

Economic Theory
and
Measurement

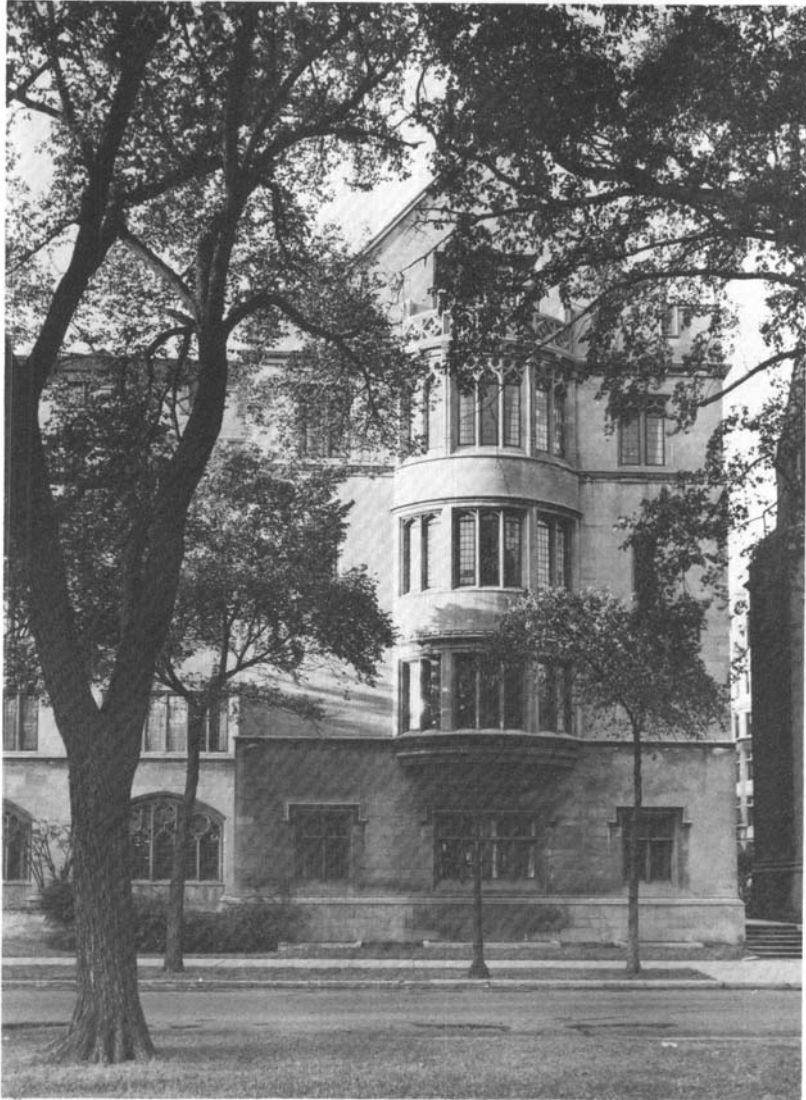
*A Twenty Year
Research Report
1932 - 1952*

COWLES COMMISSION
FOR RESEARCH IN ECONOMICS

THE UNIVERSITY OF CHICAGO

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Purpose

THE COWLES COMMISSION FOR RESEARCH IN ECONOMICS *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, and of society in general. Its approach is to encourage and extend the use of logical, mathematical, and statistical methods of analysis. It seeks to accomplish its purpose through research and instruction, through publication, and through other programs directed toward increasing the human resources devoted to such research.*

The Commission is a not-for-profit corporation, founded in Colorado in 1932 and, since 1939, chartered under the laws of the State of Illinois. Its governing bodies are its faculty, an executive committee, and a board of trustees.

Although it is an independent research organization with members of its staff in other research centers both in the United States and abroad, the Commission is affiliated in academic matters with the University of Chicago as a component of the Division of the Social Sciences. The Commission is also affiliated with the Econometric Society, an international society for the advancement of economic theory in its relation to statistics and mathematics.

INTRODUCTION

The development of economics and of the social sciences generally has come about through the constant interaction of theory and measurement. Theory starts from observation. It draws up propositions that generalize scattered observations. It then proceeds to make logical deductions of the consequences of these propositions. In this way it guides the choice of phenomena for further measurement. On the other hand, measurement also provides the basis for refuting, modifying, or refining theory. The word "measurement" is here used in its broadest sense of systematic observation. It ranged from mere classification of objects, through the establishment of preferences between objects, to the construction of numerical scales and measures.

This interplay of theory and measurement is common to all sciences concerned with the real world. In the social sciences, and particularly in economics, both theory and measurement are further influenced by the idea that knowledge should be of help in better attaining the goals of society, of organizations, or of individuals. "Welfare economics" is the clearest expression of this idea, but the same thought influences the choice of subject matter for theory and measurement throughout economics.

The traditional borderline between economics and the social sciences is beginning to disappear, largely as a result of the increasing abstractness in the formulation of theories. What promises to evolve is a science of man's pursuit of desired individual or social objectives, of the interaction among diverse interests, and of outright conflict and warfare. In this development, persons trained as economists have a contribution to make because of their traditional concern with the maximization of individual or social welfare, and because of their skill in the logical and mathematical techniques of such analysis.

The Cowles Commission for Research in Economics is an organized group of scholars dedicated to research in economic theory and measurement. It seeks to make additions to fundamental knowledge about society, through theory construction, through measurement for the testing of theory, through development of methods of measurement, and through application of results in specific areas. Its research staff blends many different educational and cultural backgrounds and unites economists engaged in theoretical and empirical inquiries with statisticians and mathematicians into a balanced cooperative research effort. Through consultant relationships with research workers at various universities in North America and abroad and through a constant flow of research fellows and other guests who visit for periods up to a year, the Commission maintains close contact with research workers who are pursuing similar objectives in economics and in other social sciences.

The story of the Cowles Commission, and of the men and ideas that have shaped its course, is told in this *Twentieth Annual Report*. The historical narrative by Carl Christ, a former staff member, describes the origins of the Commission, its early and continuing relationship with the Econometric Society, and its growth and development over a twenty year period. The report on research activities gives an account of the Commission's work in its twentieth year. A record of recent expansion and accomplishment is presented in the report on the Econometric Society. Further indicators of the activities and influence of the Commission are to be found in the list of biographies of the participants in its research over two decades, and in the lists of publications, papers, addresses, seminars, and courses which epitomize the nature and scope of its work.

HISTORY OF THE COWLES COMMISSION

1932-1952

BY CARL F. CHRIST*

- I. *The founding of the Cowles Commission*
- II. *The early years in Colorado: 1932-1937*
- III. *The later years in Colorado: 1937-1939*
- IV. *The move to Chicago: 1939*
- V. *The early years at Chicago: 1940-1942*
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- VIII. *Looking back and looking forward*

I. *The founding of the Cowles Commission*

The Cowles Commission for Research in Economics was founded in 1932. Alfred Cowles, president of Cowles and Company, an investment counseling firm in Colorado Springs, Colorado, initiated some inquiries into the accuracy of professional stock market forecasters over the period 1928-1932. This aroused his interest in fundamental economic research, which led him to offer his financial support toward the establishment of the Cowles Commission and to bear a significant share of the burden each year. Fortunately at the outset he encountered Harold T. Davis, a professor of mathematics at Indiana University whose interests included mathematical economics and statistics. Davis was to become an important figure in the

* The source material for this sketch consisted of published and unpublished records of the Cowles Commission, and even more important, the personal recollections of several of its leading members, past and present, with whom I was able to talk. I wish to acknowledge the generous assistance provided by these men. They are Alfred Cowles, Harold T. Davis, Charles F. Roos, Dickson H. Leavens, Theodore O. Yntema, Jacob Marschak, Tjalling C. Koopmans, and William B. Simpson. In addition, Ragnar Frisch gave helpful comments on preliminary drafts.



Moffett Photo

ALFRED COWLES



Evanston Photographic Service

HAROLD T. DAVIS

founding of the Cowles Commission and in its progressive development through the years. Also important was the new Econometric Society, not yet two years old, which had been organized in 1930 by Irving Fisher of Yale University, Ragnar Frisch of the University of Oslo, Charles F. Roos of Cornell University, and others.

As early as 1912, while Fisher was vice-president of the American Association for the Advancement of Science, he had attempted to organize a society to promote research in quantitative and mathematical economics. Wesley C. Mitchell, Henry L. Moore, and a few others had been interested but they were too few, and for the time being nothing came of their vision.

In the spring of 1928, Frisch was in the United States under a Rockefeller Foundation grant. At Princeton University he met Roos, then a young mathematician who was a Fellow of the National Research Council and secretary of the rejuvenated Section K (economics, sociology, and statistics) of the American Association for the Advancement of Science. They found themselves in agreement that there was a need for bringing economics, mathematics, and statistics closer together for work in what has come to be called econometrics. Frisch had corresponded with several economists about the possibility of founding a society with this objective. He and Roos decided to solicit Fisher's support in organizing such a society, and Frisch went to see Fisher at Yale. In April, 1928, all three met at Fisher's home in New Haven for a weekend to discuss the idea further. Fisher, mindful of the outcome of his earlier attempt, was pessimistic. At length he said that if Frisch and Roos could name one hundred people in the world who would join a society established for the encouragement of econometric work and the exchange of econometric papers, he would become an enthusiastic partner in organizing such a society. They were very happy with this response, thinking that it would be a simple matter to list a hundred interested people. At first, the list virtually wrote itself, but then the going got harder, and after three days they had

to give up with about seventy likely prospects. Fisher looked over their list and suggested about a dozen additional names. He was quite surprised that they had found so many, and he agreed that eighty justified going ahead. The three men drafted a letter of invitation to membership in the proposed society together with a request for the names of others who might be interested. The response to the invitation was excellent and nearly eighty more names were suggested.

The American Economic Association, the American Statistical Association, and Section K of the American Association for the Advancement of Science were to hold their first joint meeting in Cleveland, Ohio in December, 1930. Early in that year Fisher, Frisch (who was again in the United States, this time as a visiting professor at Yale), and Roos issued invitations to an organization meeting of the Econometric Society to be held in Cleveland on December 29, 1930. Twelve Americans and four Europeans attended. Joseph A. Schumpeter, then professor at the University of Bonn, was elected chairman of the meeting, and such was his enthusiasm that he himself made the motion whereby the new society was founded. Fisher was elected the first president and nine others were elected to the Council. A tentative constitution proposed by Frisch was adopted in principle, and was then phrased by a committee consisting of Frisch, Frederick C. Mills, and Roos. The constitution as amended appears with annotations in *Econometrica* for January, 1952, together with the names of those attending the organization meeting and of all officers and Council members since the beginning. The first meeting of the Society after its organization was held in September, 1931, at the University of Lausanne, Switzerland. The second meeting was held in Washington, D. C. in December, 1931, together with the meetings of other social science societies. During the year 1931 the Council elected 173 persons to charter membership, including all those who attended the organization meeting in Cleveland and all who attended the Lausanne meeting.

While the Econometric Society was being formed,

Cowles was publishing the investment service of Cowles and Company in Colorado Springs. He became interested in comparing his forecasts with those of other professional forecasters, and in checking afterwards to see whether an investor would have done well to follow their advice. After the stock market crash in 1929 and the subsequent long decline of security prices amid optimistic predictions by many investment services, he began to feel that most of the forecasters were just guessing, himself included. In fact in 1931, he discontinued his forecasting service, explaining in his investment letter that he did not know enough about the forces that govern the fluctuations of business and the stock market. He further stated that he was going to try to find out more about these matters through research of his own before making any further forecasts.

In the summer of 1931, Cowles discussed his problems with a friend, Charles H. Boissevain, a Dutch biochemist with mathematical training who was head of the Colorado Foundation for Research in Tuberculosis. Boissevain thought that multiple-correlation analysis might be an effective tool for economic research and suggested to Cowles that he consult Davis, professor of mathematics at Indiana University, who spent his summers in Colorado Springs. Shortly thereafter Davis received a telephone call from Cowles, whose first question was whether it was possible to compute the multiple-correlation coefficient in a problem involving twenty-four variables. Davis replied that he didn't know why anyone would want to compute such a correlation coefficient, but a new method of performing such computations with the aid of Hollerith (IBM) punch-card computing machines had recently become available and he thought he could carry out the desired computations. Cowles enlisted Davis' services and acquired a Hollerith computer, and together he and Davis set to work finding correlation coefficients.

On becoming acquainted with the problems on which Cowles was working, Davis suggested to Cowles that he associate himself with the newly-formed Econometric Society because there he would find the men who by training

and interest could be most helpful to him. Davis added that Cowles might enlist their aid on a continuing basis and advance his cause still further. He could offer to finance the publication of a journal for them and set up a research organization under their auspices with the resources and freedom for econometric research and publication. Cowles felt that this would be an effective way of securing first-class talent to work on the problems in which he had become interested.

Accordingly he wrote to Fisher, who was president of the Econometric Society and an old friend of his father and uncle from their undergraduate days at Yale, to propose the two projects. Fisher was delighted, for the Econometric Society was severely limited in scope by its poverty. During the first two years of its existence, 1931 and 1932, its activities consisted chiefly of small meetings at which papers were read and discussed. Because dues were very low, the Society simply could not afford more ambitious activities. Against this background, Cowles' proposal seemed like a godsend. In his excitement Fisher telephoned Roos, then permanent Secretary of the American Association for the Advancement of Science, to read him the letter. Roos was equally delighted; it seemed too good to be true. He asked whether Fisher thought it was a crank letter, and Fisher—fortunately—replied that he thought it was not. They invited Cowles to come East to discuss the matter and he accepted their invitation promptly. The three men met at Fisher's home in New Haven on a weekend in October, 1931. Cowles proposed starting with a budget of about \$12,000 per year with larger amounts to follow if the venture met with success. Fisher and Roos, having satisfied themselves that Cowles meant what he said and was genuinely interested in econometric research, were enthusiastic about the scheme.

At about the same time Davis arranged with Thornton C. Fry, a mathematician with the Bell Telephone Laboratories and a charter member of the Econometric Society, to acquaint Cowles with several other members of the Society. A few days later, Cowles and Fry met in New York

with Donald R. Belcher, chief statistician of the American Telephone and Telegraph Company; J. W. Glover, president of the Teachers' Insurance and Annuity Association of America; Harold Hotelling of Columbia University; and Walter A. Shewhart, statistician of the Bell Telephone Laboratories. Cowles discussed his proposal with them, and they assured him that in their judgment the Society would welcome the support as a "most fortunate opportunity."

Fisher and Roos, as president and secretary of the Econometric Society respectively, wrote a letter to the other members of the Council outlining Cowles' proposal and recommending its acceptance. The replies were for the most part favorable. However, some of the members of the Council became alarmed lest the Society's good name be harmed by its implication in a venture with a man who was willing to spend a considerable sum of money in order to accomplish they knew not what purposes of his own. The English and European members held a special meeting to discuss the question. They decided that they could not give their approval until a representative had come to the United States to meet Cowles and find out what his motives were. They chose Frisch as their representative and informed Fisher and Roos of their position. Fisher and Roos wrote as tactfully to Cowles as they could, explaining that his proposal was an important matter that might well have a profound effect on the future of the Society, and that the English and European members of the Council felt they would be able to give fuller support if Frisch were to come as their representative to talk with Cowles about the type of organization he had in mind. Cowles was favorably impressed by this cautious approach and responded by inviting Frisch to come as his guest to Colorado Springs. Frisch came and stayed for a week. As the two discussed the project from every viewpoint, Frisch became perfectly satisfied, as were Fisher and Roos, that Cowles was sincerely interested in econometric research. Before returning to Norway, Frisch met briefly with Fisher and Roos, and the three of them wrote a new letter to the Council of the

Econometric Society, reporting on Frisch's visit with Cowles and recommending that they accept the proposal.

This time, in January, 1932, the Council accepted. The agreement was as follows: Cowles would set up a research organization in Colorado Springs to be known as the Cowles Commission for Research in Economics; the Econometric Society would sponsor the Cowles Commission; the Cowles Commission would be guided by an Advisory Council appointed by and from the Econometric Society; and Cowles would underwrite the cost of publishing a journal for the Society. The earlier apprehensions of some of the Society's Council members, though understandable, turned out to be quite unfounded. Indeed, Cowles' generosity, farsightedness, fairness, and objectivity enabled the Cowles Commission to become established in its first few years as a responsible research organization, and have been among the most important sustaining factors in the achievements of the Cowles Commission ever since. Accordingly the Advisory Council was to play a progressively less active part in its affairs.

At first, however, even before the Cowles Commission was formally founded, the Advisory Council did take an active part in supervising its activities. The members of the Advisory Council, appointed in February of 1932 by the Council of the Society, were Fisher; Frisch; Arthur L. Bowley, professor at the London School of Economics; Mitchell, director of the National Bureau for Economic Research; and Carl Snyder of the Federal Reserve Bank of New York. They held their first meeting with Roos in Syracuse, New York, at the summer sessions of the Econometric Society in 1932; all members were present except Bowley. At this meeting it was decided that the first major project of the Cowles Commission should be the construction of indexes of stock prices, earnings, and dividends in the United States with proper adjustments for stock splits, rights, recapitalizations, etc., since any subsequent analytical work on the security market would require more adequate indexes than were then available.

On the 9th of September, 1932, the Cowles Commission for Research in Economics was formally chartered as a not-for-profit corporation in the State of Colorado. The original Articles of Incorporation contain these words: "The particular purpose and business for which said corporation is formed is to educate and benefit its members and mankind, and to advance the scientific study and development . . . of economic theory in its relation to mathematics and statistics."

Alfred Cowles was elected by the trustees as president of the Cowles Commission. A research laboratory and library were set up in the Mining Exchange Building in Colorado Springs, and good relations were established with the economics department of nearby Colorado College, of which Cowles was a trustee. In addition to Cowles, the initial research staff consisted of Davis, who was in charge of the statistical work; Frisch, who was a nonresident consultant; William F. C. Nelson, who was an economist; and Forrest Danson, who was a statistician. The latter two had been with Cowles in his investment firm before 1932. This group began work on the stock market indexes. Davis and Nelson collaborated in writing a textbook on statistics for economists based on the adaptation of a manuscript previously prepared by Davis. The initial budget was approximately \$12,000 per year.

There remains one thread to be picked up. In February of 1932, after the Council of the Society had accepted Cowles' offer to underwrite the founding of a journal, the name *Econometrica* was chosen, Frisch was elected editor-in-chief, Nelson was chosen as assistant editor, and Cowles was chosen as circulation manager and also as treasurer of the Society. Upon its incorporation in September, 1932, the Cowles Commission became host to the archives of the Society, and the offices of the two organizations have been together ever since.

The first issue of *Econometrica* appeared in January, 1933. It contained an editorial by Frisch, an introductory article by Schumpeter, summaries of previous meetings of the

Society, and papers by René Roy, Shewhart, Jan Tinbergen, John B. Canning, and James Harvey Rogers. In introducing *Econometrics* to the reader, Schumpeter wrote:

"We do not impose any credo—scientific or otherwise—and we *have* no common credo beyond holding: first, that economics is a science, and secondly, that this science has one very important quantitative aspect. . . .

What we want to create is, first, a forum for econometric endeavor of all kinds wide enough to give ample scope to all possible views about our problems. . . . On this forum, which we think of as international, we want secondly to create a spirit and a habit of cooperation among men of different types of mind by means of discussions of concrete problems of a quantitative and, as far as may be, numerical character. . . . Confronted with clear-cut questions, most of us will, we hope, be found to be ready to accept the only competent judgment on, and the only relevant criterion of, scientific method, that is the judgment or criterion of the result. . . . Theoretic and 'factual' research will of themselves find their right proportions, and we may not unreasonably expect to agree in the end on the right kind of theory and the right kind of fact and the methods of treating them, not postulating anything about them by program, but evolving them, let us hope, by positive achievement."

That is the story of the founding of the Cowles Commission, the Econometric Society, and the journal *Econometrica*.

II. *The early years in Colorado: 1932–1937*

The first Cowles Commission product to attract widespread attention, both from businessmen and from professional economists, and still one of the best known of its publications, was a paper by Cowles entitled "Can Stock Market Forecasters Forecast?" published in *Econometrica* in July, 1933. A three-word abstract of this paper runs as follows: "It is doubtful." As mentioned earlier, Cowles had begun to suspect that many forecasters had no real skill and were in effect simply guessing, and he set out to test this hypothesis. He charted the weekly individual stock purchase recommendations of sixteen established financial services from 1928 to 1932, and found that if

an investor had followed all of them, with equal initial amounts of capital allotted to each purchase of a stock, he would have come out making about one and a half per cent per year less than if he had invested in the stock market as a whole. He also calculated that if sixteen *random* series of weekly predictions were made, there was at least an even chance that one of them would lead to just as good results as the most profitable service actually did. He then checked the common stock investment records of twenty large fire insurance companies for the same period, and found that on the average they fell behind the market by slightly more than one per cent per year, while the best record among them was only slightly better than that of the best financial service. He then charted the forecasts of stock market level made by twenty-four financial publications from 1928 to 1932 and found that if an investor had followed all of them, again with equal amounts of initial capital allotted to each, he would have fallen behind the market average by about four per cent per year. Finally, he found that when twenty-four series of random forecasts were made by drawing cards from an appropriate deck, the best series of random forecasts was just as good as the best series of actual forecasts, while the worst series of random forecasts was better than any of the six worst series of actual forecasts. Far from refuting the hypothesis that stock market forecasters were operating according to chance rather than skill or insight, these results were quite consistent with it, except that the poorer actual forecasts seemed to be worse than would be expected on the basis of chance alone. The study pointed strongly to the need for more reliable knowledge upon which to base economic forecasts.

In the summer of 1934, Roos was research director of the National Recovery Administration of the United States government. He was beginning to think about where he would go next, for his opinion of the NRA's usefulness was very low, and he was in the process of writing a report for the NRA recommending that the Act under which it was created be allowed quietly to expire without renewal in 1935. He wrote to Cowles for a reference for a prospective

new employer, and Cowles replied by offering him a position as the first director of research of the Cowles Commission. Upon hearing of this opportunity, Colorado College offered him a professorship in econometrics. He accepted the two positions, taking up his duties in September, 1934.

During Roos' term as director of research, the Cowles Commission published three volumes, including the first two in its series of monographs. The year 1934 saw the publication of Monograph 1, *Dynamic Economics*, a series of essays by Roos which he had completed before he came to the Cowles Commission. Next, in 1935, was the aforementioned textbook, *Elements of Statistics*, by Davis and Nelson. Third, in 1937, was Monograph 2, *NRA Economic Planning*, by Roos. This was an enlarged version of the adverse NRA report that he had prepared as NRA research director, which the NRA had declined to publish. (Roos writes that in 1935, after the Supreme Court declared the National Industrial Recovery Act unconstitutional, House Speaker Rayburn and Senate President Garner requested and received manuscript copies of the report. Thus, it may well have contributed to the willingness of Congress to let the NRA idea die with no legislative attempt to revive it.) In preparation were three other monographs: the stock market indexes, by Cowles and other members of the staff; a study of the monetary use of silver, by Dickson H. Leavens, a new staff member; and a study of methods of analysis of economic time series, by Davis.

