."

1955

- January 13.* GARY S. BECKER, University of Chicago, "The Economics of Racial Discrimination."
- January 19.* MARTIN BRONFENBRENNER, University of Wisconsin, "Confiscation and Economic Development."
- February 3.* J. K. GALBRAITH, Harvard University, "Countervailing Power."
- February 10.* EARL R. SWANSON, University of Illinois, "Application of Linear Programming in Agricultural Production Research."
- February 17.* JACOB MARSCHAK, Cowles Commission, "A Several-Persons Firm."
- March 3.* JOHN A. NORDIN, Iowa State College, "Resource Allocation Affecting Demand Analysis."
- April 7.* ARTHUR F. BURNS, Council of Economic Advisers, "Economic Targets Under the Employment Act."
- April 14.* MARTIN BECKMANN, Cowles Commission, "The Partial Equilibrium of a Forward Market in a Stationary Economy with Uncertainty."
- April 21.* JOHN W. KENDRICK, National Bureau of Economic Research, "Progress Report on the National Bureau Study of Productivity Trends in the U.S."
- May 5.* SIMON KUZNETS, Johns Hopkins University, "Swings in the Rate of Growth of Population and National Product, United States, 1870-1950."
- May 26.* EDWARD SHAW, Stanford University, "Some Aspects of Financial Development."

# COWLES FOUNDATION SEMINARS

*July 1, 1955—June 30, 1956*

1955

*October 4.* HARRY MARKOWITZ, The RAND Corporation, "Portfolio Selection."

*November 1.* JAMES DUESENBERY, Harvard University, "Investment and the Theory of the Firm."

*November 29.* DAVID GALE, Brown University, "The Closed Linear Model of Production."

*December 15.* THEODORE W. ANDERSON, Columbia University, "Statistical Inference in Factor Analysis."

1956

*January 10.* ROBERT SOLOW, Massachusetts Institute of Technology, "An Index Number Problem in the Pure Theory of Production."

*February 7.* GEORGE KATONA, University of Michigan, "Stability or Instability of Economic Attitudes."

*February 17.* HENRY ALLAN LATANÉ, University of North Carolina, "Asset Preferences."

*February 21.* GUY H. ORCUTT, Harvard University, "Testing of Hypotheses Regarding Economic Relationships."

*February 28.* STANLEY SIGEL, Federal Reserve Board, "The Flow of Funds Study."

*March 13.* LIONEL W. MCKENZIE, Duke University, "Optimal Taxation."

*March 14.* JAMES MORGAN, Center for Advanced Study in the Behavioral Sciences, "Some Data on Consumer Investment Expenditures."

*March 16.* MURRAY GERSTENHABER, University of Pennsylvania, "Hitchcock-Koopmans Transportation Problem."

*March 20.* HENRI THEIL, The University of Chicago, "Relations Among Expected, Planned, and Actual Price Data."

*April 24.* HAROLD BARNETT, Resources for the Future, Inc., "Resources and Conservation."



*A Cowles Foundation Seminar  
Guy H. Orcutt, Harvard University*



*Cowles Foundation Library*



# LIBRARY OF THE COWLES FOUNDATION

NATALIE SIRKIN, *Librarian*

THE library consists of the collection of the Cowles Commission at Chicago, except for the collection of the late Henry Schultz, which remains at the University of Chicago. The library is maintained primarily to assist in the research program of the organization, and its composition therefore reflects the research interests of the staff. Over three-fourths of the collection is economics, with particular emphasis on its quantitative fields. Mathematics and statistics account for 8% of the titles, and the remainder are books in other social and physical sciences or reference volumes. Particular emphasis is placed on acquiring materials not available in other university library sources. The collection includes 3200 books, 7000 pamphlets, and a considerable number of unpublished papers. The library subscribes to some 150 periodicals. There were 256 accessions of books in 1955-56, and 97 obsolete or duplicate books were disposed of.

The books are catalogued according to Library of Congress rules, modified somewhat as necessitated by the highly specialized nature of the books and the needs of the readers.

The readers are primarily the Cowles Foundation staff and graduate students in economics, but the Library is open to all people connected with Yale. Books circulate for a month; journals, for two days; both are renewable. Reserve shelves are kept for courses in econometrics, mathematical economics, economic theory, and statistics.