One of the most significant contributions of the Cowles Commission in its early days was made through its summer conferences, of which the first was in 1935. In June of that year, the Econometric Society had held a meeting at Colorado College and for various reasons several economists and statisticians remained in Colorado Springs for the following week, including Davis, Hotelling, August Loesch, Isadore Lubin, Shewhart, and Snyder. Roos suggested that they have a few informal meetings, at which anyone who wished might discuss his current research work and invite help on the problems involved. The others took up the

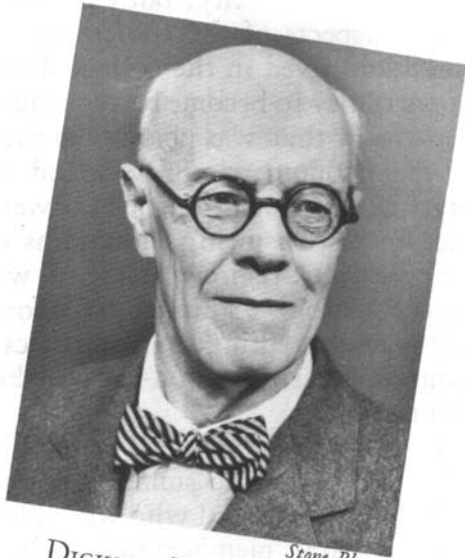
idea and during the week ten informal papers were presented, with considerably more free and substantive discussion than would have been possible in a larger and more formal group listening to finished work. This short session was such a success that Cowles and Roos decided to plan a similar conference for the following summer. They wrote up the proceedings and sent them out as part of an invitation to the second conference to be held at Colorado College in the summer of 1936. They invited thirty-two people to speak, in the hope of getting about ten acceptances, and were surprised when they received twenty, including three from staff members. As a result, the conference was extended to five weeks. The proceedings were written up, and published by Colorado College. Among the participants who were not connected with the Cowles Commission were Irving Fisher, R. A. Fisher of University College, London, Corrado Gini of the University of Rome, Shewhart, and E. J. Working of the University of Illinois.

The setting of Colorado Springs was conducive to a pleasant informality, both in the econometric and recreational aspects of the conferences. Because the group was small and lived in the college dormitories, people had the opportunity to become better acquainted professionally and personally than was possible in the more crowded meetings of the Econometric Society and American Economic and Statistical Associations. There were hikes, drives, and picnics in the inspiring mountains of the Pike's Peak and Cripple Creek regions, and there was even a play, presented by the visitors at a dinner given for the staff, in which some of the more striking characteristics of the staff and speakers came in for some good-natured but pointed and amusing scrutiny.

Four new people joined the staff while Roos was director of research. In the summer of 1935, Herbert E. Jones, a gifted young invalid who was able to work only part time, became a staff member; in 1936 he was appointed as a Fellow of the Cowles Commission. His training was in mathematics and in engineering. He worked on the stock index project and on problems of fitting equations to time series.



CHARLES ROOS



DICKSON H. LEAVENS *Stone Photo*

Leavens, a former member of the statistics research staff of the Harvard Business School, first became acquainted with the Cowles Commission through the summer conference of 1936, at which he presented a paper on gold and silver. Nelson, who had been assistant editor of *Econometrica*, had died suddenly in May, 1936, and Cowles was looking for a man to take over the editorial work of the journal and the Cowles Commission, manage the office, and share in the research work. When Leavens was summoned to Cowles' office toward the end of the conference, just after the performance of the play, he must have wondered uneasily whether it had given offense, for he had written it himself. However, if he had any apprehensions they vanished, for what Cowles wanted was to ask whether he knew any graduates of the Harvard Business School who might be interested in the opening at the Cowles Commission, or, for that matter, whether he would be interested in it himself. He was, and accordingly moved to Colorado Springs in September, 1936. His devoted and unceasing attention to the many administrative aspects of the Cowles Commission's activities up to his retirement in 1947, was an essential factor in the Commission's effectiveness.

Gerhard Tintner of Vienna accepted an invitation to become a Fellow of the Cowles Commission in 1936. Edward N. Chapman of Colorado Springs also joined the staff that year.

At the end of January, 1937, Roos resigned as research director of the Cowles Commission to become research director of the Mercer-Allied Corporation in New York. Shortly thereafter he embarked in business for himself with a new economic forecasting agency, The Econometric Institute, which he heads today.

III. The later years in Colorado: 1937-1939

Upon Roos' departure, Davis took a leave of absence from Indiana University to become acting director of re-

search of the Cowles Commission. He held this position from February until September, 1937, at which time he left to become professor of mathematics at Northwestern University. He continued to spend his summers with the Cowles Commission for several years.

The summer conference of 1937 was used partly as a recruiting ground for a new director of research, and among the prospects invited were Frisch; Jacob Marschak, then director of the Institute of Statistics at Oxford University; and Theodore O. Yntema, then professor in the School of Business at the University of Chicago. None of them was inclined to accept the position, however, for Colorado Springs was too isolated from the large academic centers to be attractive. For the next two years, until September, 1939, there was no official director of research. However, both Roos and Davis met with Cowles from time to time to advise him on the research program.

During this period, the third and fourth monographs were published, and two more were in process. Monograph 3, *Common-Stock Indexes*, by Cowles and Associates, appeared in August, 1938, and a second edition was published in 1939. It presents the results of the extensive gathering and compiling of data on the stock market, and contains indexes of prices with adjustments for rights, splits, dividends, etc., and of yield expectations, yields, dividends, earnings-price ratios, and earnings for a large group of common stocks comprising ninety to a hundred per cent of the value of all those listed on the New York Stock Exchange, 1871-1939 and for sixty-eight subgroups of these stocks. Monograph 4, *Silver Money*, by Leavens, appeared in March, 1939. It traces the history of the monetary use of silver and analyzes recent developments in some detail. Davis continued to work on his time-series analysis, and Tintner proceeded with another monograph on time series, although he left the Cowles Commission in September, 1937, to join the faculty of Iowa State College.

The summer conferences continued vigorously during the Colorado period. The proceedings after 1936 were published by the Cowles Commission itself, under the editor-

ship of Leavens. Among the participants in 1937-1939 who were not previously connected with the Cowles Commission were R. G. D. Allen of the London School of Economics, Louis Bean and Mordecai Ezekiel of the U. S. Department of Agriculture, Fry, Trygve Haavelmo of the University of Oslo, A. P. Lerner of the London School of Economics, Francis McIntyre of Stanford University, Horst Mendershausen of the University of Geneva, Rogers of Yale University, René Roy of the University of Paris, Henry Schultz of the University of Chicago, Abraham Wald of Vienna, Holbrook Working of Stanford University, and (as already mentioned) Frisch, Marschak, and Yntema. Roy came in 1938 as the official representative of the Government of the French Republic in honor of the one hundredth anniversary of the publication of Cournot's pioneering *Récherches*. Acting on a suggestion by Davis, the Cowles Commission had invited the French Government to send a representative. This invitation was accepted and Roy was designated.

Additional staff changes were as follows. McIntyre came to the Cowles Commission and the faculty of Colorado College in the fall of 1937, by way of the University of Chicago, Stanford University, and the 1937 summer conference. Two new Fellows were appointed for the year 1938-1939, Mendershausen and Wald. Both had contributed to the 1938 summer conference.

IV. The move to Chicago: 1939

Colorado Springs had many advantages as a location for the Cowles Commission, but its geographical position with respect to other centers of economic and statistical research was certainly not one of them. This disadvantage was underlined by the failure to secure as director of research any of the three men who ranked as first choice when Roos departed in 1937. For the next two years, there was continually in the background the question of whether the Cowles Commission ought to move to a more suitable location. Several universities showed interest in providing

it with a new home, including California at Los Angeles, Yale, and Northwestern, but no definite arrangements were made. Then in January, 1939, the issue was forced by the death of Cowles' father; as a result it became necessary for Cowles to make his headquarters in Chicago. Northwestern thus became a clear favorite over U. C. L. A. and Yale, but in the end the Cowles Commission did not move to any of these universities.

Schultz had begun to build a strong tradition in mathematical economics and econometrics at the University of Chicago. Then his work was cut short by his death in an automobile accident in November, 1938, and the tradition was left without its most vigorous figure. Thus the University was in a position from which the possibility of adopting a group such as the Cowles Commission appeared particularly attractive. Likewise, the University was an ideal environment for the Cowles Commission, so much so that Cowles decided to see what could be done. Through Laird Bell, his family's attorney and a trustee (now chairman of the trustees) of the University, he met Robert M. Hutchins, then President of the University, and discussed the idea with him. In the early spring of 1939, Cowles and Hutchins worked out a loose and informal relationship between the Cowles Commission and the University, under which the University provided a suite of four offices rent free on the fourth floor of the Social Science Research Building overlooking the Midway; Cowles Commission staff members were granted certain University privileges; Yntema, professor in the School of Business, became director of research of the Cowles Commission; and Jacob Viner, professor of economics, became the sixth member of the Advisory Council of the Cowles Commission. The move was made in September, 1939, the Econometric Society's offices coming along too. On September 29, 1939, the Cowles Commission was chartered as a not-for-profit corporation in the State of Illinois, and the Colorado corporation was dissolved soon afterward.

Several members of the University faculty became part-time staff members of the Cowles Commission when it

came to Chicago: Joel Dean of the School of Business, and H. Gregg Lewis, Jacob Mosak, and Oscar Lange of the Economics Department. The Colorado staff came to Chicago with five exceptions: McIntyre took a leave of absence to teach at Stanford and later resigned to accept a position at Indiana; Wald took a position at Columbia where he later became professor of mathematical statistics; Mendershausen joined the faculty of Colorado College; and Chapman and Jones also remained behind in Colorado Springs. Chapman has since devoted himself chiefly to medical research and public health work. Jones died in 1942, when his long illness ended what had promised to be a brilliant career. A memorial note to him in the 1941 Annual Report of the Cowles Commission contains these words:

“During his brief period of active participation in the work of the Cowles Commission, Herbert Jones made a number of significant contributions to statistical and econometric science. Trained in electrical engineering and equipped with an excellent understanding of fundamental mathematics, he brought to bear upon the problems of the Commission a keen and analytical point of view. His breadth of interest is readily observed from the variety and difficulty of the studies which he made. . . .

In all of these studies Herbert Jones proved himself to be a young man with an exceptional imagination and an analytical power far beyond the average. Perhaps there is no higher encomium possible than to repeat what was said about the remarkable English mathematician, W. K. Clifford, who died very young: ‘If he had lived we might have known something.’ ”

V. The early years at Chicago: 1940–1942

During 1940–1942, the fifth and sixth monographs were published. Monograph 5, *The Variate Difference Method*, by Tintner, appeared in February, 1940. It analyzes the successive differences of time series, (i.e., the year-to-year differences between adjacent numbers in a series, then the differences between adjacent differences, etc.) and uses them as the basis of a method for deciding whether one should use a straight line, or a quadratic, or a cubic, etc.

for fitting the trend of a particular time series. Monograph 6, *Analysis of Economic Time Series*, by Davis, appeared in December, 1941. It is a survey of many methods available for dealing with time series, with applications to economic situations.

Staff changes during this period were relatively few. John H. Smith, a statistician in the School of Business, joined the staff in September, 1941, and stayed until the summer of 1942 when he went to the Bureau of Labor Statistics. Leonid Hurwicz joined the staff in January, 1942, as an assistant to Lange. Aside from Cowles and Davis, Hurwicz is the only present member of the Cowles Commission staff whose association with it dates back ten years.

A summer conference was held in Colorado Springs in 1940, even though the Cowles Commission had moved to Chicago by then. Among the new participants were W. E. Deming, senior mathematician of the U. S. Census Bureau; E. A. Goldenweiser, chairman of the Board of Governors of the Federal Reserve System; Wassily Leontief of Harvard University; and Paul A. Samuelson of the Massachusetts Institute of Technology. However, with the library and computing equipment no longer available to the participants of the conference, with the added expense of moving the staff to Colorado Springs, and with the interruption of work in the office at Chicago, it was not thought worth while to continue the summer conferences.

The Annual Report of the Cowles Commission for 1940 begins with the words, "Among economic problems none is more important than unemployment of labor and other resources." It continues, "Unless there are compelling reasons for a change of plans, the long-run program of the Commission will be directed to a study of the problems centering in the flow of investment and the incomplete use of resources." There was something almost prophetic in the last statement, for the compelling reasons presented themselves within a year in the form of war. As a result, the Cowles Commission turned early in 1942 to a study of wartime price control and rationing, with a view to ap-

praising the possible policies with respect to them and the administrative devices that might be used for implementing them. Three parts of the study were planned: a theoretical analysis of the problem, an analysis of pertinent available statistical material on prices and wages, and a series of personal interviews with both buyers and sellers to learn about their actual behavior under price controls and rationing. The project was undertaken jointly with the Committee on Price Determination. It was organized under the auspices of the Price Conference of the National Bureau of Economic Research and was under the direction of Yntema and Hurwicz. A monograph was expected to be published by 1944.

Until the Cowles Commission came to Chicago, all of its funds had been provided by Cowles and his family. In 1940, another source of funds made its appearance. The Social Science Research Committee of the University of Chicago made grants so that several members of the Cowles Commission staff might employ research assistants; Melvin Reder, now associate professor of economics at Stanford University, was one of the first of these assistants. In 1942, the Cowles Commission received its first grant from the Rockefeller Foundation, for conducting the price control study. The National Bureau also contributed to the expenses of the price control study.

By 1942, something like half of the staff of the Cowles Commission had been drawn into work directly or indirectly connected with the war effort. Dean was on leave as director of gasoline rationing in the OPA in Washington. Hurwicz was teaching mathematics and statistics in the U. S. Army Signal Corps and Meteorology training programs at the Illinois Institute of Technology and the University of Chicago. Mosak was on leave as head of a section of the research department of the OPA in Washington. Yntema had been on leave in Washington as head of economics and statistics in the division of industrial materials of the Defense Commission in 1940, and was on part-time leave during the spring and summer of 1942 as a consultant to the War Shipping Administration.



Schneider Photo

JACOB MARSCHAK



Moffett Photo

THEODORE O. YNTEMA



LEONID HURWICZ

In November, 1942, Yntema resigned as director of research of the Cowles Commission and took a leave of absence, to become research director of the newly created Committee on Economic Development and organize a study of conditions favorable and unfavorable to full employment after the war.

VI. Simultaneous developments: 1943-1948

In 1939, Marschak left Oxford University to come to the United States as professor of economics at the New School for Social Research in New York. Just before taking up his duties there, he renewed his acquaintance with the Cowles Commission at the summer conference of 1939. In 1942, when Yntema made known his intention to resign, Cowles for the second time offered Marschak the position of director of research of the Cowles Commission.

At the same time, the University of Chicago was again without a senior mathematical economist, for Lange had taken a leave of absence to become visiting professor at Columbia for the years 1942-1944 and it was uncertain whether he would return. Accordingly the University offered Marschak a professorship in economics. He accepted, and came to the University and the Cowles Commission at the beginning of 1943.

During Marschak's term as director of research, which extended until July, 1948, the Cowles Commission underwent fundamental changes in several directions. The administrative structure of its relationship to the University of Chicago was reorganized. Its financial support became more extensive and more diversified. There were many changes in its staff, including the arrivals of several of the present staff. The means of making its members and their work known to the University community and to other economists and statisticians were extended. Its research program underwent a major reorientation that determined its essential character for the second ten years of its life. These developments will now be discussed in turn.

The University of Chicago handled its funds for research in the social sciences through its Social Science Research Committee. Applications for funds from outside sources such as the Rockefeller Foundation were also channeled through this committee. In the summer of 1943, to help secure better co-ordination of the research programs and fund-raising activities of the various departments and affiliates of the University, the Cowles Commission replaced the dormant Advisory Council by a new and more active Advisory Committee representing various aspects of the University's interest in the work of the Cowles Commission. The Advisory Committee originally was composed of Walter Bartky (mathematics), Garfield V. Cox (business), Simeon E. Leland (economics, chairman), Theodore W. Schultz and Viner (economics), and Louis Wirth (Social Science Research Committee). Later Neil H. Jacoby (business) and Philip Hauser (Social Science Research Committee) joined it as replacements for some of the others. It periodically received and discussed the progress reports of the research director. It also reviewed the Cowles Commission's applications to the Rockefeller Foundation for grants-in-aid. In addition to grants received from Cowles and his family, the Rockefeller Foundation, and the Social Science Research Committee of the University, the Cowles Commission also received indirect aid through the payment of Marschak's salary (and later Koopmans' as well) by the University, and through grants from the Guggenheim Foundation, the Rockefeller Foundation, and the Social Science Research Council to persons working at the Cowles Commission as guests on problems related to its program.

There were many changes in the staff during the five and a half years from 1943 to the middle of 1948; it is impractical to detail them all here. Those staff members and guests who came during this period and are no longer associated with the Cowles Commission are mentioned in connection with the research program a little further on, or in the biographical sketches.

Haavelmo had been a student and collaborator of Frisch

at the University Institute of Economics in Oslo and the University of Oslo, and had worked at several American universities under fellowships of the American-Scandinavian and Rockefeller Foundations. From 1942 till the end of 1945, he was attached to Norwegian government agencies in New York and Washington. He participated with Marschak, Wald, and others in a small econometrics seminar that met regularly in New York on weekends during 1940-1942. Marschak asked Haavelmo to become a research associate of the Cowles Commission in July, 1943. He accepted although he was not always in residence. He moved to Chicago in January, 1946, where he also became a member of the Agricultural Economics Research Group in the Department of Economics. He has been associated with the Cowles Commission as a research consultant (a new category of staff members, comprising those active but not in residence) ever since his return to Norway in March, 1947. He is now professor of economics at the University of Oslo.

Tjalling C. Koopmans, originally trained as a theoretical physicist, had studied econometrics with Tinbergen at the University of Amsterdam and with Frisch in Oslo. He met Marschak first when he visited Oxford in 1938, and again in New York in 1940 when he became a participant in the above-mentioned seminar. In December, 1943, while he was statistician to the Combined Shipping Adjustment Board in Washington, Koopmans addressed a Cowles Commission seminar. In July, 1944, under a grant of the Rockefeller Foundation, he became a research associate of the Cowles Commission. In the spring of 1946, he was appointed associate professor of economics at the University of Chicago as well.

Herman Rubin joined the staff in July, 1944, as a research assistant. He has been an intermittent staff member ever since, becoming a research associate in 1946 and a research consultant in 1952. His present position is that of assistant professor of statistics at Stanford University. Lawrence R. Klein first became acquainted with the Cowles Commission at a meeting of the Econometric Society in Cleveland in



Sturlason Photo

TRYVE HAAVELMO



LAWRENCE R. KLEIN

September, 1944. He was a research associate from November, 1944, until July, 1947, and has recently become a research consultant. He is at present a research associate both of the National Bureau of Economic Research and of the Survey Research Center at the University of Michigan. Theodore W. Anderson, Jr. was a research associate from November, 1945, to September, 1946, when he became a research consultant. He is now an associate professor of mathematical statistics at Columbia University, and editor of the *Annals of Mathematical Statistics*. Kenneth J. Arrow was a research associate from April, 1947 to July, 1949, and assistant professor of economics at the University of Chicago from October, 1948 to July, 1949. He is now a research consultant, and an associate professor of economics and statistics at Stanford University. Herman Chernoff joined the staff as a research assistant in July, 1947, and was a research associate from the spring of 1948 until September, 1949. Among his other activities was the supervision of the Cowles Commission computing staff. He is at present a research consultant, and an associate professor at Stanford University. Herbert Simon, who is professor of administration and chairman of the Department of Industrial Management at Carnegie Institute of Technology, became a research consultant in April, 1947, while he was professor and chairman of the Department of Political Science at Illinois Institute of Technology.

During the early years, the Cowles Commission made itself known through the summer conferences and through its monographs, of which six had appeared when Marschak became director of research in 1943. With the summer conferences gone, and the publication of a monograph being something less than an everyday event, the output of materials failed signally to indicate the amount or quality of research being performed. From the beginning, the staff members had published numerous articles in professional journals each year, and had presented papers at meetings of the professional societies. Marschak introduced two new devices to help bring the light out from under the bushel. First, beginning in the summer of

1943, was a series of seminars on various topics in econometrics, presented every three or four weeks at the University of Chicago by staff members or by various visitors to the Cowles Commission. The seminars were soon promoted to a regular bi-weekly schedule (except in summer) and are still conducted today.

Second, beginning late in 1943, the Cowles Commission Papers, New Series were initiated. These are reprints of the more important published articles of staff members, bound in paper either singly or in groups of two or three related articles. They are distributed free of charge to a selected list of interested people and to others who write and request individual copies. By the middle of 1948, New Series Papers Nos. 1-27 had been prepared and distributed.

During 1943-1948 the seventh, eighth, and ninth monographs were published. Monograph 7, *General-Equilibrium Theory in International Trade*, by Mosak, appeared in 1944. It extends the modern theory of general equilibrium and comparative statics, as formulated by J. R. Hicks, Allen, and others, to the field of international trade. Monograph 8, *Price Flexibility and Employment*, by Lange, also appeared in 1944. It first extends the modern theory of general equilibrium to treat money as distinct from other goods, and then analyzes the roles of price flexibility and of substitution between money and other goods in the determination of the level of employment. Monograph 9, *Price Control and Business*, describing the results of the price control study initiated in 1942, was published in 1945. Its author was George Katona, whose journalistic and research experience in both economics and psychology well equipped him to write it. He was a research associate of the Cowles Commission and in charge of the study from January, 1943, until it was finished at the end of 1944. He is currently the Program Director of the Survey Research Center and professor of economics and psychology at the University of Michigan.

The reorientation which Marschak and his new staff wrought in the Cowles Commission's research program is sketched in the following passage from the Annual Report for 1943, the first year during which Marschak was

director of research (the passage refers to three new studies that were started during the year):

“The method of the studies . . . is conditioned by the following four characteristics of economic data and economic theory: (a) the theory is a system of simultaneous equations, not a single equation; (b) some or all of these equations include “random” terms, reflecting the influence of numerous erratic causes in addition to the few “systematic” ones; (c) many data are given in the form of time series, subsequent events being dependent on preceding ones; (d) many published data refer to aggregates rather than to single individuals. The statistical tools developed for application in the older empirical sciences are not always adequate to meet all these conditions, and much new mathematical work is needed. To develop and improve suitable methods seems, at the present state of our knowledge, at least as important as to obtain immediate results. Accordingly, the Commission has planned the publication of studies on the general theory of economic measurements. . . . It is planned to continue these methodological studies systematically. The available results of mathematical analysis are currently applied and tried out in econometric investigations; conversely, new situations arising in the course of practical work present new problems to the mathematician. It is intended to make this hand-in-hand work the basis of the Commission’s activities.”

The four characteristics referred to were central to the new program of the Cowles Commission. Accordingly, brief remarks on each one follow.

“The theory is a system of simultaneous equations, not a single equation.” Consider for example the theory of the determination of the market price of a commodity. The quantity demanded by buyers depends on the price, rising when the price falls. The quantity offered by sellers also depends on price, falling when price falls. And the price adjusts itself in response to the higgling and bargaining of the market place, being driven up if there is excess demand and down if there is excess supply, until the quantities demanded and supplied are the same. Here is exhibited a system of three equations: the demand equation, the supply equation, and the price adjustment equation. There are three variables: quantity demanded, quantity supplied, and price.

It is important to notice that *none* of the three equations by itself can specify the level of even *one* of the three variables, but together the system specifies the level of all three. It is also important to notice that the number of variables to be explained by the theory is the same as the number of equations, i.e., three. These are called *endogenous* variables. There may be other variables (e.g., an excise tax) whose values are not specified by the theory but are assumed to be determined independently of the relationships described by the theory. Such variables, taken as a starting point of the explanation offered by the theory, are called *exogenous* variables. Exogenous variables are typically used to represent changes in policy or in the underlying economic environment which can effect the operation of the economic relationships described by the theory.