## THE ECONOMETRIC SOCIETY

THE Econometric Society is an international society for the advancement of economic theory in its relation to statistics and mathematics. Its main object is the promotion of studies directed towards unification of the theoretical quantitative and the empirical quantitative approaches to economic problems and penetrated by the kind of constructive and rigorous thinking that has come to dominate the natural sciences. Any activity which promises ultimately to further such a unification of theoretical and factual studies in economics is considered to be within the sphere of interest of the Society.

At the present time the Econometric Society publishes a quarterly journal, *Econometrica*. It holds one European meeting and two or three North American meetings each year. Recently a meeting was also held in India. As an international organization, the officers of the Econometric Society represent many different countries. The presidency of the Society alternates between the eastern and western hemispheres of the world, and the Council is also divided in its representation between the two hemispheres. The major governing body of the Society is its Fellows. At the present time these number 127, and a maximum of six additional fellows are elected each year. Membership in the Society is open to anyone seriously interested in the objectives of the Society. Recently, institutional memberships were set up in order to solicit the support of interested business firms and research organizations. In addition to the 1,800 members, there are 1,000 non-member subscribers to the journal, mainly libraries, business firms, and research organizations.

Three individuals, Irving Fisher, Professor of Economics at Yale, Ragnar Frisch, Professor of Economics at the University of Oslo, and Charles Roos, a research fellow at Princeton, were instrumental in the founding of the Society in 1930, two years prior to the establishment of the Cowles Commission. Initially the Society had somewhat under 200 members, and its activities were restricted to the arrangement of small meetings at which papers were read and discussed. Because of the small membership and the minimal size of the dues, it

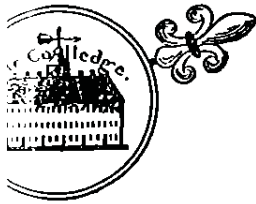
was not possible at that time to publish a journal. With the founding of the Cowles Commission in 1932, a proposal was made that the Commission support the activities of the Econometric Society, and enable it, among other things, to publish a journal. After due consideration this proposal was adopted, and the first issue of the journal *Econometrica* was published in 1933. In the following years the Society grew, and with the increase in membership and subscriptions the Society, like all good infant industries, became somewhat more self-supporting. But costs were also rising, and the Cowles Commission continued to bear a considerable portion of the administrative expenses of the Society. The two organizations were administered jointly.

With the establishment of the Cowles Foundation at Yale University, it was decided to separate the administrative functions of the Econometric Society from those of the Cowles Foundation, and if possible to draw the financial support of the Society more fully from its membership than had been done to date. A gradual reduction in the financial contribution of the Cowles Commission, begun while the Society was still located in Chicago, has been continued. At present the Society receives a contribution of \$2,000 a year from the Cowles Foundation; and it is expected that this level will be maintained in the future. Efforts are being made to replace the reduction in the Cowles Foundation contribution from such sources as institutional memberships and an increase in individual memberships.