There do exist simple economic theories that consist of one equation only (such as a theory that relates the amount of tax receipts that will be collected under a given revenue act to the national income). But in the most interesting and important problems, the theory that is relevant is typically a system of several simultaneous equations.

"Some or all of these equations contain 'random' terms, reflecting the influence of numerous erratic causes in addition to the few 'systematic' ones." Except for equations expressing definitions, which of course must hold exactly, no one has ever found a numerical theory, i.e. an equation, that fits the relevant facts exactly. Many equations have been found that fit the relevant facts approximately, with errors or deviations that are sometimes positive and sometimes negative. This is true of the "exact" sciences as well as of economics, the chief difference being that in economics the deviations are usually not negligibly small. Accordingly, it is convenient to introduce them explicitly into each equation (except definitions) in the form of an extra term added on at the end, the value of which changes with each observation so that the equation always remains exactly true. It is assumed that the values of the deviations in any equation are determined as if by chance, as if drawn at random from a large jar containing tags with a number stamped on each one, some negative and

some positive. Such variables are called "random" or "stochastic" variables. The use of random variables here is quite realistic, even though it may appear to be somewhat artificial. Each of the major factors bearing on a particular economic relationship is presumably accounted for explicitly by a separate variable, so that only the minor factors are left to be thrown into the random term, and the cumulative effect of a large number of small unrelated causes almost always acts as if it really were random.

"Many data are given in the form of time series, subsequent events being dependent on the preceding ones." The vast majority of available statistics on prices, wages, production, income and its components, inventories, etc., are published in chronological series covering successive weeks or months or years; such series are known as time series. They are important because the economy never starts with a clean slate but is always conditioned by what has happened before, and because many theories attempt to explain economic behavior through time. In addition, cross-section data, pertaining to different families, firms, industries, regions, etc. at a single point of time, are provided by surveys and censuses. The methods of treating the two types of data are essentially the same; however, there are some differences which will not be discussed here.

"Many published data refer to aggregates rather than to single individuals." This is clear from an examination of the national income statistics or almost any other familiar economic data. It becomes important when it is realized that most economic theory pertains to individual firms or families, and that there is accordingly a gap to be bridged if the published data are to be used systematically to test economic theory.

It should be noted that all of the four characteristics of economic theory and data were well-known for many years before the Cowles Commission began its research. Walras explicitly introduced systems of simultaneous equations into economics in 1874. Although the concept of a random variable did not appear as such in economic theory until fairly recently, it nevertheless lurks at the base

of all attempts to fit equations to data—in fact, the theory of correlation and regression was built upon it in the last quarter of the nineteenth century. Time series and aggregated data have been with us for centuries. It cannot be said that the Cowles Commission contributed to the discovery of any of these important characteristics.

What *can* be said is that the men who were members of the Cowles Commission staff in the early years of Marschak's directorship, realizing that traditional statistical methods are by design unsuited to problems involving systems of simultaneous equations with random components, were among the first to devise new methods that are more suitable. Frisch had published a paper in the *Nordic Statistical Journal* in 1929 entitled "Correlation and Scatter in Statistical Variables" and an amplified version in 1934 entitled *Statistical Confluence Analysis by Means of Complete Regression Systems*, in which he foresaw and dealt with some of the difficulties that arise in regression and correlation analysis where "multicollinearity" exists, i.e., where there are other equations connecting the variables in question, in addition to the equation being studied. Then in January, 1943, in *Econometrica* there appeared Haavelmo's ground-breaking paper, "The Statistical Implications of a System of Simultaneous Equations." Although this paper is scarcely twelve pages long, it contains the beginning of some of the Cowles Commission's most important subsequent research. In particular, Haavelmo considered a three-equation theory of national income, and examined the consequences of fitting one of its equations to observed time-series data by means of the traditional "least-squares" method of regression analysis. (The term "least-squares" is used because this method selects as the best-fitting line the one that produces the smallest sum of squared deviations of the observed points from the line.)

The statistical problem in fitting a line to a set of observed points is that of deriving from observed data estimates of the numerical values of the unknown constants (parameters, as econometricians call them) in the equa-

tion of the line. For example, in Haavelmo's consumption equation, the parameters to be estimated are α and β , and the equation is: national consumption expenditure in any year equals α times national income in that year, plus β , plus a random disturbance. Because of the random components, it is impossible to find the *exact* values of the parameters. However, a very powerful general method of estimating unknown parameters, called the maximum-likelihood method, was devised by R. A. Fisher just after the turn of the century. It is difficult to describe clearly in nontechnical language, but it can be likened to the principle of trying to decide a question by considering which alternative, if true, would be most likely to have produced the evidence at hand. If Cassio and Desdemona were not in fact lovers, the chance of her handkerchief coming into his possession would be smaller than if they were; hence on the evidence of the handkerchief, their guilt is more likely than their innocence. (This ironic example illustrates the importance of making sure that the events in question are random and the importance of taking into account all available additional information, such as Desdemona's veracity as opposed to Iago's.) The maximum-likelihood estimate of a parameter is that value of the parameter which, among all possible values, would be most likely to give rise to the data actually observed. The merit of the maximum-likelihood method is that in a wide class of cases, judged by three accepted statistical criteria (known as unbiasedness in large samples, consistency, and efficiency), it yields the best possible large-sample estimates of unknown parameters.

It so happens that if an equation satisfying certain conditions is not a member of a system of equations, the maximum-likelihood estimates of its parameters are identical with the least-squares estimates; thus the least-squares estimates are the best estimates for such an equation. This had been known for a long time before the Cowles Commission came on the scene. Now to return to Haavelmo: he showed how to calculate the maximum-likelihood estimates of the parameters of his consumption equation and

showed that they are *different* from the least-squares estimates precisely because the equation *is* a member of a system of simultaneous equations. Thus, the least-squares estimates are not generally the best estimates for an equation that belongs to a system. In fact, Haavelmo showed later that they are biased and inconsistent.

Before one attempts to calculate estimates of the parameters in a system of equations, or in a *model* (as economists say), it is well to pause and ask whether the observed data can really convey any information about the parameters of the model in question. Consider, for example, a two-equation model containing a demand and a supply curve for a commodity, each relating market price to quantity sold, with no other variables. The very best that can be expected from the data here is that they will locate exactly the intersection point of the two curves (random fluctuations would mean that the location could only be estimated). But even if the intersection is exactly located, no light is thrown on the shapes and directions of the curves, because there are infinitely many pairs of curves relating price to quantity that *could* intersect at the observed point. In this case, there is more than one set of parameters consistent with the observations and hence the observations cannot determine the values of the parameters.

This property of a two-variable supply-and-demand model had been commented on by many economists, including E. J. Working, Henry Schultz, and Haavelmo. Koopmans initiated a systematic study of such problems, which he called *identification* problems because the aim is to identify the true values of the parameters among all the possible sets of values consistent with the data and with the known or assumed properties of the model. An equation of a model is declared to be *identifiable* in that model if, given a sufficient (possibly infinite) number of observations of the variables, it would be possible to find one and only one set of parameters for it that are consistent with both the model and the observations. The equations of the simple supply-and-demand model of the preceding paragraph are thus not identifiable.

There are various properties which, if known or assumed a priori about a system, will produce identifiability. For example, if it is known above that the demand curve remains fixed while the supply curve shifts, then all price-quantity observations must lie *on* the demand curve, and the shifts in the supply curve will necessarily trace out the demand curve. Then the demand curve is identifiable, but the supply curve is not. However, for most commodities, the demand curve is not known to be either more or less free from random shifts than the supply curve, so that this kind of a priori information is not typically available.

Information *is* typically available a priori as to what variables appear in each equation; such information is derived from economic theory, from previous observation, or both. For example, we know that most demand curves depend on income as well as price, so that if income rises then larger quantities of goods are demanded at the same price. This is the most frequently available and often the most reliable type of a priori information about theoretical models. Koopmans and Rubin worked out criteria using this type of information to determine the identifiability of equations in linear systems. It is important to note that the determination can be made before any data are observed at all. This is of great importance, for it is futile to try to estimate the parameters in unidentifiable equations. Hurwicz and Wald further clarified the identification problem in logical and mathematical terms.

For several years one part of the Cowles Commission staff, including T. W. Anderson, Meyer A. Girshick, Haavelmo, Hurwicz, Koopmans, R. B. Leipnik, and Rubin, worked on the development of identifiability criteria and of methods for obtaining consistent estimates of the parameters in systems of equations with random elements. In January, 1945, the Cowles Commission held a research conference on the statistical problems arising out of economic theories that are systems of simultaneous equations. The proceedings of this conference were revised and enlarged, becoming Monograph 10, *Statistical Inference in Dynamic Economic Models*, edited by Koopmans.

Contributor revisions, editorial efforts toward uniformity in notation, and exploration of alternative printing techniques all combined to delay the appearance of the monograph until 1950. By that time papers on related topics by several of its contributors had appeared in various journals, and had been included in the Cowles Commission Papers, New Series. It is the most difficult and technical of all the Cowles Commission monographs, but it is one of the most important because it presents the fruits of several years of statistical research in a field where the Cowles Commission has been a pioneer. In reviewing it for the *Review of the International Statistical Institute* in 1950, R. G. D. Allen referred to the 1945 research conference and wrote:

"A comprehensive report of their results has been long promised and eagerly awaited. . . . More than half the volume is taken up with an introductory essay by J. Marschak and the main paper on simultaneous equation systems in dynamic economics, contributed by T. C. Koopmans with the assistance of H. Rubin and R. B. Leipnik. Marschak's introduction leads into the main problems (identification and estimation) of stochastic models by considering the simple case of non-stochastic models, a good expository device. Koopmans' treatment in the main paper, again, is to start with a general survey of problems, before passing to a detailed development, first, of the problem of identification of economic relations and, then, of the derivation of maximum-likelihood estimates of the parameters in the relations. . . . Everyone seriously interested in econometrics should make the effort necessary to read, at least, Marschak's introduction and Koopmans' main contribution. From these, it is evident that the method of simultaneous equations is potentially of great value in dynamic economics, that not all the theoretical problems are yet solved, and that the decisive tests of the method in its applications have still to be made."

While the volume sets a new standard in adapting statistical methods to econometric analysis, further difficulties remain to be overcome in this area. In reviewing it for the *American Economic Review* in 1952, Guy H. Orcutt of Harvard University wrote:

"For all practical purposes, the models dealt with are restricted to linear systems of difference equations. . . . Besides an extensive treat-

ment of the identification problem with respect to such models, estimating their parameters from observational data also represents a problem central to this volume. While greatly impressed with the skill shown in attempting to handle this problem, this reviewer has many misgivings as to the applicability of the results obtained to problems of estimation facing the economist. These misgivings do not stem from any discovery of error in the deductive logical processes carried out, but rather in a failure to accept the premises as being realistic and the large sample characteristics of the estimators as applying to small samples."

In addition to Marschak's introductory survey and the long paper on estimation by Koopmans, Rubin, and Leipnik, there are papers on related problems by R.L. Anderson, T. W. Anderson, Jr., Haavelmo, Hotelling, Hurwicz, Koopmans, H. B. Mann, Rubin, and Wald. T. W. Anderson's contribution is a short summary of a paper by himself and Rubin, published in the *Annals of Mathematical Statistics* in March, 1949, and December, 1950, deriving the so-called "limited-information maximum-likelihood method," a more economical way of obtaining consistent estimates than the "full-information maximum-likelihood method" of Koopmans, Rubin, and Leipnik. It acquired the appellation "limited-information" because it yields estimates of only one or a few of the equations at a time and uses considerably less information (both theoretical and empirical) to get them. It is not as accurate as the full-information method but for reasons of cost it has always been used instead, except in small or simplified systems.

Another part of the staff, including William H. Andrews, Jr., Gershon Cooper, Girshick, Haavelmo, Klein, Marschak, and Don Patinkin, worked on the construction of economic models and the estimation of their parameters by the new methods. The construction of a model, starting from considerations of economic theory, must come before the estimation of its parameters by whatever method: the estimation of the parameters of an equation, i.e., the fitting of a graph to a set of observed points, can only proceed *after* one has decided what variables are to appear in the equation, what the form of the equation is to be

(linear, quadratic, exponential, etc.), and what the other equations of the system (if any) are like. Of course the validity of any statistically fitted equation depends heavily on whether the model chosen to begin with is realistic or not (light can be shed on this issue by checking the fitted equation against the same or, even better, against new data). This is why the construction of models is so important in econometrics.

The estimation of the parameters of the models is equally important. Their *numerical* values must be known at least approximately if predictions are to be made about the effects of various possible changes in the economic environment, and such predictions are essential if we are to choose intelligent policies. This applies whether the changes in the economic environment are brought about by deliberate policy action (such as the imposition of an excise tax or a subsidy, or the fixing of quotas on the use of certain materials) or by fortuitous but foreseeable events (examples are shifts in population and the introduction of new products such as nylon and atomic energy). It applies especially if the change, the effect of which is to be predicted, is one with which the economy has had no direct previous experience on which to base predictions. For example, if an excise is applied to a commodity that has previously been tax free, one needs to know certain parameters of both the supply and demand curves for *that commodity* in order to foretell the effect of the tax upon its price and output.

The early results of the Cowles Commission's research in this field appeared in four publications. First was a paper by Marschak and Andrews in *Econometrica* in 1944, estimating the relationship between inputs and outputs in production. Next were two papers in 1947 by Haavelmo and by Girshick and Haavelmo, on the consumption function and the demand for food, published in the *Journal of the American Statistical Association* and *Econometrica*, respectively. Fourth was Monograph 11, *Economic Fluctuations in the United States* by Klein. This was essentially completed in 1948 but additional computational work was

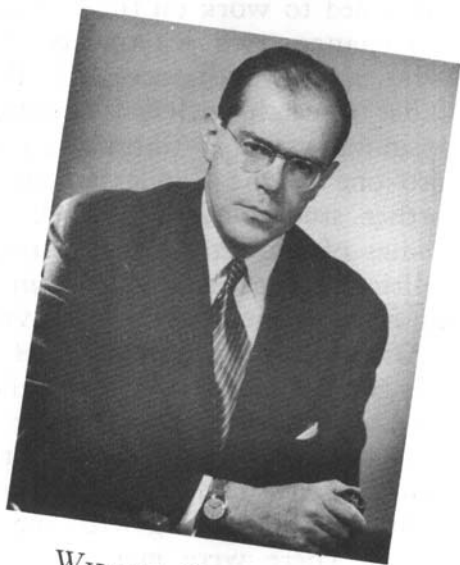
undertaken in 1949 and the book did not actually appear until the middle of 1950. It presents three economic models for the American economy, containing from three to fifteen equations, with the estimates of their parameters as obtained by both the least-squares and maximum-likelihood methods. For the large model, the limited-information maximum-likelihood method is used. It represents forward steps in several respects: it contains a good deal of material on the appropriate theoretical procedures for passing from the familiar theory of individual behavior to equations describing entire sectors of the economy; it contains the largest model hitherto fitted by the new techniques; and it presents a statistical test of the hypothesis that the deviations *are* random as assumed, as well as tests of several economic hypotheses.

In 1946, a study of the economic implication of the development of atomic energy was initiated by the Social Science Research Council under the direction of Marschak and Sam H. Schurr. Their coauthors were Simon, who has continued to work on the economic theory of technological change, two economists, E. Boorstein and H. H. Wein, and two engineers, G. Perazich and M. F. Searl. Other research included a study by Koopmans of the optimum use of a transportation system (later to grow into one of the Cowles Commission's major projects), further studies of stock-market forecasting by Cowles, studies of the econometric interpretation of history and politics, and extensive work in preparing and cataloguing mathematical tables by Davis.

Although the informality of the summer conferences was gone, there were still activities on the lighter side at the Cowles Commission. At one party in 1946, a skit was presented portraying the mock trial of Klein on the grave charge of stealing into the Social Science building late at night and finagling with the data for his econometric model. There were many witnesses and clever counsel played by various staff members, and it made delightful entertainment. The record should show, of course, that Klein was acquitted of all wrongdoing.



TJALLING C. KOOPMANS



WILLIAM B. SIMPSON

VII. *Economic theory revisited: 1948-1952*

In July, 1948, Koopmans and Marschak exchanged places in the Cowles Commission. Koopmans became director of research and also professor of economics in the University of Chicago, while Marschak became the senior research associate and continued as a professor of economics in the University. With the recent growth of the Cowles Commission, which was expected to continue, the sheer weight of administrative work involved in its affairs had become so great that the director of research had relatively little time or energy to devote to the research program and to his own research. Therefore, a new administrative position of assistant director of research was created as part of the arrangement whereby Koopmans became director of research. William B. Simpson, whose acquaintance with the Cowles Commission had begun during his tenure of a Social Science Research Council fellowship for study and research in economics at the University in 1946-1948, was chosen for the new position. He began in May, 1948 and was appointed a research associate at the same time. In September, Simpson was elected secretary of the Econometric Society by its Council. In January, 1949, he became in addition managing editor of *Econometrica*, and then in 1951 co-editor. His great energies in administrative affairs and his dedication to the development of econometrics were to make possible a substantial growth of both the Cowles Commission and the Econometric Society in the subsequent period.

In the fall of 1948, there were further changes in the organizational structure of the Cowles Commission, still preserving its highly valuable academic connection with the University. The Cowles Commission was granted the right to recommend academic rank in the University for its qualified staff members independently of their status in other departments, and thus begin to build up a faculty of its own. This made it easier to attract and hold research workers of high qualifications and attainments. The first

appointment was that of Clifford Hildreth, an econometrician, formerly of Iowa State College, who became assistant professor in the Cowles Commission in January, 1949, and associate professor in July, 1950. Hildreth's appointment was a joint one with the Agricultural Economics Research Group in the Department of Economics in the University where he has the complimentary rank of associate professor. Subsequent appointments went to John Gurland in September, 1949, conferred jointly with the University's Committee on Statistics, Gerard Debreu in June, 1951, and H. S. Houthakker in January, 1952, all as assistant professors. Gurland is a mathematical statistician, formerly an instructor at Harvard. Debreu is a mathematical economist, who joined the Cowles Commission first as research associate in June, 1950, after teaching and doing research at several French institutions and holding a Rockefeller fellowship. Houthakker is an economist, formerly with the Department of Applied Economics, University of Cambridge. Koopmans, Marschak and Simpson (ex officio) are also faculty members of the Cowles Commission. This faculty, now numbering seven men, has gradually emerged as a responsible, self-governing body under the general supervision of the new Executive Committee which was set up in the fall of 1948 in place of the University of Chicago Advisory Committee. The Executive Committee was constituted of the dean of the Division of the Social Sciences (Ralph W. Tyler), the chairman of the Department of Economics (Theodore W. Schultz), the president of the Cowles Commission (Cowles), the director of research (Koopmans), and the assistant director of research (Simpson).

While the Cowles Commission faculty was coming into being, numerous other staff changes took place but they are again too numerous to detail. Hence those who came during this period and are no longer with the Cowles Commission are mentioned later on in connection with the research program, or in the biographical sketches. Franco Modigliani, an erstwhile member of the weekend New York econometrics seminar of 1940-1942, became

a research associate in September, 1948, while he held a post-doctoral fellowship from the Department of Economics in the University. Shortly thereafter, he resigned to become associate professor at the University of Illinois and director of a research project on expectations and business fluctuations. He is now a research consultant of the Cowles Commission. Stephen G. Allen joined the staff in January, 1949, as a research assistant. He is now a research consultant and a research associate of the Applied Mathematics and Statistics Laboratory at Stanford University. Carl F. Christ became a research associate in September, 1949, after having been an informal member of the staff for the preceding year while holding a Social Science Research Council fellowship. He is now a research consultant, and an assistant professor of political economy at Johns Hopkins University. In September, 1949, William C. Hood became a research associate and a post-doctoral fellow in the Department of Economics in the University of Chicago. He is now a research consultant and an assistant professor of economics at the University of Toronto. Roy Radner became a research assistant in March, 1951, and a research associate in November, 1951. Martin J. Beckmann, I. N. Herstein, and Daniel Waterman became research associates in July, 1951. Herstein was given the complementary rank of assistant professor as well. William J. Dunaway and C. B. McGuire became research assistants in January, 1952. Aryeh Dvoretzky, professor of mathematical statistics at Hebrew University in Jerusalem, Erich Lehmann, associate professor of mathematics at the University of California in Berkeley, and Robert G. Strotz, assistant professor of economics at Northwestern University, became research consultants during 1951-1952.

Although Abraham Wald was a staff member of the Cowles Commission only briefly in 1938, he subsequently participated in several conferences sponsored by the Cowles Commission and contributed extensively to the literature of econometrics with papers in *Monograph 10*, *Econometrica*, and elsewhere. Therefore it seems appropriate at this point to pause and recall the high points of his career up to its untimely termination in an airplane

crash in southern India on December 13, 1950, in which both he and his wife were killed. He was born in Cluj (also known as Clausenburg), Rumania, in 1902. After overcoming great obstacles to his education, he became associated with the University of Vienna in 1925, where he remained until he was dismissed from his position shortly after Hitler's annexation of Austria early in 1938. In July of that year, at Frisch's suggestion, the Cowles Commission offered him a research fellowship, which he accepted. Soon afterward he moved on to Columbia University where he eventually became professor of mathematical statistics. In his fifteen years there he became one of the most distinguished contributors that mathematical statistics and econometrics have known. He solved many problems of the estimation of parameters in statistical models, and his penetrating decision function analysis (see below) is basic to much of the current research in mathematical statistics. The 1952 volume of the *Annals of Mathematical Statistics* has been dedicated to his memory.

In its new status, the Cowles Commission dealt directly with some of the organizations providing its financial support instead of through the University of Chicago, while of course all contracts and applications for funds were first approved by its Executive Committee. Support continued to come from Cowles and his family, from the University in the form of the salaries of the two senior faculty members and the free use of facilities, and from the Rockefeller Foundation in the form of a grant for the project, "Foundations of Rational Economic Policy." Fellowship aid for persons working in econometrics at the Cowles Commission was provided by the Social Science Research Council, the Rockefeller Foundation, the University of Chicago, and various sponsors in Canada and Europe.

In addition, the Life Insurance Association of America made a grant in 1948 to help finance the study begun in 1946 of the economic implications of the development of atomic energy. The Cowles Commission entered into a contract with the RAND Corporation beginning in January, 1949, for the conduct on a cost basis of a research

project called "Theory of Resources Allocation." The Cowles Commission entered into another contract with the U. S. Office of Naval Research beginning in July, 1951, for the conduct of a research project known as "Decision-Making Under Uncertainty," also on a cost basis. For the most part, these grants and contracts are for periods of two or three years, and are subject to renewal.

Concurrent with this growth, the Commission gave thought to adjustments in organizational structure which would recognize formally realignments of functions which had developed since 1948 and which would better prepare the organization to meet the problems of the future. Although the plans outlined in the 1950-1951 Report did not all reach fruition in the current year, an initial step was taken by the appointment of an executive director to serve as the chief executive agent of the Commission. Simpson was named to the new post as of July, 1951. The executive director is responsible to the executive committee (of which he is a member) and to the board of trustees, and together with the director of research is responsible for advising those bodies on matters related to the interests, aims, and policies of the Commission.

From 1948 to the present, the research of the Cowles Commission has proceeded along the lines laid out by Marschak with no fundamental changes in philosophy, but with important amplifications and changes in emphasis. In particular, there was a relative shift toward theoretical work to obtain better models preparatory to another phase of empirical work. There was also more concentration on the proper choice of mathematical methods (see below). The central part of the program, including the four projects mentioned in preceding paragraphs, can be described under the headings *actual behavior* and *rational behavior*. The headings *statistical methods*, *mathematical tools*, and *special studies* include ancillary research on analytical tools and several other studies. "Actual behavior" requires no special definition; it is behavior as it occurs in the real world. "Rational behavior," or as it is sometimes called "optimal behavior,"

is defined as that behavior which best attains the goal (utility, profit, survival, growth, etc.) of the individual or group whose behavior is in question. The study of actual behavior is the attempt to find general laws that describe behavior as it occurs, or would occur, under specified circumstances. The study of rational behavior is the attempt to discover what kind of behavior on the part of an individual or group in specified circumstances would most completely achieve the goals pursued; it presupposes that the goals are known and stated in objective terms, and that their probable achievement or lack of achievement as a result of following a particular pattern of behavior can be discovered. Studies of these two types may be called "descriptive studies" and "prescriptive studies," respectively.

There is a good deal of overlapping between the descriptive and the prescriptive studies for the following reasons. First, in setting up models of actual behavior in a world where monetary and material matters are of great importance, it is convenient and is often a good approximation to reality to assume, as a basis for such models, that individuals and firms do behave rationally. Thus, the assumption of rationality enters into many theories of actual behavior. Second, in order to prescribe what one individual or group should do in order to achieve his or its goals, the economic doctor must know how *other* individuals and/or groups will behave in the future, and in particular how they will respond to the actions of his patient. This requires knowledge about the actual behavior of others, whether it is rational or not. Thus prescriptive studies draw on the results of descriptive studies. Because of this two-way overlapping the distinction must be regarded as an expository device, and it must be remembered that an accepted description or prescription may become inapt if either the prescriptions or descriptions upon which it is based turn out to be incorrect.

The five headings mentioned above will now be discussed.

Actual behavior can be investigated by the techniques outlined in the previous section. Several such studies were undertaken. Andrew W. Marshall tested Klein's fifteen-equation model with its estimated parameters, as presented in Monograph 11, by checking whether it fitted the data for 1945-1946 as well as it did the 1921-1941 data from which its parameters had been estimated. He found that of the twelve random equations (the other three being definitions), only seven could be considered valid in the postwar period; of the remaining five, two were of doubtful validity and three were clearly contradicted by the postwar data. Christ, starting from Marshall's work, revised those equations of Klein's model which did not pass Marshall's tests. He then re-estimated the parameters of the revised model using data for 1921-1947, omitting the war years 1942-1945, and then tested the results against data of 1948, using tests similar to Marshall's and several other tests. He found that the revised and refitted model performed better on extrapolation to 1948 than Klein's had on extrapolation to 1945 and 1946, but it still was not in itself an accurate instrument for prediction. Christ's work, containing also a summary of Marshall's work, appeared in *Conference on Business Cycles*, published in 1951 by the National Bureau of Economic Research. These two studies were among the first to act on the precept that econometric models, like any other theories, must be tested by their performance in making predictions.

Allen worked on equations describing the inventory behavior of firms in the linseed oil industry. Hildreth has used cross-section data from farms in Iowa to estimate the technological relationship between agricultural inputs and outputs. Together with Frank Jarrett, research associate in agricultural economics at the University of Chicago, he has worked on an econometric study of U. S. livestock production. Arnold C. Harberger, now of Johns Hopkins University, set up import-demand equations for the United States and estimated the elasticities of demand for various types of imports and for imports as a whole.

Harry Markowitz, now of the RAND Corporation, studied the financial behavior patterns of open-ended investment trusts and set up equations to describe them; the statistical results are in preparation. George Borts, now of Brown University, constructed a model of the relations between inputs and outputs in the railroad industry, which is different from most industries in that railroads do not control their own outputs, due to the common carrier law; a part of his work appeared in *Econometrica* in January, 1952.

Rational behavior is typically treated in studies that seek to answer questions like this: given an individual or a group, and given the goals of the individual or the goals of the group or its members, and given some kind of environment in which the individual or group operates, what behavior will lead to the most complete achievement of the goals? The Cowles Commission's work in this field springs from three somewhat related origins.

First, Koopmans had been thinking intermittently, ever since his wartime days with the Combined Shipping Adjustment Board, about a systematic way to find the optimum routing plan for empty ships when there are fixed tonnages of cargo per month to go from each port to other ports. The "optimum" routing plan is the one, among all those that deliver the required fixed amounts of goods, for which the required number of ships in service is smallest. Clearly the optimum routing will not send empty ships to any port which is receiving more goods than it is shipping because such a port is already an exporter of empties and it would be wasteful of ships to send any more empties there. Similarly, if New York and Liverpool are exporters of empties and Philadelphia and le Havre are importers of empties, then it would be silly to send empties from New York to le Havre if empties were also going from Liverpool to Philadelphia, because it would take less time for the empties from New York to go to Philadelphia, and for those from Liverpool to go to le Havre. As a result of this shift less shipping time would be used up in empty voyages, so the number of ships required would be decreased. Considerations of this sort indicate a possible, if unsystematic, approach.

In seeking a systematic approach, Koopmans hit upon the principles of an analytic method that was first known as "linear programming" but has now come to be called more accurately "activity analysis of production." It has grown up from several converging sources, including analyses by Wald and von Neumann of the Walrasian general equilibrium theory, discussions in welfare economics, Leontief's interindustry analyses, and the programming activities of government administrators as studied in the U. S. Air Force by G. B. Dantzig and M. K. Wood. It is *similar* to the traditional economic theory of production in that it seeks first to establish the technological relation between inputs and outputs, i.e., to answer questions like these: if the quantities of all inputs and all outputs but one are held at specified levels, what is the maximum quantity of the remaining output that can be produced? Alternatively, if the quantities of all outputs and all inputs but one are to be held at specified levels, what is the minimum quantity of the remaining input that is required? For example, consider cattle raising, where inputs are grazing land, feed, and labor, and outputs are milk and beef (the cattle themselves are purposely not mentioned, as they are a sort of "intermediate product" that is used up in the process of producing the final outputs of milk and beef). A successful analysis of this industry, or of a firm engaged in it, would be able to tell which combinations of land, feed, labor, milk, and beef are *achievable*, and which are not (i.e., one man using one acre of land and one sack of feed per week cannot produce fifty gallons of milk and fifty pounds of beef every day). Further, it would be able to tell how much milk could be gotten from a given combination of land, feed, and labor if the amount of beef to be produced per week was specified, or how much labor would be required to produce specified amounts of milk and beef per week using a given combination of land and feed, etc. A combination of inputs and outputs is said to be *efficient*, if, when that combination is the status quo, it is impossible to increase the rate of any output without at the same time increasing some input or decreasing

some other output. Note that for any inefficient combination, there are efficient combinations that are preferable to it in the sense of producing more outputs with the same inputs, or the same outputs with less inputs. Note also that to move from one efficient combination to another, it is necessary to give up some of one commodity (be it output or input) to get more of another; technological "exchange rates" between commodities can be found showing how much of one can be gained by giving up a unit of another. Note finally that not all efficient combinations are rational or optimal. For example, if we should all become vegetarians, then any combination that produced beef at the expense of milk, even if it did so efficiently, would become irrational. As a more realistic example, suppose that certain amounts per week of milk and beef are being produced efficiently; that to consumers, one gallon of milk is worth one pound of beef; and that the combination of land, feed, and labor actually being used to produce a pound of beef would, if turned to dairy cattle, produce two gallons of milk. To continue in this state of affairs is not rational: if beef-raising were curtailed, and dairying were expanded, then for every pound of beef given up *two* extra gallons of milk could be had, and this would represent a net gain because consumers would have been willing to give up a pound of beef for only one gallon of milk. The rational or optimal combination of milk and beef is obtained by increasing milk production and decreasing beef production to the point where no further gain is obtained by continuing the process. This point may be reached either because consumers find that a pound of beef has become more desirable than a gallon of milk now that they have so little of it and so much milk, or because producers find that they cannot get another two gallons of milk from the resources that are freed by producing one less pound of beef now that they are producing more milk and less beef, or because of both. These developments are related to the economic principles of diminishing utility and diminishing returns to changes in input-proportions, respectively.

Thus in finding the optimal combinations of inputs and outputs, there are three successive winnowings of all the conceivable combinations. First, the achievable ones are selected and the others are discarded. Second, from the achievable combinations the efficient ones are selected and the others are discarded. (These two steps can be accomplished by means of purely technological knowledge, with no notions of which commodities are highly valued and which ones are not.) Third, from the efficient combinations the optimal one(s) is (are) selected, by considering the relative values to producers and consumers of the inputs and outputs. In these respects, activity analysis is like any other good theory of production.

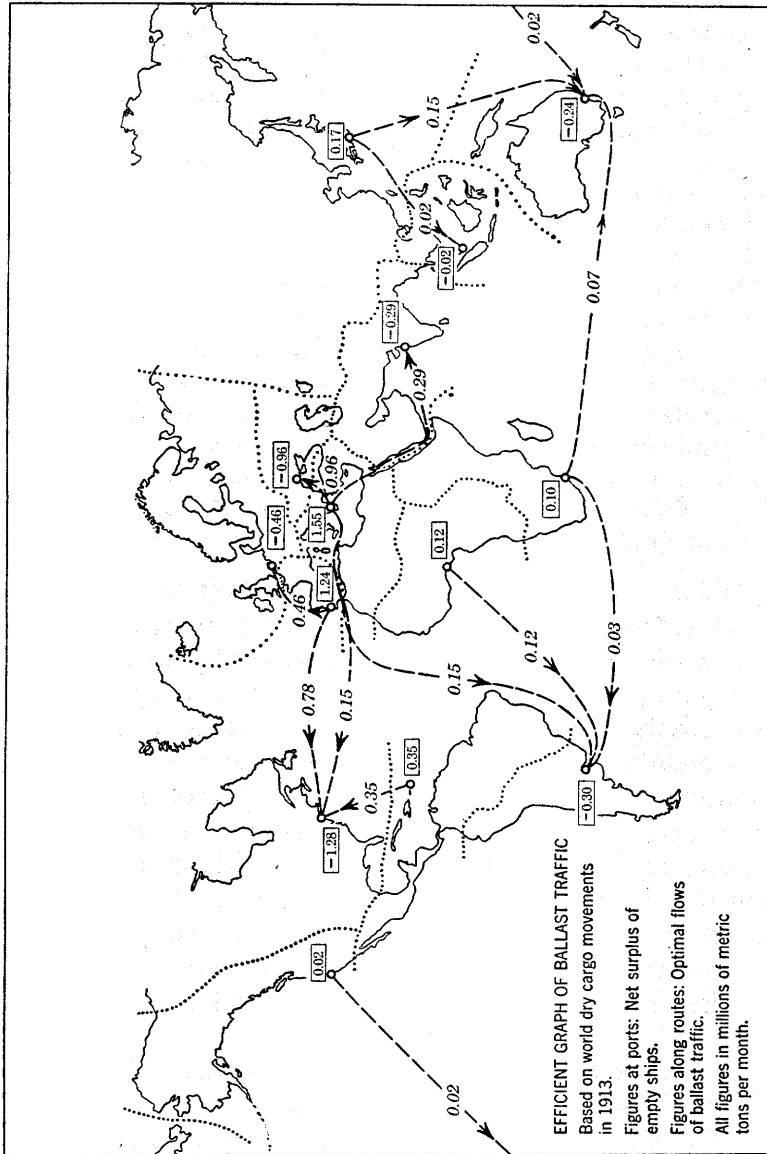
Activity analysis *differs* from the traditional economic theory of production by being more specific about the technology behind the concepts of achievable and efficient combinations and the substitution of one commodity for another. It regards production as resulting from a number of separate activities, each one of which can be operated on a large or small scale, and each one of which uses certain inputs and produces certain outputs in an assumed fixed proportionality to the scale of operation. Thus any possible combination of scales of operation of the respective activities produces an achievable combination of inputs and outputs. If there is to be any substitution of inputs or outputs for one another in production, it cannot be accomplished *within* any one activity, but must come about through changes in the scales of operation of the various activities, resulting in a partial substitution of some activities for others. In the dairy-beef case above, one might substitute the activity of grazing for that of using feed, and thus effect a substitution of land for feed. Or one might substitute the activity of producing a breed of dairy cattle for that of producing a breed of beef cattle, and so substitute milk for beef.

In the shipping problem the outputs are tonnages delivered from each port to each other port, the input is the use of ships, and there are two separate activities corresponding to the dispatching of ships from each port

to each other port, i.e. with and without cargo. The original problem of accomplishing a certain pattern of shipping with the smallest number of ships then is seen to be the problem of finding the efficient combination of flows of empty and loaded ships when the tonnages to be shipped (outputs) are given. It is purely a problem of physical efficiency (even if more than one firm is involved) and not a problem of an economic optimum because there is no question of whether the stated pattern of shipping is worth its cost as compared with other possible patterns. But economic optimum problems can also be handled with this analysis: if the relative values placed upon ships and tonnages shipped on different routes are known, then the rational or optimal shipping plan can be found.

In June, 1949, the Cowles Commission sponsored a conference in Chicago on activity analysis, at which papers were presented by economists, mathematicians, statisticians, and administrators. The greater part of the proceedings of the conference were published in 1951 as Cowles Commission Monograph 13, *Activity Analysis of Production and Allocation* edited by Koopmans. (Monograph 12 will be discussed below.) It begins with a long section on the theory of programming and allocation, followed by a section on application of allocation models. The shipping problem appears in a paper by Koopmans and Stanley Reiter (formerly of the Cowles Commission, now of Stanford University) entitled "A Model of Transportation." Other applications appear in "Development of Dynamic Models for Program Planning" by Wood and Murray A. Geisler of the U. S. Air Force, "On the Choice of a Crop Rotation Plan" by Hildreth and Reiter, "Effects of Technological Change in a Linear Model" by Simon, and "Representation in a Linear Model of Nonlinear Growth Curves in the Aircraft Industry" by Wood. In conclusion there are two shorter sections on mathematical properties of convex sets and problems of computation (see below, under the discussion of mathematical tools).

In reviewing the volume for the *American Economic Review* in 1952, Robert Solow of the Massachusetts Institute



of Technology wrote as follows:

"Like all things good for body and soul, this book is going to hurt. Nevertheless there is no escaping the fact that everyone seriously interested in economic theory ought to keep a stiff upper lip and attempt to read it. This will be no easy task, since mathematical concepts whose use in economics is relatively new abound; . . . Still, by careful selection and constant attention to the *economics* of what is being said, almost everyone can profit.

It must be said at once that many of the general economic results stated in the book are not new; they are, in other forms, already part of the literature of welfare economics and the theory of production. What the new methods offer are first, a clearer insight into the meaning of some established propositions, such as those concerned with the much more than institutional significance of a set of price ratios in the optimal allocations of resources, and second, a framework for formulating many kinds of optimum-problems in such a way that they lend themselves to systematic computation. . . . In sum, the subject matter of this anthology is one of the frontiers of detailed and aggregative economic theory. It deserves a serious try."

Debreu devised a measure for the extent to which a given allocation of resources is efficient, being the smallest fraction of the given input levels (all reduced proportionally) that permits the community to attain through efficient redistribution of outputs the same standard of living for each member as prevailed under inefficient utilization of resources before the cuts in inputs. It appeared in his paper, "The Coefficient of Resource Utilization" in *Econometrica* in July, 1951. Kirk Fox undertook a study of the routing of railroad boxcars in the United States. Markowitz in his study of the behavior of investment trusts is inquiring whether their portfolios are efficient or not, i.e., whether they achieve a minimum risk for their rate of return.

The second source of the Cowles Commission's work on rational behavior lies in von Neumann and Morgenstern's *Theory of Games*, Wald's *Statistical Decision Functions*, and related work. In their book von Neumann and Morgenstern ask questions like these: given a game and its rules, how should a player behave so as to win as much as possible on the average over a large number of plays of the

game, and what is the amount that he will win on the average if he so plays? So far the chief applications of the theory as such have been to games (e.g., chess, poker) and to problems in military strategy and some work in the economics of bilateral monopoly. But it soon became evident that many practical situations calling for decisions are very much like a one-person game in which the winnings depend on the decisions of the "player" and on the (perhaps unknown) "state of nature"; it is as if the player had nondiscriminating "Nature" as his "opponent," instead of another player who is hostile and out to win as much from him as possible. With this realization, the formal apparatus of the theory of games was taken over and applied to decision-making in many familiar situations, with a view to finding out what is the rational behavior appropriate to each. For example, suppose a monetary authority such as the Federal Reserve Board were making an estimate of whether the coming year would bring inflation or deflation if no action were taken in order to decide whether to decrease or increase the money supply. This can be regarded as a game played by the Federal Reserve against an economic "Mother Nature" with the Federal Reserve winning if it makes the right decision and losing if it errs. But since the consequences of deflation are most serious from most viewpoints than those of equally severe inflation (with severity measured let us say by the size of the fiscal deficit or surplus required to maintain stability), the Federal Reserve must regard itself as losing more if it prepares erroneously for inflation than if it prepares erroneously for deflation. Therefore it should be willing to run a bigger risk of predicting deflation incorrectly than of predicting inflation incorrectly. Its rational estimate of what the coming year will bring is not the unbiased estimate, but is instead an estimate *biased* somewhat in favor of preparing for deflation. Furthermore, while the range of uncertainty of the estimate presumably can be reduced up to a point if more resources are invested in the estimation process, the optimal extent to which the Federal Reserve should do this is found by balancing the expense against what the expense buys,

namely the resulting reduction in the expected loss due to erroneous decisions. Wald's *Statistical Decision Functions*, published in 1950, is a formalization of this approach.

The accepted theory of the behavior of a business firm under competitive conditions is based on the assumptions that the firm is concerned only with flows of inputs, outputs, and sales, not with stocks of assets and debts, and that the firm knows its cost curves and demand curves exactly so that it can tell just how much profit it will make from any given level of output. For several years Marschak had been interested in making this theory more realistic by introducing the assumption of uncertainty together with the firm's asset and debt structure—particularly its liquid assets and inventories, because as has long been recognized the most compelling reason why these assets are desirable is the fact of uncertainty about future demand, prices, or other economic factors. His paper entitled "The Role of Liquidity under Complete and Incomplete Information," in the *American Economic Review* for May, 1949, and an earlier paper by Hurwicz, "Theory of the Firm and of Investment," in *Econometrica* for April, 1946, present work in this field.

As a different example, suppose that a firm's daily sales are not exactly known in advance, but are determined as if by being drawn at random from a hat containing numbers; that prices are constant; and that there are certain costs of ordering and storing inventories and certain costs of being caught "out of stock." This is similar to a game between the firm and the market; there is an optimal inventory policy for the firm telling, in terms of the numbers that are in the hat and the various costs, how low the firm should let its stocks get before reordering and how much it should order at a time, so as to minimize the total of all three types of cost. Further complications arise if the numbers in the hat are not known, so that the firm does not even know what its sales will be on the average nor how widely they will fluctuate, or if prices are assumed to be random variables and the firm speculates in inventories. Marschak, Arrow, and T. Harris of the RAND Corporation have published a paper on this work, "Opti-

mal Inventory Policy," in *Econometrica*, for July, 1951. Other work in the area of decision-making under uncertainty, much of it using the decision-function approach, has been done by Arrow, Debreu, Hurwicz, Markowitz, Marschak, Radner, and Erling Sverdrup.

The third source of the Cowles Commission's work on rational behavior lies in welfare economics, and the attempt to deduce from the preferences of individuals a concept of social preference or of the general welfare. Monograph 12, *Social Choice and Individual Values* by Arrow, published in 1951, is addressed to this problem. Arrow assumes that each individual has a consistent value scale which ranks all the possible states of society in the order of his preference, and then he uses symbolic logic to try to deduce from this a social preference scale which has certain reasonable properties. He proves that it is impossible to do so, unless the preferences of the individuals are sufficiently in agreement in the beginning. Further work in this area by Hildreth and Markowitz and also by Leo Goodman is described in the reports on research activities for 1951-52 and 1950-51.

Statistical Methods received further attention during this period with concentration in four areas. The first is an expository monograph (No. 14, *Studies in Econometric Method*) being edited by Koopmans and Hood, to accompany Monograph 10 and offer its conclusions and some new results in more accessible and usable form. The second consists of inquiries into the extent and direction of the bias inherent in the least-squares method of estimating the parameters of econometric models, and more generally, into the consequences of using models that are incorrect. This work has been executed chiefly by Allen, Jean Bronfenbrenner (now of the Department of Commerce), Harberger, and Hurwicz. Some of it will appear in Monograph 14. The third is the application of the decision function approach to the problem of finding the best estimates of the parameters of econometric models, along the lines indicated in the monetary policy illustration mentioned earlier. Hildreth, Hurwicz, Radner, and Sverdrup were engaged in this work. The fourth is the theory of

statistical procedures to deal with time series where the successive random terms are interdependent, to which Gurland has made several contributions.

Mathematical tools for handling of problems in activity analysis had to be developed or adapted from branches of mathematics that had been little used in economics previously. The essential mathematical concept in activity analysis is the maximization of a function (value or profit) of several variables (inputs and outputs) when certain *inequalities* among the variables must be satisfied (when input levels are given, output cannot be greater than a certain maximum achievable amount). When the relationships in question are linear, the mathematics of such inequalities turns out to be the theory of convex bodies or sets. Murray Gerstenhaber, Koopmans, and Morton Slater have been chiefly responsible for this work, with Slater extending his research to nonlinear relationships as well.

Special studies includes, principally, *Economic Aspects of Atomic Power* by Schurr and Marschak with contributions by Simon and others, published in 1950. It contains the results of the study mentioned at the end of the previous chapter. It attempts to analyze the effects that the peacetime development of atomic energy may be expected to have on particular industries that use large quantities of either heat or electricity, which are the forms that atomic energy is almost sure to take, and on the underdeveloped areas of the world. The method in brief is to consider the probable costs of atomic versus heat and hydroelectric energy in various industries and geographic areas, and also the probable demands for new energy supplies. This work is closely related to the Cowles Commission's research on technological progress pursued by Simon and Debreu. In reviewing the atomic energy study for the *American Scientist* for January, 1951, Kirtley F. Mather wrote:

"This is in many ways an extraordinarily significant book. It undertakes the unprecedented task of assaying the social consequences of the practical application in human affairs of newly discovered scientific knowledge, even before the technologic problems pertaining to that application have been solved. . . . And it accomplishes this extremely difficult project by teamwork organized on a scale rarely observed even in the

most complex research enterprises. Its ingenious methodology provides a pattern for procedures that may well be emulated by research groups concerned with many varied problems in quite different aspects of the broad topic of the social implications of science."

There was levity amid the serious research in this period too. The most notable bit was a skit by some of the junior staff members and others burlesquing the department of economics and its affiliates in songs set to the music of Gilbert and Sullivan's operas and other familiar melodies. The Cowles Commission was featured in this one, to the tune of "The American Patrol" march:

*We must be rigorous, we must be rigorous,
We must fulfill our role.
If we hesitate or equivocate,
We won't achieve our goal.
We must investigate our systems complicate
To make our models whole.
Econometrics brings about
Statistical control!*

*Our esoteric seminars
Bring statisticians by the score.
But try to find economists
Who don't think algebra's a chore.
Oh we must urge you most emphatically
To become inclined mathematically,
So that all that we've developed
May some day be applied!*

Its exact authorship is surrounded by a certain degree of obscurity, which perhaps is just as well.