RICHARD RUGGLES

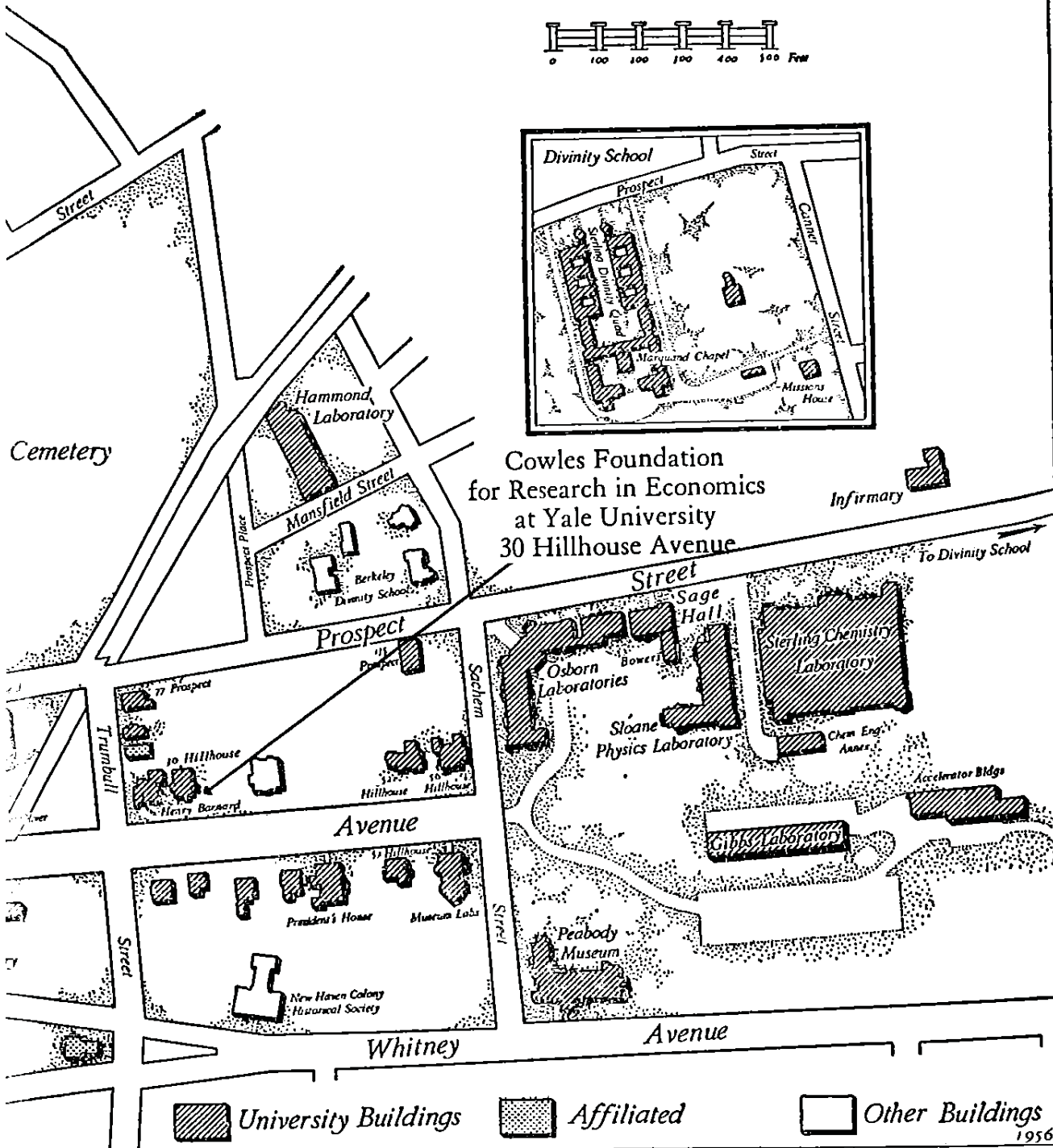
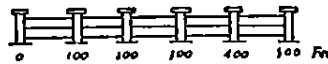
*Professor of Economics, Yale University  
Secretary*