VIII. Looking back and looking forward

Since 1932, the motto of the Cowles Commission has been *Science is Measurement*. It was originally suggested by one of Davis' favorite quotations from the British physicist Lord Kelvin, to the effect that when you can measure what you are speaking about, you know something about it, but when you cannot measure it, your knowledge is of a meager and unsatisfactory kind. Although the motto was

inspired by a venerable source, it has been criticized several times by social scientists on the ground that not all science is measurement, even if the term "measurement" is given a very broad meaning. While this is admitted, tradition and the ideals of precision and empiricism are on the side of retaining the original motto. However, in 1952 a partial change was suggested by Clifford Hildreth to make the meaning more appropriate and still to preserve some continuity with the original. The suggestion was accepted, and accordingly the new motto of the Cowles Commission is *Theory and Measurement*. It will be inscribed in the emblem that has carried the motto since the beginning.

In twenty years, a characteristic approach to research has grown up at the Cowles Commission. This is true in a methodological sense, as the preceding pages show. It is also true in an operating sense. The work of the Cowles Commission has been characterized from the beginning by a great deal of discussion and cooperation among staff members. The seminars and New Series Papers have been helpful in this activity, but they are rather in the nature of finished products. Far more important in the working stages are the hectographed "Cowles Commission Discussion Papers." As currently stated on the first page of each, these are "preliminary materials circulated privately to stimulate private discussion and are not ready for critical comment or appraisal in publications." Since 1947 the papers have been numbered consecutively in three series, and in the five years down to June 30, 1952, there have been 143 in economics and 74 in statistics. Recently a separate series has been inaugurated for mathematics papers, which formerly were included in the other series. There have been 14 of these to June 30, 1952. Each is circulated to the staff and guests and to a group of other interested persons in the United States and abroad. Each is typically presented by its author or authors at an informal staff meeting, where it gets a thorough going-over by the staff and guests. Following such criticisms, and written comments received from those too far away to attend the meetings, papers commonly undergo several revisions, usually with further discussions and comments on each, before being ready for

publication (of course not all are published). In addition to the staff meetings and discussion papers, there is a still more informal level of communication, that of private conferences and correspondence often extending across the seas.

This cooperative approach to work in progress serves several purposes: authors have the benefit of keen criticism of their research while they are working on it; preliminary results are circulated to other workers in the field more quickly than regular channels of publication permit, a larger community than the resident staff of the Cowles Commission is enabled to participate in its work; and the cross-fertilization of ideas that is so important to research is fostered.

The Cowles Commission has always been partly international in character, even while its home was in Colorado Springs. Particularly since the end of World War II this feature has been enhanced by the regular stream of fellows and other visitors from outside the United States who have come as guests for various periods of time. This international flow goes on in both directions. Several Cowles Commission staff members have traveled in other countries as fellows, lecturers, or consultants from time to time, including Anderson, Arrow, Klein, Koopmans, Marschak, Tintner, and Wald. Other present or former staff members are associated with universities in several countries (Dvoletzky, Haavelmo, Hood, Patinkin, Reiersøl, and Sverdrup).

Some members of the Cowles Commission staff offer or have offered courses in the University of Chicago (in the Department of Economics, the Committee on Statistics, the School of Business) and occasionally elsewhere. This has been the case since the Cowles Commission came to the University in 1939.

The ideas and methods developed by the Cowles Commission and by people working in association with it are being taken up, in a number of instances, by economists in other institutions and in government. Several examples follow. Klein is continuing his studies in constructing models of the United States economy at the Survey Research Center of the University of Michigan. T. M. Brown, D. J.

Daly and others in the Canadian Department of Trade and Commerce in Ottawa have been working since 1947 on a systematic program of constructing econometric models of the Klein type and estimating their parameters for purposes of prediction and policy advising. Brown's paper, "Econometric Research and Forecasting" presented before the Econometric Society in Boston in 1951, is a preliminary account of this work. A second paper of his entitled "Habit Persistence and Lags in Consumer Behaviour," in *Econometrica*, for July, 1952, concerns another part of it.

The limited-information method of estimation, described in Section VI, is being used experimentally in several places, including the U. S. Department of Agriculture under the direction of Karl Fox; a U. S. Treasury project under the direction of Francis M. Boddy of Minnesota; at Iowa State College under the direction of Gerhard Tintner and John Nordin; and at the University of California under the direction of George S. Kuznets.

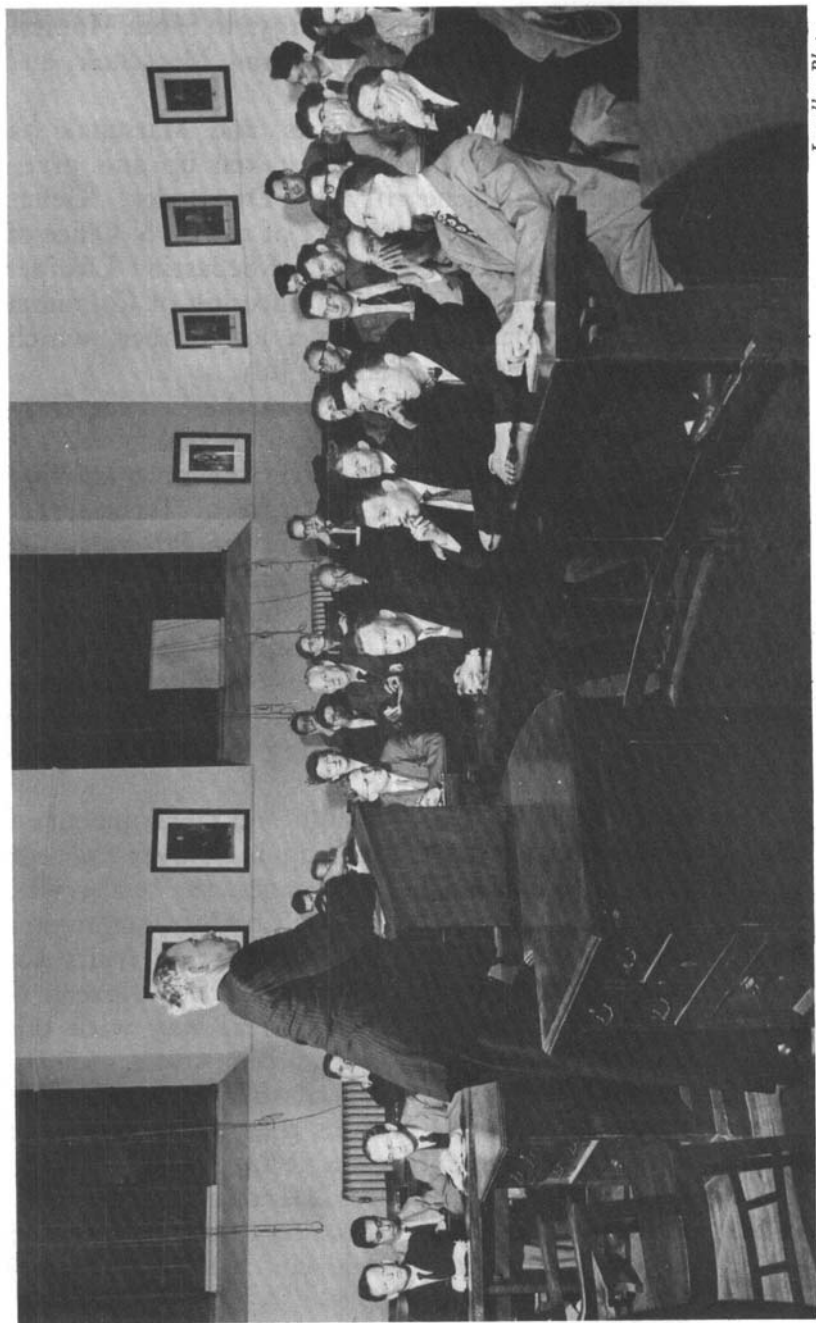
There has been regular cooperation between the Cowles Commission and a research project on expectations and business fluctuations conducted jointly by the Bureau of Business Research of the University of Illinois and the Public Opinion Research Center of the University of Chicago, under the leadership of Franco Modigliani. Arrow's work on social values has been discussed intensively by a joint seminar of social scientists and mathematicians at the University of Michigan early in 1952. Marschak's work on the theory of teams and organizations, described in the report on research activities in 1951-52, was presented at a colloquium on risk and uncertainty organized by the Centre Nationale de la Recherche Scientifique with the aid of the French Government and the Rockefeller Foundation held at the Institut Henri Poincaré in Paris in May, 1952. Other participants in the colloquium associated formally or informally with the Cowles Commission were Arrow and Edmond Malinvaud, who was a guest of the Cowles Commission in Chicago during 1950-1951. A conference on design of experiments on decision processes, organized by the University of Michigan

group, is to be held in the summer of 1952 in Santa Monica, California in which Hildreth, Koopmans, Marschak, and Radner will participate.

The joint work of Arrow, Harris, and Marschak on optimal inventory policy has been taken up and given greater mathematical generality by Dvoretzky, Kiefer, and Wolfowitz on a logistics project of the U. S. Office of Naval Research under the direction of Sebastian Littauer of the Department of Industrial Engineering of Columbia University. This work resulted in a long paper, which appeared in *Econometrica* for April and July, 1952.

Activity analysis, developed both at the Cowles Commission and in the U. S. Air Force in Washington, has been a stimulating element in practical programming studies carried on at Carnegie Institute of Technology. "Blending Aviation Gasolines—A Study in Programming Interdependent Activities in an Integrated Oil Company," by W. W. Cooper, A. Charnes, and B. Mellon, in *Econometrica* for April, 1952, presents the results of their application of activity analysis to the problem of gasoline blending. Melvin Salvesson of the University of California at Los Angeles is applying programming methods to problems of production scheduling.

This brings up to date the growth and development of the Cowles Commission. In thinking back over the last twenty years as portrayed in these pages, the reader will realize that much of the work of the Cowles Commission is of an abstract nature, and that many of its fruits are not likely to be reaped in the immediate future. Nevertheless, its work is connected in a very real way with the fundamental problems of a free and democratic society. It is by learning to predict in detail the consequences of *general* economic and social policies that we will be best able as a society to achieve desirable objectives without resort to direct controls over individual economic behavior. In the direction of learning to predict, research like that of the Cowles Commission should continue to yield important dividends in the future.



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COWLES COMMISSION SEMINAR

RESEARCH ACTIVITIES

July 1, 1951–June 30, 1952

- I. *Formulation of individual and social objectives*
- II. *The pursuit of given objectives under certainty*
- III. *The pursuit of given objectives under uncertainty*
- IV. *The study of actual economic behavior*
- V. *Concepts and tools of research*

Economics is both a descriptive and a prescriptive science. In a descriptive sense the economist studies the actual economic behavior of individuals and firms, singly or in groups, in a given environment. The prescriptive side of economics has two parts: the evaluation and selection of the most desirable social and economic objectives from among all those possible, and the evaluation and selection of the most effective means for achieving chosen objectives.

Cowles Commission research of the past year has contributed to both these areas of economics. Essential to the establishment of a prescriptive science is the delineation of objectives and their formulation in precise terms. Part of the work of the Commission, reported in Section I below, has been concerned with this task. Sections II and III, on the other hand, report on theoretical studies of the Commission which assume some individual or social objective as given and evaluate the effectiveness of different forms of behavior or organization in accomplishing that objective under a variety of circumstances.

The descriptive phase of Cowles Commission work is covered principally in Section IV, which reports on empirical studies of actual economic behavior. Section V describes the development of the conceptual, statistical, and mathematical tools which serve the substantive research.

Research during the year was influenced by three working conferences, two held at the Commission and one held

in Washington, D. C. From October 29 to November 1, 1951, a small, intensive conference on Decision-Making under Uncertainty started off a Commission research project of the same name, initiated under a contract with the Office of Naval Research. In early January, 1952, staff members of the Commission participated in the Third Annual Logistics Conference in Washington, D. C., sponsored jointly by George Washington University and the Office of Naval Research. In April, the Commission was host to colleagues from the Bureau of Business and Economic Research of the University of Illinois and the Department of Industrial Management of the Carnegie Institute of Technology for an intensive three-day conference on Business Decision-Making. Participation in these conferences was a reflection of as well as a stimulant to, the research of the Commission during the year.

I. Formulation of individual and social objectives

The traditional theory of individual choice starts with the assumption that the individual has a consistent preference (or indifference) between any two given *states of life*. It is often assumed that, if the *states of life* can be catalogued by a finite set of reference numbers (such as rates of consumption of specific goods and services), then the preference ordering can be represented by a numerical "utility function" of these numbers.

This function takes on the higher value for the preferred item in each pair of *states of life* under comparison, and the same value for the item in an indifferent pair. However, the number system may not be rich enough to provide a different numerical label for each set of mutually indifferent *states of life*. This will be the case if in the preference ordering one aspect of the *state of life* (say, the chance of escaping death) receives absolute priority over another aspect (say, the consumption of cigarettes). Aware of this logical possibility, known as a "lexicographic" ordering, Gerard Debreu has formulated conditions for a

preference structure under which a numerical utility function does indeed exist. Visiting colleagues from the University of Michigan, the psychologist Clyde H. Coombs and the mathematician Robert M. Thrall, and an economist from Oxford University, I. M. D. Little, discussed related problems in staff meetings and seminars.

The connection between a utility function and the theory of choice is simplest in the case where the individual can by his own action choose, with certainty of attainment, any state of life (or "outcome") within a given set of states (known as his "opportunity set") and no others. If consistent and rational, he will then obviously select a state of life as good as or better than all other states open to him. The utility function obtained by observing choice in such circumstances is *ordinal* utility: it exhibits the fact of preference but not the strength of preference.

Cardinal utility—a procedure for expressing the preference for *B* over *A* as a multiple of that for *C* over *A*—can be constructed by observing choice in circumstances where the state of life achieved is the joint outcome of an act of choice and a chance event, unknown at the time of choice. For instance, an individual may be asked to choose between a glass of milk and a fifty-fifty chance for a cup of tea as against a cup of coffee. Axioms about individual choice that permit the construction of a cardinal utility on this basis were first developed by John von Neumann and Oskar Morgenstern. Stimulated by a reformulation of this axiom system by Jacob Marschak, described in an earlier report (1949–1950), I. N. Herstein and John Milnor (the latter of Princeton University) developed a further simplified system of behavior axioms that leads to cardinal utility by a more direct route of deductions.

The theory of choice is further complicated if the *state of life* achieved is the joint outcome of a choice act and an unknown *state of the world* which cannot even be described by a probability distribution. Most choices made in real life are of this kind. (San Francisco was built without knowing the probability distribution of earthquakes in that location.) Each action leads to a set of possible

states of life containing the outcomes of that action under all conceivable *states of the world*. A variety of principles have been proposed for basing a preference ordering of such sets of *states of life* on a given cardinal utility function of the *states of life* contained in these sets. These principles have been appraised by asking the question: what does each principle make one do under each of various sets of circumstances? For instance, studies by statisticians have led to principles such as preferring that choice which minimizes the maximum loss (Abraham Wald), sustained by the individual after his choice is made and thereupon the state of the world is revealed. A modification of this is the principle of minimizing the maximum regret (L. J. Savage), that is the excess of the loss actually sustained over the loss that would have been incurred had the individual known the state of the world before making his choice.

The first version ("minimax loss") of this principle seems overly conservative if applied (as we assume here) in facing a neutral nature, such as when one sails in unknown waters, or sows in unknown climate or soil. It would lead us to take costly precautions (such as earthquake-proof buildings everywhere) against catastrophes. Under the second version ("minimax regret"), as shown by Herman Chernoff (*Annual Report for 1949-1950*), if opportunity limits the objects of choice, the preferred course of action may depend on whether some other nonpreferred course of action is available or not. Chernoff completed the study this year after adding many new considerations. This work has led Leonid Hurwicz to propose a less conservative principle of choice, considering both the best and the worst possible outcomes, on the basis of the incomplete information given, which can be associated with each course of action.

Marschak and Roy Radner, helped by their correspondence with Erich Lehmann, have studied situations where certain available courses of action, at a given cost of observation or experimentation, reduce the range of ig-

norance regarding the *state of the world*. The requirement that the choice principle be responsive to low cost opportunities to increase available information revealed further "unreasonable" features of both versions of the minimax principle and also of Hurwicz's generalization. Radner studied the question of when it is reasonable to add observations (and thus possibly to postpone choice). He also developed the concept of a "consistent" principle of choice which, with an indefinite increase in the number of observations, would converge toward that action which would be preferred if the *state of the world* were known. This concept is analogous to a consistent estimate or test in statistical theory.

Instead of asking for a definite principle of choice under ignorance, one may take a more detached attitude and require only that the various choices made when opportunities vary shall in some logical sense be consistent with each other. A study started earlier by Herman Rubin, indicating that this type of consistent choice pattern permits inferences about the degrees of belief (psychological probabilities) that the choosing individual associates with possible states of the world, was further advanced during the year.

It should be noted that the above criticisms of the minimax principle do not apply to its use in situations studied in the theory of games where the choosing individual does not face unknown blind forces of nature, but faces a calculating opponent who is out to win over him.

The foregoing studies are based on the assumption that an individual can choose among alternative states of life or among known probability mixtures of alternative states. Ethical judgments beyond the acceptance of individual preferences as a motive for decision-making do not arise. When one considers criteria for decision-making by groups, new problems, essentially ethical in nature, are encountered. Preferences of the individual members of a group will usually conflict to some extent and the best basis for resolving such conflicts is not intuitively clear.

Economists have frequently considered the problems of determining group preferences from individual preferences.

The Pareto criterion that there will be a group preference for one *state of life* over an alternative if some individuals prefer that state while none prefer the alternative has been fairly generally accepted.

Important conclusions—such as the usefulness of a price system in the allocation of resources—follow from this criterion, but many controversial issues cannot be resolved by it. The most important recent investigation of the possibility of developing stronger criteria is contained in Kenneth Arrow's book, *Social Choice and Individual Values*. As described in preceding annual reports, Arrow showed that if certain conditions are imposed on group preferences, such preferences can be obtained only in special cases.

Stimulated by this work, Clifford Hildreth has reconsidered the Arrow conditions and their motivation. He disagreed with Arrow's premise that a satisfactory set of group preferences could not be based on interpersonal comparisons of utility and regarded the problem as principally one of seeking ethical bases for making such comparisons. This difference led him to object to Arrow's Condition 3 (irrelevance of unavailable alternatives) and he has shown that if this condition is waived, the other conditions can be strengthened without giving rise to the difficulty that no admissible sets of group preferences exist.

Hildreth has also concluded that giving effect to individual preferences may be only one of a number of considerations on which criteria for group choice might be based. He has started to construct a more general theoretical framework in the hope that it will facilitate inclusion in the discussion of such values as individual freedom, security, equality, and other commonly cited criteria for evaluating public policies.

The following papers dealing with the formulation of objectives were those presented in staff meetings or completed or published during the year 1951-1952 by staff members or guests of the Commission. Papers marked by

an asterisk are also included in the Appendix, which lists all papers published or publicly presented by staff members during the period, July 1, 1951-June 30, 1952.

- Real Representation of a Preference Ordering: *Debreu*
A Comment to Marschak's paper on a Simplification of the Axiomatics of Measurable Utility: *Herstein*
Discussion of the Measurement of Individual and Social Utility: *Coombs*
Generalized Utility Functions: *Thrall*
Some Remarks on Utility: *Little*
Axiomatic Approach to Measurable Utility: *Herstein* and *Milnor*
Remarks on a Rational Selection of a Decision Function: *Chernoff*
Optimality Criteria for Decision-Making Under Ignorance: *Hurwicz*
Note on Optimality Criteria for Decision-Making: *Herstein*
Criteria for Planning Under Incomplete Information:* *Marschak* and *Radner*
Note on Generalized Convex Functions and the Decision Problem: *Radner*
Use of Previous Experience in Decision-Making: *Lehmann*
Rational Selection of a Decision Function in an Observational Situation: *Radner*
Consistent Decision Functions and Bayes Solutions: *Radner*
Postulates for Rational Behavior Under Uncertainty: *Rubin*
Games Against Nature: *Milnor*
An Alternative Approach to Welfare Functions:* *Hildreth*
Alternative Conditions for Social Orderings: *Hildreth*

II. *The pursuit of given objectives under certainty*

Once one or more objectives of economic behavior have been specified, the problem of how best to achieve the objective selected, or how best to strike a balance between competing objectives arises in many forms. The studies in this category are intended primarily as prescriptive, although some can better be seen as theoretical inquiries into what happens if different decision-makers pursue different individual objectives. The studies differ according to the number of individuals and the number and kinds of objectives considered, the restraints placed on the achievement of objectives by technological possibilities, and the

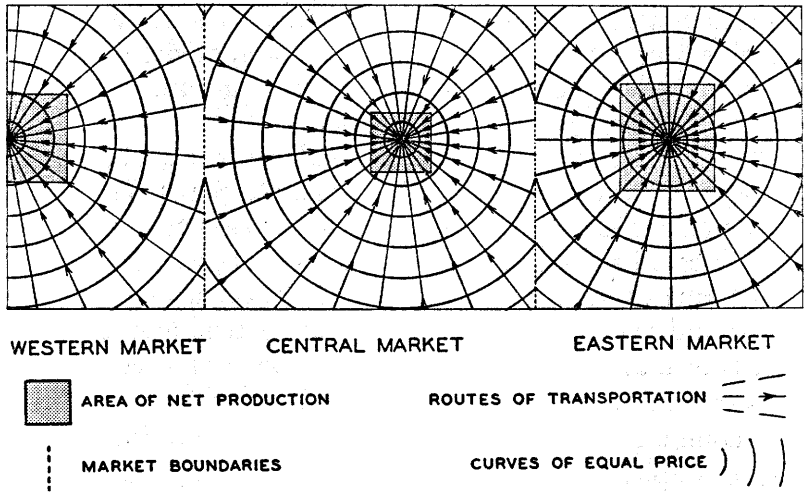
extent to which risk or uncertainty surrounds the consequences of available actions. We shall in Section II review studies that assume certainty about the effects of decisions, and proceed in Section III to cases where risk or uncertainty is introduced.

The first group of studies (among those assuming certainty) examines static models of equilibrium in a society of utility and/or profit maximizers. It is a classical theorem of static welfare economics that a competitive market organization achieves efficiency (or "Pareto optimality") in the allocation of resources. By this is meant a state in which it is impossible, by changes in the production or in the distribution of goods, to increase any individual's utility any further without decreasing at least one other individual's utility. It has long been recognized that commodity taxes or subsidies have the effect of moving the economy away from the efficiency frontier reached by competitive organization. Various measures of the social loss associated with such policies have been proposed. Debreu applied his coefficient of resource utilization (*Annual Report for 1950-51*, p. 15) to develop an improved measure of this loss. Unlike its predecessors, this measure recognizes the redistributive purpose of taxation: it compares the situation resulting from taxes and subsidies, not with the situation that would exist without these policies, but with a hypothetical situation in which the income distribution is the same as that resulting from taxes and subsidies, while their adverse allocative effects are removed.

The problem studied by Robert Strotz is a logical sequel to Debreu's measure of social loss. Accepting as a social objective, greater equality of incomes than that which would be achieved by the competitive market, he appraises alternative redistributive techniques by the extent to which they maintain allocative efficiency in the sense already explained.

The classical theorem concerning the efficiency of competitive market organization in a static economy, quoted above, depends on certain deep mathematical propositions

that have only rarely been examined with the preciseness necessary in specifying technological and psychological assumptions. Mere counting of equations and unknowns is insufficient to establish the existence of a state in which each individual or firm has maximized its utility or profit at the given prices. Arrow and Debreu independently obtained, and will jointly complete, extensions and generalizations of earlier studies by Wald and by von Neumann on this fundamental problem of mathematical economics.



A closer approximation to economic reality is the aim of a second group of studies concerned with the arrangement of productive activities in space and in time. Martin Beckmann completed a study of a continuous model of transportation that he had started before joining the staff. This model assumes given continuous geographical distributions of supply and demand of a number of commodities and a given dependence of per-mile transportation cost on the location of the route. Minimization of the total transportation cost incurred in moving goods from where they are available to where they are wanted leads to a pattern of flow lines for each commodity, intersected at right angles by lines of equal price for that commodity.

The price difference between two points on the same flow line equals the cost of transportation between these points. The problem of most economical return routing of empty equipment, studied separately in an earlier study by Tjalling C. Koopmans and Stanley Reiter (Cowles Commission Monograph 13, Chapter XIV), is incorporated in this study by treating equipment as one of the commodities in the model.

In order to provide empirical background for the problem of most efficient routing of empty railway cars in the United States, Kirk Fox has prepared data showing net surpluses of inflows over outflows of commodities carried in boxcars, for the eight quarters of 1949 and 1950, for each of twelve suitably chosen areas.

A second study by Beckmann deals with transportation on a given network of possibly congested roads. The traffic capacity of each road and the transportation cost on it, are both treated as functions of the (uniform) speed of vehicles (or trains or barges) using it. The capacities of intersections and the number of vehicles are introduced as given limiting factors. A routing of commodity and equipment flows so as to fit given availabilities of and requirements for commodities at given terminals at a minimum cost again implies a locational price pattern for each commodity. However, the price difference between two points connected by a flow of that commodity now also contains a charge for the passing of each congested road or intersection point on the way. This charge reflects the social cost that each vehicle causes by adding to congestion delays of other vehicles.

C. B. McGuire has made a study of the literature on highway and railway traffic engineering, in order to provide empirical background for the capacity and cost functions used in the network model just described. In addition, Beckmann and McGuire are studying the effects of individual choice of speeds and routes by vehicle drivers where only the cost of congestion to themselves is taken

into account, which is realistic in the case of highway traffic.

In all the foregoing studies the locational distribution of productive activities is assumed to be given. To make it into a variable raises at the same time the problem of the treatment of indivisibilities in production, since the land or space input into any process of production cannot economically be made arbitrarily small. One is thus led to problems of maximizing the utilization of resources by reshuffling (permutation) of productive activities over available elementary land or space units. A forthcoming paper by von Neumann, "The Problem of Optimal Assignment and a Certain Two-Person Game," (kindly made available to the Commission in advance of its publication in the second volume on the theory of games, A.W. Tucker, ed., *Annals of Mathematics* series) makes computation methods developed for the solution of games applicable to this class of problems. Beckmann considered a modified problem where transportation costs between assigned locations are taken into account.

One of the purposes of the Commission's studies in transportation and location, in which Koopmans has provided general guidance and stimulation, is to prepare the way for more realistic insight into the efficiency or inefficiency of industry's present geographical distribution and of our metropolitan concentrations of population and production. It is hoped that the efficiency aspects of various methods, modes, and degrees of dispersal of these concentrations, such as may be found desirable for reduced vulnerability in war, may also be better understood through these studies. A discussion by Jack Hirschleifer, of the RAND Corporation, of war damage insurance schemes as an incentive to dispersal, provided perspective in this connection. It is mentioned here for that reason, although it will be mentioned again under its proper classification of problems involving uncertainty.

The methods of "activity analysis," developed in Cowles Commission Monograph 13 and described in two

preceding annual reports, throw new light on classical problems of international trade theory. Reiter of Stanford University completed a discussion of an example showing the effect on overall output of barriers to the movements of goods. François Morin, a Rotary International Fellow from the Ecole Polytechnique in Paris, France, was led to the same problem through consideration of a technical question in the stowage of goods in transportation under space and weight limitations, and developed the international trade interpretation of this problem with greater validity.

A study of the efficient arrangement of productive activities over time, started by Edmond Malinvaud when visiting the Commission as a Rockefeller Fellow in 1950-1951, was brought to completion after his return to Paris. This study extends to dynamic situations earlier results of Koopmans and Debreu concerning the criteria of efficient allocation of resources in a static economy, and the role of prices in making it possible to reach or maintain efficiency under decentralized allocative decision-making. Of considerable interest for capital and interest theory is the special case of an efficient stationary state, which differs from earlier static models in that the time structure of production processes is explicitly taken into account.

On a more practical level, Franco Modigliani and Franz Hohn of the University of Illinois, have discussed the problem of how best to distribute production over time to meet a given program of delivery dates and quantities, under various assumptions as to storage cost and the dependence of cost of production on the rate of output. Morin indicated simplifications that can be achieved in this problem by treating time as a continuous variable.

Time also enters, as a label of two successive states of technology, into Debreu's application of his coefficient of resource utilization to the measurement of technological change. He proposes to represent technological change numerically by the highest proportional saving in all primary inputs which, in a hypothetical static economy,

would permit the attainment of this year's standards of living if next year's technology could be substituted for this year's.

Problems of allocative efficiency under certainty as well as under uncertainty are studied from a general classificatory and analytical point of view by Hurwicz. The problem of computing an efficient state of a static economy by iterative methods is linked with the dynamic problem of determining the path whereby an economy with decentralized decision-making may approach efficiency through time. Further reference to this study will be made in the next section.

A Classical Tax-Subsidy Problem:* *Debreu*

An Economic Equilibrium Existence Theorem: *Debreu*

On the Existence of Solutions to the Equations of General Equilibrium under Conditions of Perfect Competition: *Arrow*

A Continuous Model of Transportation: *Beckmann*

Economic Routing of Empty Railroad Freight Cars: *Fox*

Efficient Transportation in Networks: *Beckmann*

Road Utilization Under Conditions of Individual Choice: *Beckmann*
and *McGuire*

Additivity in Linear Models of Production: *Reiter*

Linear Activity Analysis and International Trade: *Morin*

Capital Accumulation and Efficient Allocation of Resources: *Malinvaud*

The Effect of the Inventory Constraint on the Solution of Certain Problems of Production Planning Over Time: *Modigliani* and *Hohn*

Note on an Inventory Problem Discussed by Modigliani and Hohn: *Morin*

III. The pursuit of given objectives under uncertainty

The problem of inventory control in response to sales reports is one of the simplest examples of a problem in decision-making under uncertainty. Two types of uncertainty may be distinguished here: the case of "complete information," where at least the probability distribution of future demand is known, and the case of "incomplete information," where even that is not known. The work by

Arrow, Harris, and Marschak on this problem, described in our *Annual Report for 1950-1951*, stimulated a more complete and general mathematical study carried out by Aryeh Dvoretzky, J. Kiefer, and Jacob Wolfowitz, of Cornell University on which Dvoretzky (also of the University of Jerusalem) reported in a staff meeting. They treat the inventory problem as a special case of the general problem of how to utilize such influence as one may have on a chain of successively dependent chance events (a "stochastic process") in the outcome of which one has a definite interest. In a report to the staff on conversations with river control engineers in the Tennessee Valley Authority, Koopmans presented the problem of best balance between flood prevention and electricity generation as another control problem in this category.

In taking actions the outcome of which depends on uncertain future events, businessmen must form their best judgments regarding these events. However, since the attempt to forecast or assess uncertainty absorbs attention and effort, it is important in preparing decisions to specify for which events the anticipations really matter. These considerations led Modigliani and Hohn to formalize the concept of the relevance of anticipations about various future events to a given decision problem. In particular, their study of production scheduling over time, referred to above, led them to point out the significance of storage costs and seasonal fluctuations in demand or supply that cut down the length of the period ahead for which anticipations are relevant to present decisions. A similar concern with the cost of preparing and making a decision, and with the cost incurred at successively higher levels in setting up methods and procedures for preparing and making decisions, is found in a discussion of rational decision-making in business contributed by Charles Holt of the Carnegie Institute of Technology.

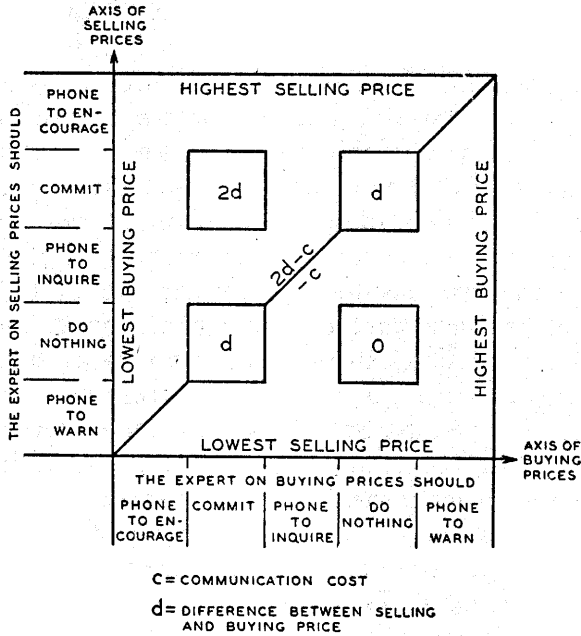
The problem of best actions in the light of given anticipations is illustrated by Harry Markowitz's discussion of portfolio selection. This is treated as a problem in mini-

mizing variability of return for given expected average return on securities, or conversely.

In this, as in the other problems of decision-making under uncertainty mentioned so far, the analysis proceeds from the assumption of one controlling interest such as the maximization of expected profit of one firm. Actions by representatives of other interests enter in some cases as uncertain events to be predicted (such as future demand), but do not become the object of analysis. The assumption of subordination to one controlling interest is still maintained in Marschak's model of a team of two partners, but each partner has access to a different field of information. The analysis assumes as given: the cost of communication between partners (in time, money, etc.), the joint probability distribution of the two states of (correct) information, and the outcome (profit) resulting from any given pair of decisions by the two partners. The possible decisions are (1) to commit the partnership if not contacted by the other partner, (2) to abstain from commitment if not contacted, (3) to exchange information and commit, and (4) to exchange information and abstain from a commitment. The problem is to find rules of response to information for each partner that maximize the mathematical expectation of the profit.

Marschak, Karl Faxén, a visiting Rockefeller Fellow from Sweden, Beckmann, and Dvoretzky, guided by experimental computation conducted by Daniel Waterman, studied an interesting special case exemplified by an arbitrage firm in which one partner is informed of the buying price and the other of the selling price. It was shown that proceeding from less favorable to more favorable information, the best responses from each partner form the following sequence: communicate (to warn the partner); do nothing; communicate (to get information); commit; communicate (to encourage the partner). Each pair of decisions (one by each partner) will result in a certain profit or loss, as entered in the five different fields on our diagram; where the axes represent the two prices

per unit of finished product. The five intervals marked on each axis represent the price ranges at which certain decisions of one partner are called for by the particular rule.



Depending on the probability of various pairs of prices and on the cost of communication, some of the five price intervals may disappear. For the case when the two prices are distributed independently and with uniform probability over the same range, the best of all rules that are symmetrical with respect to the two partners were found by Kiefer and O. Orey of Cornell University, in their comments on various Cowles Commission discussion papers. Valuable comments were also received from J. Laderman of the Logistics Branch, Office of Naval Research.

The model just described contains in a highly simplified form one basic element of the theory of organization: the dispersal of information among members of an organization, and the communication procedures between them. Another element, emphasized by Herbert Simon in a

Cowles Commission Seminar is the coalition character of organizations: the organization is viable as long as the distinct and individual interests of its members are best served by an agreement to follow the rules of behavior that make up the organization. Both of these elements of organization theory are recognized and elaborated in Hurwicz's analysis of information processing in resource allocation. In particular, the market economy is studied as a decentralized form of organization whereby the flow of information between "participants" (buyers and sellers) takes the form of price offers and quotations and quantities ordered.

A central problem of organization theory is how to set up the rules and incentives in such a way as to obtain "best results" in the sense of the efficiency concept described above. An example is the formulation of tax laws in such a manner as to make profit maximizing behavior of business in the face of uncertainty serve general ends of society most effectively. Beckmann and Marschak extended an earlier study of the latter into the income tax structure that will produce a given revenue with a minimum deterrent effect on risk-bearing investment. Another example is Hirschleifer's discussion, already referred to, of a war damage insurance scheme that carries incentives for the most economical degree and type of dispersal of productive activities to reduce vulnerability to air attack.

Optimal Inventory Decisions: *Dvoretzky*

Report on a Visit to the Tennessee Valley Authority: *Koopmans*

On the Relevance of Entrepreneurial Anticipation to Current and

Future Activity of the Firm: *Modigliani* and *Hohn*

Rational Decision-Making in Business: *Holt*

Portfolio Selection:* *Markowitz*

On Optimal Communication Rules for Teams:* *Marschak* and *Waterman*

Organized Decision-Making: *Marschak*

Note on Marschak's Model of an Arbitrage Firm: *Faxén*

Note on Organized Decision-Making: *Beckmann*

Risky Assets and Optimal Tax Policy: *Beckmann*

War Damage Insurance: *Hirschleifer*

IV. The study of actual economic behavior

If we ask ourselves what motivates the empirical study of economic behavior, we recognize here the same urge that motivates many other empirical sciences: the scientific curiosity that desires to explore and understand the physical, technological, human, and social environment in which life is lived. Another motivation is shared with many empirical sciences: knowledge of actual behavior is indispensable in assessing and predicting the effectiveness of policies recommended for individual or social improvement. Both motivations can be discerned in the choice of topics and methods of empirical research in economics by the economic profession generally, and at the Commission.

Through its research consultants and by other means, the Commission maintains close contact with programs of empirical work in other academic centers. This section therefore describes not only the empirical work in which the Commission itself is engaged, but also describes studies made elsewhere that have been brought into the discussions in the Commission, or with which contact has been maintained in other ways. The term "empirical work" is here to be interpreted broadly. It includes theoretical studies of the implications of assumptions made for purposes of empirical analysis.

The historical survey of the Commission's research mentioned earlier, describes the work by Lawrence R. Klein on the construction of systems of aggregative behavior equations as an aid in explaining or forecasting business fluctuations and in assessing the effect of stabilizing policies. This work is at present being continued and extended under Klein's direction at the Research Seminar in Quantitative Economics of the University of Michigan. Klein presented his program in a discussion at a staff meeting. In another discussion Donald Daly of the Department of Trade and Commerce of the Canadian Government reported on experience with similar systems applied to the Canadian economy with emphasis on the testing of forecasting meth-

ods against actual developments. In both cases this work was undertaken with the idea of utilizing additional and improved statistical data, against which to test a wider range of more detailed and refined theories in order to achieve more accurate estimation of behavior parameters. These studies have been based mostly on annual time series, in some cases on quarterly series. Fuller use of quarterly series, such as is made in a pilot study carried out jointly by Klein and Harold Barger of Columbia University (involving at present the estimation of small systems of three equations) will provide additional information. The development of electronic computing devices may make such studies possible on a larger scale.

At the same time, economists are to an increasing extent going beyond aggregative time series in order to obtain data richer in information which permit more powerful tests of hypotheses. They have looked for enrichment of data in the following directions in particular, singly or in combination: (a) disaggregation through the study of individual markets, (b) disaggregation by industrial classes (in the study of production relationships), (c) use of cross section data, often collected by sample surveys and concentrated on particular types of decisions, such as consumers' choice or the formation of anticipations.

The empirical work of the Commission's resident research staff has been concerned mostly with the study of individual markets. The motivation of the choice of markets for study has been not only a desire for better knowledge of these particular markets, but even more a desire to increase our knowledge of economic behavior generally by the thorough study of cases where circumstances for study are favorable. Also, studies of particular markets have been a valuable testing ground for statistical and computational methods of estimating behavior constants.

A study of certain markets with forward trading (corn, other feed grains, wheat, cotton) has been undertaken by H. S. Houthakker, with the assistance of William Dun-

away, to clarify the empirical background for current theories of economic dynamics, behavior under uncertainty, and speculation. The principal variables to be explained are the level of stocks and the price spreads among different futures and between futures and cash prices. In the case of feed grains this is supplemented by a more detailed investigation of their demand structure.

Hildreth, in his association with the Agricultural Economics Research Group of the University of Chicago, is conducting a statistical study of supply and demand relationships for livestock products in the United States, assisted by Frank Jarrett. This is a semi-aggregative study in the sense that, although only one group of markets is considered, the demand and supply relations studied connect aggregate quantity and price indices for all livestock products included (ranging from cattle to eggs). The fact that these commodities are competing in demand as well as in production facilitates this aggregative procedure.

Miss Hendrieke Goris of the Netherlands Economic Institute made a progress report on her study of the United States tobacco markets, carried out while spending a fellowship period with the Commission.

The studies of Houthakker and Goris, as well as that of Hildreth and Jarrett were discussed in joint staff meetings with the Agricultural Economics Research Group.

The study of aggregative production relationships expressing balance in the rates of outputs of various industries, initiated, developed, and stimulated by Wassily Leontief of Harvard University, has grown in recent years into a field of large-scale empirical research, variously referred to as input-output analysis or interindustry economics. Ronald Shephard of The RAND Corporation described at a staff meeting his research proposal to study changes over time in input-output coefficients, in response to scale of output (increasing or decreasing returns), age distribution of capital equipment, fluctuations in output, and gradual cumulative factors such as technological change. Arrow and Robert Solow, the latter of the Massa-

chusetts Institute of Technology, cooperated with Shephard as RAND consultants in formulating this proposal.

Klein pointed out that if input-output ratios are measured as ratios of money values of interindustry commodity flows in a given year, and if the prices underlying these value aggregates are formed in competitive markets, any observed constancy over time of these input-output ratios is compatible with the existence of production functions permitting substitution among physical inputs originating in different industries, and joint production of commodities produced by one industry. Koopmans finished an expository paper discussing results reached by various authors in Cowles Commission Monograph 13 regarding the constancy of relative prices of commodities under shifts in demand, if each commodity is produced separately in one industry, while only one scarce primary factor (e.g., labor) limits the rates of output attained by all industries.

The Commission benefited from the presentations of several pieces of research in the theory and econometrics of consumption, carried out by Michael Farrell and Houthaker at the Department of Applied Economics of the University of Cambridge, by William Hamburger as a thesis project at the University of Chicago, and by Klein at the Survey Research Center of the University of Michigan. Many of these studies made or envisaged use of data obtained from consumer surveys or budget studies.

Modigliani reported empirical findings of the research project on the role of expectations in business fluctuations, directed by him at the Bureau of Business Economics of the University of Illinois (in cooperation with the Public Opinion Research Center of the University of Chicago). This project, based on the evaluation of survey data as well as on the study of time series of recorded forecasts, may be expected to provide a more realistic framework for theories relating economic behavior to anticipations.

The general purpose of most of the studies described in Section IV is to provide a stronger empirical basis for the explanation of cyclical fluctuations. In a research memo-

randum of the Economic Institute of the University of Oslo, Trygve Haavelmo has indicated the need for econometric study of problems of long-range development and of the persistent and widening differences in economic level among different areas of the world. He has constructed and compared simple models discussing economic development in terms of a few aggregative variables such as population, production, accumulated capital, level of education and know-how, plus random disturbances. Even at this level of simplification, it is found that with the same structure of behavior as regards productive effort, capital accumulation, and human reproduction, small differences in "initial conditions" may over time lead to large discrepancies in economic level.

- A New Econometric Model for the United States: *Klein*
- The Canadian Econometric Model in Comparison with Carl Christ's Findings: *Daly*
- A Proposed Inquiry into Some Markets with Forward Trading:* *Houthakker*
- A Statistical Study of Livestock Production and Marketing: *Hildreth* and *Jarrett*
- An Investigation into Price-Determining Factors in American Leaf Tobacco Markets: *Goris*
- An Econometric Model for the Study of Changes in Input-Output Coefficients: *Shephard*
- The Interpretation of Professor Leontief's System: *Klein*
- Maximization and Substitution in Linear Models of Production: *Koopmans*
- Irreversible Demand Functions: *Farrell*
- The Shape of Engel Curves: *Houthakker*
- Analysis of Quality Variations in Consumption: *Houthakker*
- The Free Demand for Rationed Foodstuffs in Britain:* *Houthakker*
- Consumption and Wealth: *Hamburger*
- Evaluation of Consumer's Expenditures Survey Data:* *Klein*
- Relevance of Entrepreneurial Anticipations: *Modigliani*
- Contribution to the Theory of Economic Evolution:* *Haavelmo*

V. Concepts and tools of research

The formation of concepts and the development of research tools are an integral part of the research of the Com-

mission. The report on progress during the year will be arranged under the categories "concept formation," "statistical methods," and "mathematical tools," although no sharp boundaries separate these categories.

Simon has continued and extended his examination of the concept of causality. Besides the discussion of causal hierarchy of variables in a system of linear algebraic equations, described in our previous report, he has developed the notion of a causal ordering of propositions, defined in terms of the concepts of formal logic. While applicable to all empirical sciences, this analysis arose in connection with the study of production control systems.

Several guest speakers in staff meetings or seminars contributed to problems of concept formation. Coombs and Thrall, both of the University of Michigan, discussed ramifications of the concept of measurement ranging from mere nominal classification of objects to complete numerical measurement, and including such intermediate forms as partial ordering and complete but ordinal measurement. Menger discussed the introduction of probability into ordering relations. This will facilitate interpretation of experiments on the measurement of preferences in which the responses of individuals exhibit an element of randomness.

Those working in the application of statistical methods to econometric model construction are more and more concerned with the fact that the assumptions which specify the model are always approximations, consciously adopted to make statistical procedures applicable, but not believed to be strictly valid. On the other hand, the statistical procedures of estimation, assessment of accuracy of estimates, and testing of hypotheses are strictly valid only if the models are. We are thus faced with the problem of so-called "specification error."

Two ways of dealing with this problem are being explored and will no doubt be pursued further in the future. One method is to study the performance of inference processes derived to fit one particular model if the observations are generated by some other model belonging to a

wider class of models. A conceptual basis for this approach to the specification problem is laid in Hurwicz's study of the consequences of incorrect specification. Studies by Stephen Allen and Jean Bronfenbrenner of particular cases of specification error have been mentioned in previous reports, and will be included in the forthcoming Cowles Commission Monograph 14, *Studies in Econometric Method*. In the same category is John Gurland's study of the effects of serial correlation in the disturbances in behavior equations, and of incorrect specification of the stochastic process that generates these disturbances. The importance of a particular type of "specification error," that of incorrectly treating certain variables as exogenous, was emphasized at the Boston meeting of the Econometric Society by Guy Orcutt of Harvard University in a paper of which William Hood was a discussant. Subsequently, Koopmans contributed a written discussion of Orcutt's paper to a panel discussion, to be printed with that paper in the *Review of Economics and Statistics*.

Another approach is the development of more flexible statistical inference procedures, which are perhaps less efficient or powerful for a narrowly specified model, but which are valid with determinable accuracy within a wider range of assumptions. Stimulated by earlier work of Wald in this direction, Hildreth has studied methods of estimating coefficients of simultaneous equation systems by means of suitably chosen subsets of the observations.

At the same time, the development and presentation of statistical methods for given parametrically defined models has been continued. Koopmans and Hood completed an expository presentation (for Monograph 14) of the application of the maximum-likelihood method of estimation to linear equation systems with normally distributed disturbances. They considered various cases with regard to the utilization or disregard of a priori knowledge as to which variables occur in each equation. T. W. Anderson contributed a suggestion toward computationally economical methods for utilizing this type of a priori knowledge.