R. Galvin

# YALE UNIVERSITY

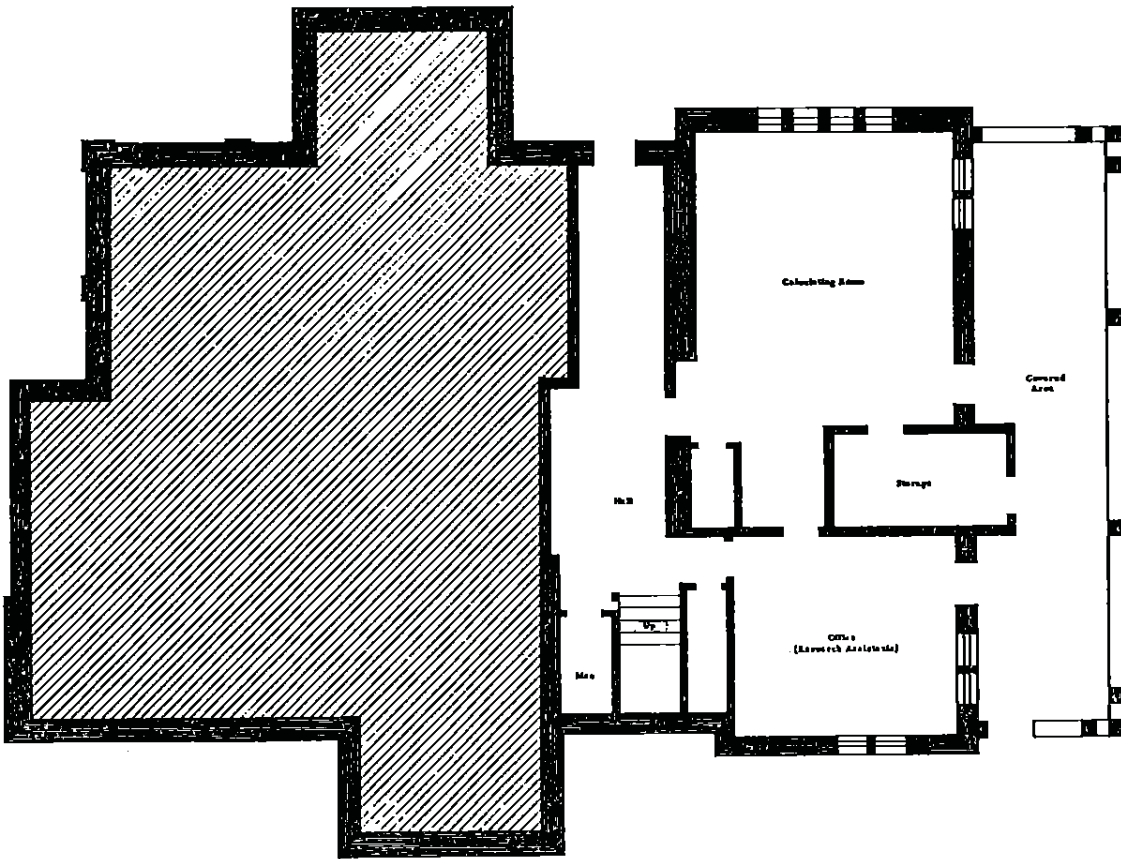


Cowles Foundation  
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30 Hillhouse Avenue

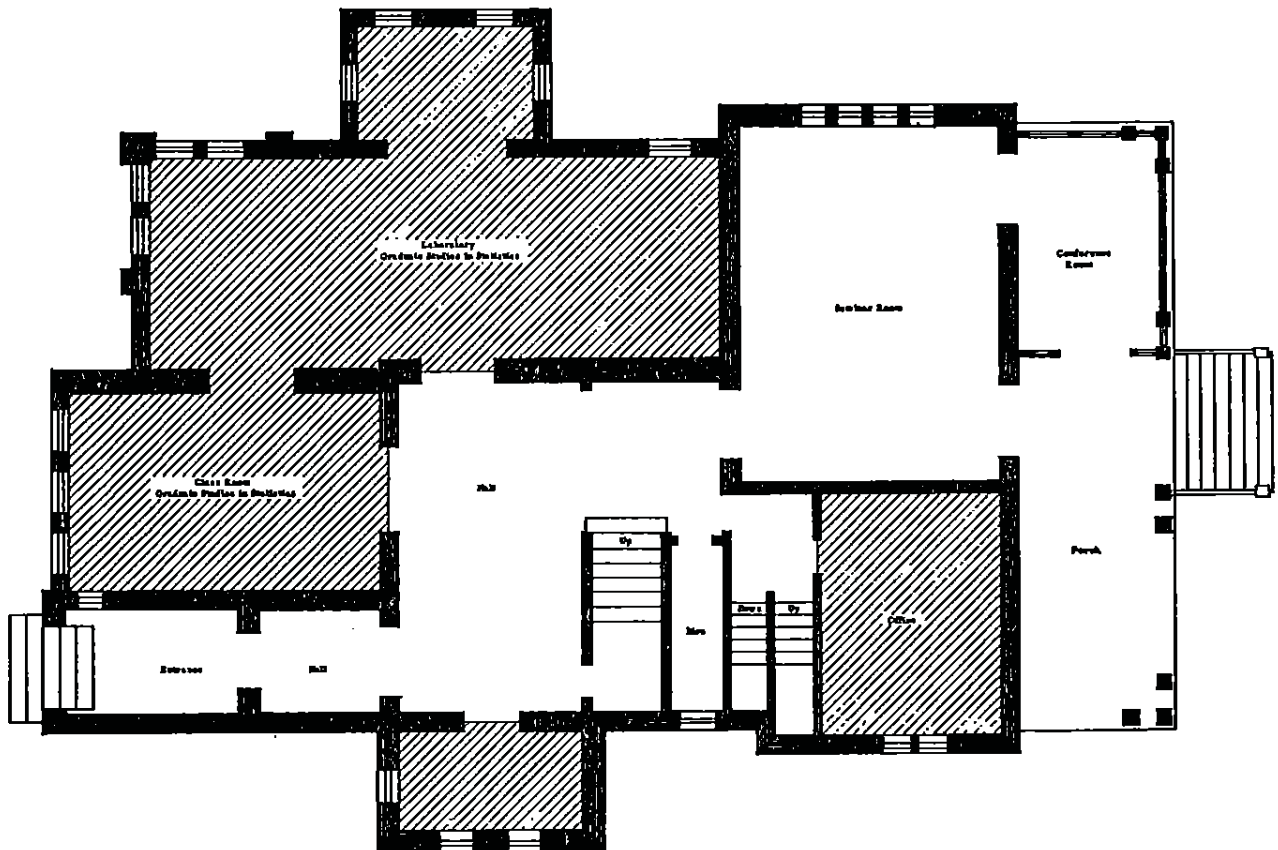
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## THIRTY HILLHOUSE AVENUE