Allen discussed methods for the simultaneous utilization of cross-section and time-series data.

Two guest speakers, G. S. Watson, of the University of Australia, and Ulf Grenander, on leave from the University of Stockholm while associated with the Committee on Statistics of the University of Chicago, discussed the estimation of regression coefficients in cases where the disturbances are serially correlated. This and similar problems involving intertemporal dependence of observations provided the motivation for Gurland's research into the distribution of quadratic forms in random variables, and the ratios of such forms.

Erling Sverdrup's study of statistical decision problems and their solution by the minimax principle, mentioned in the *Annual Report for 1949-1950*, was brought to completion after his return to the University of Oslo. This study includes a discussion of prediction problems as a special class of statistical decision problems.

Progress was made in several directions toward generalization and simplification in making available mathematical tools to economists. In studies of the interaction of various parts of the economy, frequent use is made of matrices of which all elements are positive or zero. Hirstein located and translated a paper by Helmut Wielandt of the University of Mainz giving a concise treatment of the properties of such matrices. Jointly with Debreu he introduced further clarity and simplification by the use of a "fixed-point theorem" and gave a unified treatment of matrix properties scattered through the literature. Additional properties were derived and applied by John Chipman of Harvard University, who participated in research discussions of the Commission while a fellow of the Department of Economics of the University of Chicago. Debreu and Marschak cooperated in developing a proof of the central theorem relating to two-person zero-sum games which appeals to geometrical intuition. A computation method for the solution of such games was presented by Howard Raiffa of the University of Michigan.

The problem of maximization of a function (such as utility or profits) under constraints (of budget or technology) is basic to much of economic theory. If differentiability is assumed, this problem reduces to that of finding a maximum of a quadratic function under linear restrictions. Conditions for such a maximum are well-known to economists but satisfactory proofs are hard to find. Debreu provided a concise and complete proof, which was published in *Econometrica*. Clarification of mathematical tools resulted also from Debreu's work on the existence of a saddle point and of an equilibrium point, referred to in Section II above.

The problems of location theory associated with indivisibilities, referred to in Section II, have led to a renewed interest in the study of permutations and functions of permutations. A somewhat related problem—to define and find the combinatorial rank of a matrix—was discussed by Simon in connection with his work on causal hierarchy of variables.

Besides giving mathematical advice to the group on a variety of problems, Herstein is writing an exposition, from the mathematician's view point, of mathematical methods and tools used or of use in economics. Waterman has supplied direction to the computation staff of the Commission.

On the Definition of the Causal Relation: *Simon*

Probabilistic Theory of Relations: *Menger*

On the Consequences of Incorrect Specification: *Hurwicz*

Autocorrelation of the Disturbances in Regression: * *Gurland*

Comments on Orcutt's Paper 'Toward the Partial Redirection of Econometrics': *Koopmans*

Structural Estimates From Means of Subsets of Observations: *Hildreth*

The Estimation of Simultaneous Linear Economic Relations: *Koopmans* and *Hood*

A Suggested Application of the Limited-Information Maximum-Likelihood Method of Estimation: *Anderson*

Estimations of a Single Equation in an Incomplete System of Stochastic Equations with Cross-Section Time Series Data: *Allen*

Serial Correlation in Regression Analysis: *Watson*
On the Estimation of Regression Coefficients in the Case of an Auto-correlated Residual: *Grenander*
Distribution of Quadratic Forms and Ratios of Quadratic Forms:*
Gurland
Weight Functions and Mimimax Procedures in the Theory of Statistical Inference:* *Sverdrup*
Indecomposable, Nonnegative Matrices: *Wielandt*
Positive and Nonnegative Matrices: *Herstein*
Nonnegative Square Matrices: *Debreu* and *Herstein*
An Algorithm for the Determination of all Solutions of a Two-Person Zero-Sum Game: *Raiffa*
Definite and Semidefinite Quadratic Forms:* *Debreu*
A Social Equilibrium Existence Theorem: *Debreu*
Some Theorems on the Combinatorial Ranks of Matrices: *Simon*
Mathematical Methods and Tools in Economics: *Herstein*



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COWLES COMMISSION LIBRARY

GUESTS AT THE COWLES COMMISSION

July 1, 1951-June 30, 1952

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

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

HERMAN G. BIERI, who received his doctorate from the University of Bern, Switzerland, came to the Commission under a fellowship from the Rockefeller Foundation. His interest while at the Commission centered around mathematical methods in economics with special application to welfare economics. An article is to be published in Ammann's *Festschrift* and in the *Schweizerische Zeitschrift für Volkswirtschaft und Statistik* which is a fruit of the visit at the Commission.

GLAUCO DELLA PORTA received the Ph.D. degree from the University of Rome and is now assistant professor of economics there. He came to the Cowles Commission on a fellowship from the Rockefeller Foundation. His research interests during his visit concerned the various approaches to short-term forecasting. Resulting from this two papers have been written in manuscript form, "A Critical Appraisal of the Various Approaches to Short-Term Forecasting" and "Hick's Trade Cycle Model Revised" (tentative title).

MICHAEL FARRELL received the Ph.D. degree from Oxford University, England, in philosophy, politics, and

economics. He came to the Cowles Commission under a Commonwealth Fund fellowship. While here he has participated in many of the Commission's activities and has worked on the application of activity analysis to the theory of the firm. He has also presented a paper, "Irreversible Demand Functions," later published in *Econometrica*, April, 1952, which had resulted from his research with the Department of Applied Economics of Cambridge University.

KARL OLAF FAXÉN received his *fil.kand.* at the University of Uppsala, 1944, and his *fil. lic.* at the University of Stockholm, 1951. He came to the University on a Rockefeller Foundation fellowship. His interest while at the Commission centered around decision-making under uncertainty and the theory of organizations. He also presented the papers, "Note on Marschak's Model of an Arbitrage Firm" and "Games with Non-Measurable Utilities."

GIOVANNI GERA, a lawyer, is a member of the Faculty of Jurisprudence at the University of Rome. While at the Commission he gathered material for a paper on the incidence of a tax on profit.

MISS HENDRIEKE GORIS, who obtained the degree *economisch doctoranda* at the Netherlands School of Economics in 1949, visited the United States on a Fulbright Smith-Mund scholarship. While at the University of Chicago she gathered material for a Ph.D. dissertation on tobacco markets in the United States. She presented a paper before a joint meeting of the Cowles Commission staff and the Agricultural Economics Research Group entitled, "Tobacco Production and Distribution in the United States."

FRANÇOIS MORIN graduated from the Ecole Polytechnique and the Ecole Supérieure des Mines, both of Paris. He is at present Ingénieur du Corps des Mines. He came to the University under a fellowship awarded by the Rotary International and contributed discussion papers entitled "Note on an Inventory Problem Discussed by Modigliani and Hohn" and "Linear Activity Analysis and International Trade."

In addition to the above, the following also participated

in seminars and staff meetings of the Commission during the year: CLYDE H. COOMBS, psychologist at the University of Michigan; DON DALY, economist at the Department of Trade and Commerce, Canadian Government; ULF GRENANDER, mathematician and statistician, on leave from the University of Stockholm; WILLIAM HAMBURGER, economist, University of Chicago; MELVILLE J. HERSKOVITS, anthropologist, Northwestern University; JACK HIRSCHLEIFER, economist at the RAND Corporation; CHARLES HOLT, Carnegie Institute of Technology; HERBERT D. LANDAHL, mathematical biophysicist, University of Chicago; ABBA P. LERNER, economist, Roosevelt College; I. M. D. LITTLE, economist, Oxford University; KARL MENGER, mathematician, Illinois Institute of Technology; JAMES G. MILLER, psychologist, University of Chicago; JOHN MILNOR, mathematician, Princeton University; HOWARD RAIFFA, mathematician, University of Michigan; RONALD W. SHEPHARD, mathematical economist, RAND Corporation; ROBERT M. THRALL, mathematician, University of Michigan; and G. S. WATSON, mathematical statistician, University of Melbourne.



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COWLES COMMISSION COMPUTATION LABORATORY

OFFICE, LIBRARY, AND COMPUTATION
LABORATORY

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Mathematical Technicians

* Staff departures prior to June 30, 1952.

The library, offices, and computation laboratory are located in the Social Science Building on the University of Chicago quadrangles. A staff of approximately nine full-time and a varying number of part-time persons provides a variety of supporting services for the research staff, resident guests, and advanced students associated with the Cowles Commission. Several of the staff also perform related functions for the Econometric Society which shares the offices of the Commission.

LIBRARY

The library of the Cowles Commission is maintained primarily to assist in the research carried on by the Commission. As this research transcends the boundaries of conventional fields of inquiry, it has been advantageous to have the diverse subjects which are relevant to the studies of the Commission brought together and organized in one collection. The collection covers the fields of quantitative economics, economic theory, statistics, mathematics, descriptive data, and bibliography. To a lesser extent, it also has material on psychology, sociology, theory of communication and organization, and related topics. In view of the library's close proximity to the University of Chicago libraries, particular emphasis has been placed on journals, pamphlets, reprints, documents, and other materials that are not available through usual library sources.

During the past year the library has been recatalogued and reclassified according to the rules of the American Library Association and the Library of Congress. This integrates the various materials in the Cowles Commission collection under one system and provides conformity with the arrangement of the University of Chicago libraries.

Additions to the library during 1951-52 total 287 books, 419 pamphlets, and 118 bound volumes of journals. The collection consists of 3,015 books, 5,966 pamphlets, and 862 bound journal volumes. Currently 141 journals are being received from 19 different countries. Many reprints

of articles of interest are received from journals that primarily specialize in subjects outside the field of the Commission, permitting the library to have in its collection nearly all articles that touch on or relate to its research. The library also contains the collection of the late Professor Henry Schultz, consisting of 950 books and 1,750 pamphlets; a particularly valuable addition to the library since many of the books and articles are out of print and unavailable elsewhere in Chicago.

The library is open to members of the Department of Economics as well as to advanced students by arrangement.

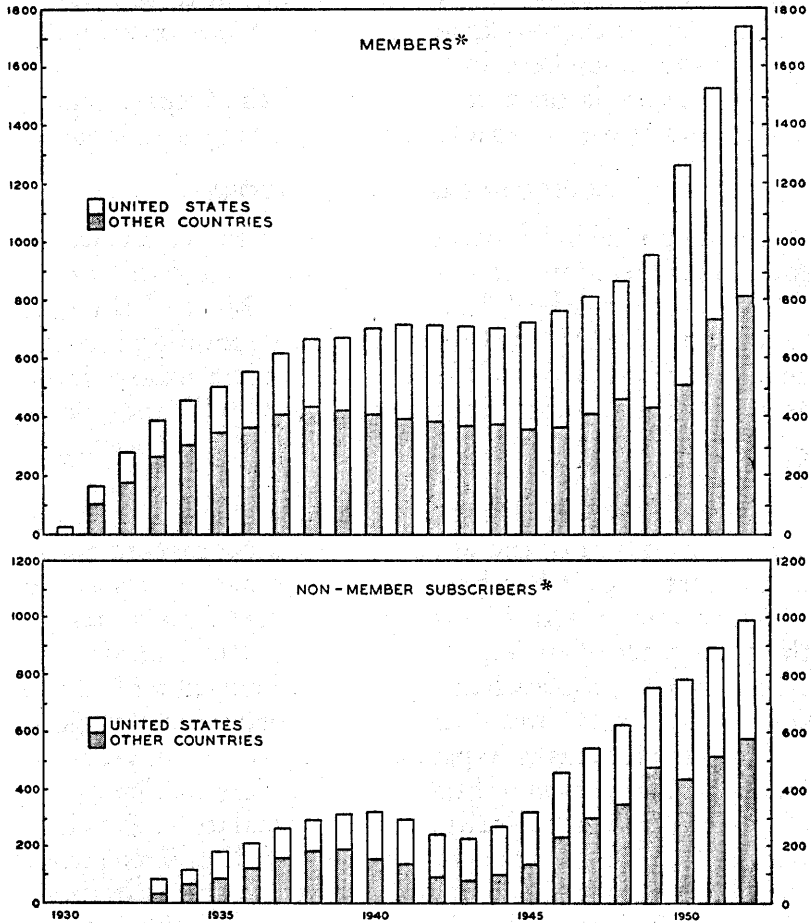
COMPUTATION LABORATORY

The computation laboratory employs the equivalent of four full-time computers whose work is confined for the most part to standard desk calculators. Most of the computers employed by the Commission have training in mathematics or statistics and for this reason can follow standardized outlines for "maximum-likelihood" and "least-squares" estimation. Daniel Waterman, research associate, directs the activities of the laboratory.

The work of the laboratory is, however, much more diverse than that of the usual statistical computing group. In the last year it has been engaged in such work as the computation of sets of orthogonal polynomials, testing the convergence of various series representations of distribution functions, the evaluation and maximization of certain definite integrals, and estimation of behavior equations.

Computation tasks expected during the next year will include the inversion of high-order matrices, which cannot be performed economically on desk calculators. Provision is therefore being made for the use of digital electronic computers belonging to outside agencies. The availability of such machines will make it possible to utilize complex estimating techniques which are not feasible at this time.

GROWTH AND DISTRIBUTION OF MEMBERSHIP IN THE ECONOMETRIC SOCIETY AND OF SUBSCRIBERS TO ECONOMETRICA



*Data as of September 30 of each year.

THE ECONOMETRIC SOCIETY

The principal activities of the Econometric Society, an international society for the advancement of economic theory in its relation to statistics and mathematics, consist of the publication of a journal, *Econometrica*, and the arrangement of scientific meetings in various parts of the world. In these and other activities in which the Econometric Society has engaged, it has enjoyed the advantages of a close association with the Cowles Commission through sharing office facilities and through the participation of members of the Commission's staff; an association which was the outgrowth of early ties and common sympathies set forth in detail in the "History of the Cowles Commission" which is included in this report.

The Fellows represent the highest authority of the Society. They are 94 in number, including residents of 18 different countries. In 1951 a revision of the rules for election of new Fellows was put into effect which facilitates consideration of the qualifications of candidates. Six new Fellows were elected in the current year: T. Barna, G. Darmois, H. S. Houthakker, J. J. Polak, O. Reiersøl, and J. Tobin.

The Fellows elected the following members of the Society to the Council for 1952: C. Bresciani-Turroni of Italy, J. Tinbergen of the Netherlands, and T. C. Koopmans and Wassily Leontief of the United States. The Council includes in addition the officers of the Society and Colin Clark, Australia; R. G. D. Allen and J. R. Hicks, England; Ragnar Frisch, Norway; Herman O. A. Wold, Sweden; and Griffith C. Evans and Simon Kuznets, United States.

The officers of the Society in 1951 were R. G. D. Allen, London School of Economics, president; Paul A. Samuelson, Massachusetts Institute of Technology, vice-president; and two members of the Commission, William B.

Simpson and Alfred Cowles, as secretary and treasurer, respectively. The Council elected René Roy of the Institut de Statistique de l'Université de Paris to be vice-president in 1952, Samuelson was elected president, and Simpson and Cowles were re-elected to their respective offices. In May, Simpson submitted to the Council his resignation as secretary of the Society to become effective at the end of the fiscal year, upon completion of four years in office.

A total of 243 individuals were elected to membership during the fiscal year ending September 30, 1952. This brought membership in the Society to 1741, double the membership four years earlier. The number of countries represented increased to 64. Although the number of members outside Europe and North America continues to be small, the highest rates of growth in membership strength are found respectively in Central and South America, Asia, Africa, and Australasia and Oceania. Since 1949 a geographical index of members and subscribers has been published in the October issue of *Econometrica*.

A policy of encouraging meetings of the Econometric Society in additional parts of the world and of seeking the appointment of broadly representative program committees wherever possible has been followed in recent years. In 1951, for example, approximately 50 members participated in planning and arranging the seven meetings of the Society. Papers and formal discussions totaling 171 in number were presented at its sessions. Many more members participated through attendance, some serving as session chairmen or offering informal discussion. Other members had access to the proceedings through abstracts published in *Econometrica*.

In August, 1951, the West Coast regional meeting of the Econometric Society was held at the RAND Corporation in Santa Monica in conjunction with the Southern California Economic Association. In 1952 it was held at the University of Oregon in Eugene, June 19-21, in conjunction with the American Mathematical Society, Biometric Society, Institute of Mathematical Statistics, and Mathematical Association of America.

The American summer meeting of the Econometric Society was held at the University of Minnesota in September, 1951, in conjunction with the meetings of the American Mathematical Society, Mathematical Association of America, Institute of Mathematical Statistics, and Section A of the American Association for the Advancement of Science. This year the joint summer meeting with the mathematical groups was held at Michigan State College in East Lansing, September 2-5.

The American winter meeting of the Society is usually held at the same time and place as the meetings of the American Economic Association, American Statistical Association, Institute of Mathematical Statistics, and other components of the Allied Social Science Associations, and some joint sessions are arranged. This was held in Boston in 1951. The 1952 meeting with the social science organizations will be held in Chicago, December 27-29.

The European meeting of the Econometric Society was held at Louvain, Belgium, in 1951, and this year at Cambridge, England, August 13-15.

The Japanese meeting of the Econometric Society was held at the Tokyo University of Commerce, in 1951. This year the meeting is scheduled for November 1-3 at Nagoya University as a joint meeting with the Society of Theoretical Economics. Arrangements were concluded with the Japanese Science Council for Dr. Takuma Yasui to attend the year-end professional meetings in the United States as the official delegate of the Japanese branch of the Society.

In December, 1951, joint sessions of the Society were held in New Delhi with the International Statistical Institute and in Patna in conjunction with the Indian Economic Conference. Participation is now being planned in the All-India Economic Conference to be held at Travancore University in Trivandrum, December 26-30, and in a meeting of the statistical section of the Indian Science Congress to be held at Lucknow, January 2-8, 1953.

In April, 1952, a questionnaire was sent to all members of the Econometric Society in Mexico, Central and South

America, and adjoining Caribbean areas to determine the extent of interest in the institution of regular meetings of the Society in the Latin American countries. On the basis of the response which was received, meetings in Mexico City, Mexico; Rio de Janeiro, Brazil; and Santiago, Chile, are under consideration for 1953

A report on the present status of econometric teaching at the university level was prepared for the Econometric Society by Gerhard Tintner in early 1952. Conducted under provisions of a contract between the Society and UNESCO, the study forms part of UNESCO's general inquiry into teaching in the social sciences and will be published in that connection. Because of the short interval in which the report was to be prepared, major reliance was placed upon questionnaires sent members and institutions teaching econometrics in eight countries specified by UNESCO. The survey included Egypt, France, India, Mexico, Poland, Sweden, the United Kingdom, and the United States.

The Econometric Society is cooperating informally with the Training Center for Economic and Financial Statistics which is being established in Santiago, Chile, by the Inter American Statistical Institute and Pan American Union as part of the technical assistance program of the United Nations. A consultative panel has been appointed by the Society which will be available on a continuing basis to assist in designing a set of courses appropriate to the objectives of the Center's program. No formal connection will exist, however, between the Society and the Center or its sponsoring agencies. Calvert L. Dedrick, Lester S. Kellogg, William G. Madow, and Gerhard Tintner will serve on the panel.

During the year the Econometric Society continued its affiliations with the International Statistical Institute, the American Association for the Advancement of Science, the division of mathematics of the National Research Council, and the Allied Social Science Associations. It also maintained its informal contacts with the International Economic Association. The Society is on the consultative regis-

ter of the Economic and Social Council of the United Nations and steps have been taken to complete a consultative relationship with UNESCO. The Econometric Society continued to be represented on an intersociety committee studying the mathematical training appropriate for social scientists.

On recommendation of the secretary, the Council approved the creation of an institutional (nonvoting) membership status. Academic or nonacademic institutions subscribing a specified amount or more in support of the activities of the Society will receive two copies of each publication of the Society and may designate representatives to attend its meetings. A committee will report to the Council within two years as to the experience gained with institutional memberships and as to any addition to the constitution of the Society as may then seem desirable.

During 1951, Volume 19 of *Econometrica* was published, consisting of four quarterly issues totaling 573 pages. The twentieth year volume being published in 1952 will include 806 pages. This brings the journal to double the size it had prior to 1949. The journal is now being mailed to over 2700 individuals and libraries in 72 different countries. A 160 page supplement edited by Kirk Fox is in preparation containing a twenty-year author index and analytical subject guide to *Econometrica*. The Cowles Commission gave support to the indexing project in the form of salaries paid the editor of the index and his assistants.

Arrangements were made for the publication of a Japanese translation of Trygve Haavelmo's "The Probability Approach in Econometrics," *Econometrica*, Vol. 12, Supplement, July, 1944, which is in preparation by Isamu Yamada of Hitotsubashi University, Tokyo. Royalties from the sale of the edition will be used for the purchase of econometric materials for presentation to libraries in Japan.

Ragnar Frisch continued as editor of *Econometrica* and William B. Simpson as co-editor. The following persons were appointed as associate editors during the year to assist in arranging the refereeing of articles: Nicholas

Georgescu-Roegen, Vanderbilt University; Edmond C. Malinvaud, Institut National de la Statistique et des Etudes Economiques; and J. R. Stone, Cambridge University. John R. Hicks, Oxford University, participated until 1952. Other associate editors include Harold T. Davis, Northwestern University; Kenneth O. May, Carleton College; J. Tinbergen, Netherlands School of Economics; Gerhard Tintner, Iowa State College; James Tobin, Yale University; and Herman O. A. Wold, University of Uppsala.

Econometrica began carrying a book review section, edited by Gerhard Tintner, starting with the July, 1951, issue. The journal arranged translations of articles underlying the development of econometrics to make these contributions generally accessible. During the year Mrs. Ruth Skinner succeeded Mrs. Jane Novick as editorial secretary. Mrs. Jane Diller was appointed assistant editorial secretary in June.

Other activities of the Society during the year included the establishment of an emeritus membership status, completion of a project on collation of definitions of econometrics and further work on the preparation of encyclopedias and dictionary entries, and efforts directed toward securing support for an international survey of facilities related to the quantitative approach to economics. The desirability was also explored of arranging for a publication channel for occasional contributions not suitable for either book or journal publication.

Miss Helen Docekal continued as administrative secretary during the year. Mrs. Dolores Mosher succeeded Mrs. Marilyn Holmes King as financial secretary in June, 1952. The following individuals served as financial agents of the Society in their respective countries: R. G. D. Allen, England; Francesco Brambilla, Italy; Jacques Dumontier, France; J. C. du Plessis, Union of South Africa; Ragnar Frisch, Norway; N. S. R. Sastry, India; J. Tinbergen, The Netherlands; and Isamu Yamada, Japan.