YALE University provided space for the Cowles Foundation and the Econometric Society in the house at 30 Hillhouse Avenue, New Haven, which the University had recently acquired from Mrs. J. Dwight Dana. Built in 1884, the house is a large residence with spacious and pleasant grounds; it is typical of Hillhouse Avenue, a short but justly famous street. The University remodeled the house as necessary to provide a library, a seminar room, a computation laboratory, and convenient office space. The floor plans (pp. 43 and 44) show the arrangement. As the map (pp. 40 and 41) shows, it is conveniently located within the University, particularly in relation to the Economics Department in Strathcona Hall and the Mathematics Department in Leet Oliver Memorial. The University Statistics Laboratory is located on the first floor of 30 Hillhouse Avenue itself.

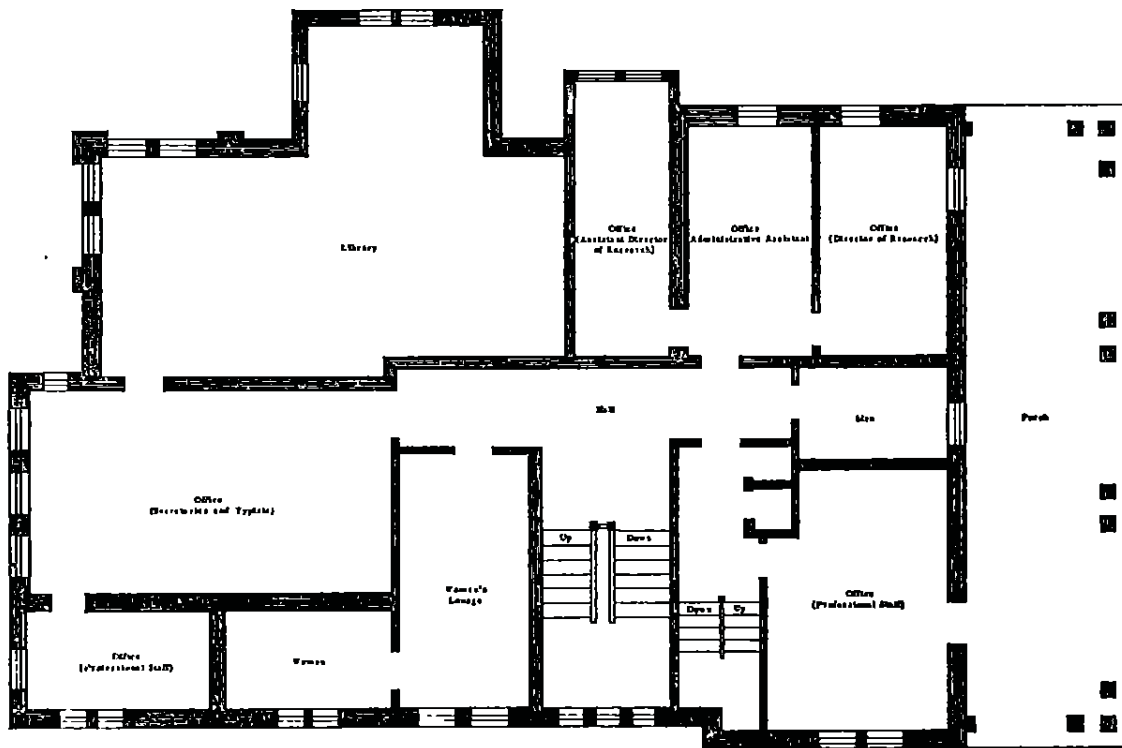


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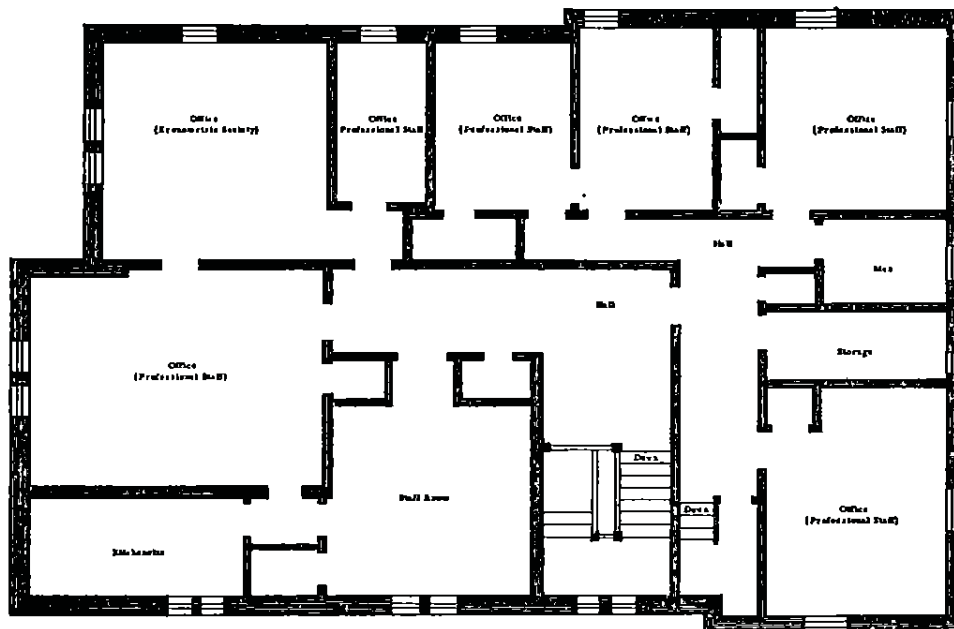


FIRST FLOOR

*Floor plans of 30 Hillhouse Avenue  
Shaded areas indicate space not used by the Cowles Foundation.*



SECOND FLOOR



THIRD FLOOR

*Floor plans of 30 Hillhouse Avenue*



# COWLES COMMISSION MONOGRAPHS

1934-1956\*

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

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

No. 3. *Common-Stock Indexes*, by ALFRED COWLES and ASSOCIATES. Second Edition, 1939. Evanston, Ill.: Principia Press. 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. Evanston, Ill.: 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. Evanston, Ill.: 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.

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No. 9. *Price Control and Business*, by GEORGE KATONA. 1945. Evanston, Ill.: Principia Press. 246 pages. Price \$3.00. A study of the working of

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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 Tjalling 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.

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.

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.

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No. 14. *Studies in Econometric Method*, by Cowles Commission Research Staff, edited by Wm. C. Hood and T. C. Koopmans. 1953. New York: John Wiley and Sons. 324 pages. Price \$5.50. Presents and extends methods developed in Monograph 10 in an expository style addressed primarily to the user of methodology.

No. 15. *A Statistical Study of Livestock Production and Marketing*, by Clifford Hildreth and F. G. Jarrett. 1955. New York: John Wiley and Sons. 156 pages. Price \$4.50. Economic relations underlying the operation of livestock markets in the United States are estimated and tested by several alternative procedures.

#### SPECIAL PUBLICATIONS

*Economic Aspects of Atomic Power*, an exploratory study under the direction of Sam H. Schurr and Jacob Marschak. 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. Orders should be sent to Princeton University Press, Princeton, New Jersey.

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This series includes selected articles published by members of the research staff or by others working in close association with them.

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MARTIN J. BECKMANN

*Studies in the Economics of Transportation* (co-author)

Papers: CFP 99, 102, 105

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- E. "The Economics of Location" (Review Article), *Kyklos*, Vol. 8, 1955, pp. 416-421.
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DONALD BRATTON

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GERARD DEBREU

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HAROLD W. GUTHRIE

Other Publications:

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- B. "A Report of Research at Yale University on Consumer Behavior," *Papers and Proceedings of the American Economic Review*, Vol. 46, May, 1956, pp. 151-154.

TJALLING C. KOOPMANS

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- A. *Three Essays on the State of Economic Science*, to be published by the McGraw-Hill Book Company in July, 1957.

ALAN S. MANNE

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- A. "On the Solution of Discrete Programming Problems," to be published in *Econometrica*.

HARRY MARKOWITZ

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- A. "On the Solution of Discrete Programming Problems," to be published in *Econometrica*.
- B. "The Maximization of a Quadratic Form Subject to Linear Constraints," to be published in *Naval Research Logistics Quarterly*.

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C. B. MCGUIRE

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LIONEL MCKENZIE

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RICHARD MUTH

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