APPENDICES

- I. *Biographies of staff, fellows, and guests: 1932-1952*
- II. *Staff publications and addresses: 1951-1952*
- III. *Cowles Commission papers: 1943-1952*
- IV. *Cowles Commission monographs: 1934-1952*
- V. *Cowles Commission seminars: 1951-1952*
- VI. *List of courses at the University of Chicago in econometrics, mathematical economics, economic theory, and statistics*



Published for the Cowles Commission
for Research in Economics

**ECONOMIC ASPECTS
OF ATOMIC POWER**

An Exploratory Study
under the direction of
**SAM H. SCHURR &
JACOB MARSCHAK**

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IN DYNAMIC ECONOMIC MODELS

STATISTICAL
INFERENCE
in
DYNAMIC
ECONOMIC MODELS

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FLUCTUATIONS
in the
UNITED STATES,
1929-1957

SOCIAL CHOICE
and
INDIVIDUAL
VALUES

ACTIVITY ANALYSIS
of PRODUCTION
and ALLOCATION
Proceedings of a Conference

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COWLES COMMISSION PUBLICATIONS

BIOGRAPHIES OF STAFF, FELLOWS, AND GUESTS†

1932-1952

STEPHEN G. ALLEN

Stephen G. Allen (M.A. in economics, University of Chicago, 1950) was a research assistant at the Cowles Commission in 1949. Prior to coming to the University of Chicago in 1946, he studied at the University of Texas, 1941-44, and served in the U. S. Naval Reserve, 1944-46. In 1950 he became a research assistant in the Department of Statistics at Stanford University, and was made a research associate in the Applied Mathematics and Statistics Laboratory in the following year. While at Stanford, Allen undertook further work toward a Ph.D. degree in statistics and was elected to Sigma Xi. Since 1951, he has been a research consultant of the U. S. Treasury Department, on which behalf he is currently participating in an econometric study of the petroleum industry. He became a research consultant of the Cowles Commission in December, 1950, and this autumn will rejoin the staff to conclude work on a study of the linseed oil industry. In the spring of 1953 he will join the faculty of the School of Business Administration of the University of Minnesota. A contribution by Allen is included in *Studies in Econometric Method* (forthcoming).

THEODORE W. ANDERSON

Theodore W. Anderson (B.S., Northwestern University, 1939; M.A., 1942 and Ph.D., 1945, Princeton University) has been with the Commission as a research associate, November, 1945 through June, 1947, and as a research consultant since that time. He is currently an associate professor of mathematical statistics at Columbia University. Earlier he was an instructor at Princeton University, 1941-43, and a research mathematician in the Statistical Research Group, Princeton, 1943-45. In 1947, he took leave of absence from his position as assistant professor of mathematical statistics at Columbia to do research work as

† Names of guests are marked by an asterisk (*). Information on guests during 1951-52 is given on pp. 95-97 of this Report. Since information on guests in the period prior to World War II could not be collected with sufficient coverage, only guests in the postwar period are included.

a Guggenheim Fellow at the Institute of Mathematical Statistics, University of Stockholm, September, 1947 through April, 1948, and at the Department of Applied Economics, University of Cambridge, April-June, 1948. He has served as a consultant of the Bureau of Applied Social Research since 1947 and in 1951 was appointed to the Board of Governors of that organization. He is a consultant of the RAND Corporation. Anderson has served as editor of the *Annals of Mathematical Statistics* since 1951, is a member of the executive committee and council of the Institute of Mathematical Statistics, and is a representative of the Institute on an intersociety committee to study the mathematical training appropriate for social scientists. He was elected a Fellow of the Institute of Mathematical Statistics in 1947, of the American Statistical Association in 1949, and of the Econometric Society in 1950. His articles have appeared in *Annals of Mathematical Statistics*, *Econometrica*, *Journal of American Statistical Association*, *Journal of the Royal Statistical Society*, *Proceedings of the International Statistical Conferences*, *Proceedings of the Second Berkeley Symposium on Mathematical Statistics and Probability*, *Psychometrika*, *Skandinavisk Aktuarietidskrift*, and *Statistical Inference in Dynamic Economic Models*, 1950.

WILLIAM H. ANDREWS

William H. Andrews (B.S., 1933 and A.M., 1937, Indiana University; Ph.D. in economics, University of Chicago, 1949) was a research associate of the Cowles Commission from July, 1943 to March, 1944. He then became an ensign in the U. S. Naval Reserve. Andrews was an instructor in economics at Purdue University, 1937-41, a fellow at the University of Chicago, 1942-43, and a research associate of the Department of Economics, 1943-44. At the present time he is assistant professor of economics at Indiana University and is currently doing research in the fields of taxation and national income. An article by Andrews has appeared in *Econometrica*.

KENNETH J. ARROW

Kenneth J. Arrow (B.S., College of the City of New York, 1940; M.A., 1941 and Ph.D., 1950, Columbia University) served in the Weather Division of the Army Air Force, 1942-46. He was an instructor in economics at College of the City of New York, summer session, 1946; and an assistant in statistics, School of Business, Columbia University, in the fall of 1946. He joined the Cowles Commission as a research associate in April, 1947, and was appointed assistant professor in the Department of Economics, the University of Chicago, October, 1948. In addition to regular teaching and research duties, he helped in

the editing of the *Journal of Political Economy* and did consultative work during the winter of 1948 with the U. S. Bureau of the Budget and for a project of the RAND Corporation. Arrow became a research consultant of the Commission upon accepting an appointment at Stanford University in July, 1949, where he is now associate professor of economics and statistics. He was elected a Fellow of the Econometric Society in 1951. He is an editorial collaborator of the *Journal of the American Statistical Association*. His papers have appeared in the *American Economic Review*, *Econometrica*, *George Washington University Logistics Papers*, *Journal of Meteorology*, *Journal of Political Economy*, and *Mathematical Reviews*. Contributions by Arrow have appeared in *Activity Analysis of Production and Allocation*, 1951; *The Policy Sciences*, 1951; and *Proceedings of the Second Berkeley Symposium on Mathematical Statistics and Probability*, 1951. His book, *Social Choice and Individual Values*, was published in 1951.

SELMA SCHWEITZER ARROW*

Selma Schweitzer Arrow was appointed a Sarah Frances Hutchinson Cowles Fellow in 1946. The fellowship was awarded to students preparing for advanced degrees in the fields of the social sciences and statistics, with preference to students who would be working on quantitative economics or mathematical statistics.

EARL F. BEACH*

Earl F. Beach, professor of commerce and chairman of the Department of Economics, McGill University, participated in the research discussions of the Commission and of the Committee on Statistics of the University of Chicago during the academic year, 1949-50.

MARTIN J. BECKMANN

Martin J. Beckmann (*Vordiplom* in mathematics, University of Goettingen, 1947; *Diplom* in economics 1949 and *Dr. ver. pol.*, 1950, University of Freiburg) was an assistant of L. Miksch at the University of Freiburg in 1950 prior to becoming a postdoctoral fellow in political economy at the University of Chicago, 1950-51. Beckmann became a research associate with the Cowles Commission, July, 1951. Currently he is working on location and transportation efficiency and the best utilization of roads. He has published in *American Economic Review*, *Econometrica*, and *Weltwirtschaftliches Archiv*.

PETTER JAKOB BJERVE*

Petter Jakob Bjerve, while research fellow of the University of Oslo and chief of the national economic planning unit in the Nor-

wegian Ministry of Trade, was with the Commission from September, 1948, to April, 1949, as a Rockefeller Fellow. He returned to Oslo to become director of the Norwegian Central Bureau of Statistics. His research interests include the theory of economic planning.

EDWARD BOORSTEIN

Edward Boorstein (B.S., College of the City of New York, 1936; M.A. Columbia University, 1940) joined the staff in the autumn of 1946 as a research associate with the rank of instructor in the study of the economics of atomic energy. Boorstein was economic assistant to the Board of Governors of the Federal Reserve System, 1940-42; economist, War Production Board, 1942-43; and economist, Civilian Production Administration, 1946. He continued his work with the Commission until December, 1947, at which time he went to Berlin, Germany, to work as an economist-statistician with the U. S. Army Occupation Forces. Boorstein contributed to *Economic Aspects of Atomic Power*, 1950.

GEORGE H. BORTS*

George H. Borts was in residence at the Commission as a fellow of the Social Science Research Council in 1949-50, and continued as a guest of the Commission until the late summer of 1950, at which time he became assistant professor of economics at Brown University. A summary of the results of his research while at the Commission was published as an article in *Econometrica*.

JEAN ANDRUS BRONFENBRENNER

Jean Andrus Bronfenbrenner (B.A. in economics, University of Chicago, 1939; M.A. in mathematics, University of Colorado, 1945; M.A. in economics, University of Chicago, 1950) became a research assistant with the Cowles Commission in July, 1948. She was a teaching assistant in mathematics at the University of Colorado, 1943-44; instructor in mathematics at the University of Arizona, 1945-46; and a teaching assistant in mathematics and statistics at the University of Wisconsin, 1947-48. Mrs. Bronfenbrenner continued as a research assistant of the Cowles Commission until October, 1949, at which time she joined the faculty of the University of Illinois as research associate and assistant professor of economics. In November, 1951, she accepted a position with the Office of Business Economics, Department of Commerce. She has had papers published in *Econometrica*, *National Tax Journal*, and *Survey of Current Business*. A contribution by her appears in *Studies in Econometric Method* (forthcoming).

KARL BRUNNER*

Karl Brunner (Ph.D., University of Zurich) was a guest of the Commission under a grant from the Rockefeller Foundation throughout most of the period from January, 1950 through June, 1951. He is now on the economics faculty at the University of California at Los Angeles, where he is currently working on a research project on the behavior of the financial sector. Brunner was a temporary consultant to the Economic Commission for Europe, an economic adviser to the Swiss Watch Chamber of Commerce, and a research associate at the Swiss Institute for Research in International Economics at the Handelshochschule, St. Gallen. Articles published by him have appeared in *Econometrica* and *Kyklos*. In 1944 the following book was published in Zurich: *Studies in the Theory of International Trade*.

EDWARD N. CHAPMAN

Edward N. Chapman (B.A., Yale University, 1917; M.D., Harvard University, 1921) was a research associate of the Cowles Commission from 1936 to 1941. For several years prior to that time he had devoted himself to economic research. Chapman is at present director of the Division of Tuberculosis Assistance for the Colorado Department of Public Welfare.

HERMAN CHERNOFF

Herman Chernoff (B.A., College of the City of New York, 1943; Sc. M., 1945 and Ph.D. in applied mathematics, 1948, Brown University) became a research assistant with the Cowles Commission in June, 1947. In 1946-47 he was a National Research Council Predoctoral Fellow. In the spring of 1948 he became a research associate of the Cowles Commission and supervised the computational work of the Commission. In the winter of 1948 he taught mathematical statistics at the Illinois Institute of Technology. He became an assistant professor of mathematics and statistics at the University of Illinois in 1949 and was made an associate professor of mathematics in 1951. He is now an associate professor in the Department of Statistics at Stanford University. Chernoff was appointed a research consultant of the Commission in October, 1951. His articles have been published in the *American Journal of Mathematics*, *Annals of Mathematical Statistics*, *Mathematical Tables and Other Aids to Computation*, and *Proceedings of the American Mathematical Society*. Contributions by Chernoff appear in *Studies in Econometric Method* (forthcoming).

JOHN CHIPMAN*

John Chipman (B.A., and M.A., McGill University; Ph.D., Johns Hopkins University) was a guest of the Cowles Commission, 1950-51, while holding a postdoctoral fellowship in the Department of Economics at the University of Chicago. Since 1951 he has been an assistant professor of economics at Harvard University. Chipman was elected to Phi Beta Kappa at Johns Hopkins University. He is the author of *The Theory of Inter-Sectoral Money Flows and Income Formation*, 1951, and has published articles in the *Canadian Journal of Economics and Political Science*, *Econometrica*, *Economia Internazionale*, and *Economic Journal*.

CARL F. CHRIST

Carl F. Christ (B.S. in physics, 1943 and Ph.D. in economics, 1950, University of Chicago) was elected to Phi Beta Kappa in 1943. He was a junior physicist in the Manhattan Project, 1943-45, and an instructor in physics, Princeton University, 1945-46. In 1947 he received the Harper fellowship in economics at the University of Chicago. During his tenure as a Social Science Research Council Fellow, 1948-50, he participated as a member of the Commission's staff, becoming a research associate in September, 1949. The following year he became an assistant professor of political economy at the Johns Hopkins University. At that time he was appointed a research consultant of the Commission in connection with work he is doing with Marschak on an introduction to econometrics for a monograph. His current research interests includes a critical evaluation of input-output analysis. Papers and reviews written by Christ have been published in *American Economic Review*, *Conference on Business Cycles*, and *Journal of Political Economy*.

GERSHON COOPER

Gershon Cooper (A.B., University of Chicago, 1942) assisted Haavelmo in work on agricultural models for a joint project of the Agricultural Economics Research Group and the Cowles Commission. He began this work in December, 1946, on a part-time basis. During the spring quarter of 1947 he participated in leadership of a university seminar on Agricultural Demand Analysis. Cooper was a research associate of the Commission, 1947-48. More recently he has been a staff member of the RAND Corporation. Articles of his have been published in the *Journal of Farm Economics* and *Quarterly Journal of Economics*.

ALFRED COWLES

Alfred Cowles (B.A., Yale University, 1913) was the founder of the Cowles Commission and has been its president since the beginning.

For ten years prior to its foundation he maintained a private organization for statistical research on problems of investment and finance. He is a Fellow of the American Association for Advancement of Science and the Econometric Society (treasurer); trustee of the Chicago Historical Society, Colorado College, and Illinois Children's Home & Aid Society (treasurer); a director of Chicago Maternity Center, Home for Destitute Crippled Children, Passavant Memorial Hospital (treasurer), and Tribune Company and affiliated corporations. He is the author of *Common Stock Indexes*, 1939 and contributed to *Econometrica* and *Journal of American Statistical Association*.

FORREST DANSON

Forrest Danson (A.B., Colorado College, 1929) joined the staff of the Cowles Commission as a research associate at its beginning in 1932 and remained with the Commission until March, 1943. He made various studies of common-stock prices and took part in the field work of the study of price control. In 1943 he took a statistical position in the Army Air Force Materiel Command at Wright Field, Dayton, Ohio. He is now chief, Budget Section, Plans and Programs Office and Directorate, Procurement and Industrial Planning, Air Materiel Command, U. S. Air Force.

HAROLD T. DAVIS

Harold T. Davis (A.B., 1915 and LL.D., 1949, Colorado College; A.M., Harvard University, 1919; Ph.D., University of Wisconsin, 1926) has been associated with the Cowles Commission since its beginning, spending several months each year in the Commission's laboratory while it was at Colorado Springs and serving as a consultant throughout the balance of the time. From February to August, 1937, he was acting research director. He has been professor of mathematics at Indiana University, 1923-37, and at Northwestern University since 1937, becoming full professor and chairman of the Department of Mathematics in 1942. Davis is a Fellow of the Econometric Society. He is an associate editor of *Econometrica*, and has served in the same capacity for *Isis* and the *Bulletin of the American Mathematical Society*. During the past year he continued studies in the field of political statistics and has submitted several books for publication. Numerous papers, abstracts, and reviews have been published in *American Mathematical Monthly*, *Annals of Mathematical Statistics*, *Bulletin of the American Mathematical Society*, *Mathematical Tables*, and *Other Aids to Computation*, *National Mathematics Magazine*, *School Science and Mathematics*, and *Science*. He is the author of the following books: *The Volterra Integral Equation*, 1930;

Philosophy and Modern Science, 1931; *Tables of the Higher Mathematical Functions*, 1933, Vol. II, 1935; *Elements of Statistics* (with F. C. Nelson), 1935; *General Mathematics*, 1935; *Theory of Linear Operators*, 1936; *College Algebra*, 1940; *Theory of Econometrics*, 1941; *Mathematical Monograph*, 1941; *The Analysis of Economic Time Series*, 1941; *Political Statistics*, 1948; *Essays in History of Mathematics*, 1948; *Differential Equations and Mathematical Physics*, 1949; *Quantitative Aspects of the Action of Carcinogenic Substances*, 1951; and *Quantitative Aspects of the Carcinogenic Radiations*, 1952.

JOEL DEAN

Joel Dean (A.B., Pomona College, 1929; M.B.A., Harvard University, 1929; Ph.D., University of Chicago, 1936) joined the Cowles Commission staff as a research associate in September, 1939. He was on the staff of the International Business Machines Corporation, 1930-32; assistant professor of economics, Indiana University, 1934-37; consulting economist, McKinsey, Wellington and Co., 1937-38; executive secretary of the Conference on Price Research, National Bureau of Economic Research, 1938-39; and assistant professor of statistics and marketing, the School of Business, and director of the Institute of Statistics, the University of Chicago, 1939. In 1941 he went on leave of absence to become a price executive in the Office of Price Administration, where he later became director of fuel rationing. He was associated with McKinsey and Co. as a management consultant, 1944-46. In 1944 he was a visiting professor at the School of Business, Columbia University and in 1945 resigned from the Commission to accept a position as professor of business economics there. At present he is a partner in Joel Dean Associates, economic and management consultants; a director of the American Marketing Association; a member of the planning council of the American Management Association; a director of American Hard Rubber Co.; and trustee of the Bureau of University Travel. Dean is on the editorial board of the *Journal of Marketing* and is an associate editor of the *Journal of Industrial Economics*. His current research is on managerial economics. Articles by him have appeared in *Accounting Review*, *American Economic Review*, *Australian Accountant*, *Harvard Business Review*, *Journal of the American Statistical Association*, *Journal of Business*, *Journal of Marketing*, and *Zeitschrift für Ökonometrie*. He is the author of the following books: *Statistical Determination of Cost*, 1936; *The Management Counsel Profession*, 1940; *Statistical Cost Functions of a Hosiery Mill*, 1941; *The Relation of Cost to Output*, 1941; *The Long-Run Behavior of Costs* (with J. W. James), 1942; *Cost Behavior and Price Policies*

(others), 1942; *Social Control of Business* (ed. with E. Hoover), 1942; *Pricing from the Seller's Standpoint*, 1949; *Managerial Economics*, 1951; and *Capital Budgeting*, 1951.

GERARD DEBREU

Gerard Debreu (Agrégé de l'Université, 1946) joined the Cowles Commission as a research associate in June, 1950, upon completion of a Rockefeller fellowship under which he studied at Harvard University, the University of California at Berkeley, and the Universities of Chicago, Uppsala, and Oslo. Earlier he studied at the Ecole Normale Supérieure, 1941-44, prior to serving in the French army, 1944-45. From October, 1946 to December, 1948, he was attaché de recherches at the Centre National de la Recherche Scientifique, assistant professor of mathematics at the Conservatoire National des Arts et Metiers, professor at the Ecole d'Application de l'Institut National de la Statistique et des Etudes Economiques at the Collège Libre des Science Sociales et Economiques, and director of a seminar on economic theory at the Ecole Nationale Supérieure des Mines. In June, 1951, he was appointed assistant professor in the Cowles Commission. Currently he is conducting research on the existence of an equilibrium for social systems, application to a competitive economy, numerical representations of technological change, structure of linear models and nonnegative square matrices, zero-sum two-person games, loss of efficiency due to a system of indirect taxes and subsidies, and real representation of a preference ordering. Debreu has published articles in *Econometrica*.

BAREND A. DE VRIES

Barend A. de Vries (Ph.D., Massachusetts Institute of Technology, 1951) studied at the University of Utrecht, 1942-46. He joined the Commission as a research assistant in August, 1946, and continued through July, 1948. While at the Commission he aided in the supervision and improvement of computational work which applied statistical methods developed by the staff. During 1946-48 he held a scholarship in the Department of Economics, the University of Chicago. Since 1949 he has been an economist with the International Monetary Fund where he is currently conducting research on monetary and commercial problems in international trade and on policy and analytical problems in economic growth and development. He held a research training fellowship of the Social Science Research Council in 1951. Papers by de Vries have appeared in the *Staff Papers* of the International Monetary Fund.

NATHAN J. DIVINSKY

Nathan J. Divinsky (B.S., University of Manitoba, 1946; M.S., 1947 and Ph.D., 1950, University of Chicago) joined the staff as a research associate in June, 1949, to supervise the computational work of the Commission. In this connection he participated in a conference on computing machines at Harvard University in September, 1949. During the year prior to joining the Commission he was a teaching assistant in the Department of Mathematics at the University of Chicago. In July, 1950, he left the Commission to become assistant professor of mathematics at Ripon College. Divinsky spent the summer of 1951 teaching at the University of Southern Illinois, and in September of that year entered upon his present position as assistant professor of mathematics at the University of Manitoba. He was elected to Sigma Xi in 1950. A contribution by Divinsky appears in *Studies in Econometric Method* (forthcoming).

EVSEY D. DOMAR

Evsey D. Domar (B.A., University of California at Los Angeles, 1939; A.M. in mathematics, University of Michigan, 1941; M.A., 1943 and Ph.D., 1947, Harvard University) was a teaching fellow at University of Michigan, 1940-41, and at Harvard University, 1941-43. In 1943 he joined the Division of Research and Statistics of the Board of Governors of the Federal Reserve System. In 1946 he returned to academic pursuits as an assistant professor of economics at Carnegie Institute of Technology, and in 1947 joined the University of Chicago with the same rank. He also taught at George Washington University, summer 1944, and the University of Michigan, summer 1946. Domar became a research associate in the Cowles Commission in July, 1947, and continued with the Commission and as assistant professor of economics until July, 1948. At that time he accepted his present position as associate professor of political economy at the Johns Hopkins University. He taught at the College of the University of Chicago, summer 1948, and at the University of Buffalo, spring 1949. Since 1951 he has been a visiting associate professor at the Russian Institute of Columbia University. He was chairman of the Russian Economics Project, Operations Research Office, Johns Hopkins University, 1949-51. Domar has also been consultant for the RAND Corporation since 1951. In September, 1952, he goes to Oxford University as a lecturer on a Fulbright grant for a year. His current field of interest is in the theory of economic growth and soviet economics. His articles have been published in the *American Economic Review* and *Econometrica*.

WILLIAM L. DUNAWAY

William L. Dunaway (A.B. in business administration, 1949 and M.A. in mathematical statistics, 1952, University of California) was elected to membership in Phi Beta Kappa and Sigma Xi in 1949. He came to the University of Chicago on a William Rainey Harper fellowship, and became a research assistant of the Cowles Commission in January, 1952. Prior to service in the army, 1942-46, he attended Cameron College, 1939-41, and was a reporter for various daily newspapers in Oklahoma, becoming city editor of the Woodward Daily Press. He is currently working on a study with Houthakker on futures trading.

ARYEH DVORETZKY

Aryeh Dvoretzky is a consultant for the Cowles Commission. He is at present professor of mathematics at Hebrew University, Israel. He has formerly been associated with Columbia University, Cornell University, and the Institute of Numerical Analysis of the National Bureau of Standards at the University of California, Los Angeles. He participated actively in the conference on decision-making and uncertainty held at the Cowles Commission, November, 1951. During 1951-52, he was research consultant on the Cowles Commission project on decision-making under uncertainty. He has published articles in the *Annals of Mathematical Statistics* and *Econometrica*.

MARIANNE ABELES FERBER

Marianne Abeles Ferber was a part-time research assistant during the first half of 1946 while she was a fellow of the Department of Economics, the University of Chicago. During her association with the Commission she collected statistical data for Klein's studies on economic models in the United States. From September, 1946, until October, 1948, she worked in the Economic Section of the Standard Oil Co. (New Jersey). During 1947 and 1948 she taught evening courses at Hunter College. Currently Mrs. Ferber is working on her Ph.D. thesis in economics at the University of Chicago.

FRANÇOISE FERDINAND-DREYFUS*

Françoise Ferdinand-Dreyfus, formerly of the Institute of Statistics University of Paris, studied at the Cowles Commission from October, 1947, to July, 1948, on a Sarah Frances Hutchinson Cowles fellowship. She is now a member of the Econometric Seminar at the French Centre National de la Recherche Scientifique and is a statistician at the Institut National de Sécurité.

KIRK FOX

Kirk Fox (M.A. in economics, University of Chicago, 1951) became a research assistant at the Commission in November, 1950. This position he held until February, 1952, at which time he became a research associate in the Departments of Food Technology and Agricultural Economics, University of Illinois. During 1951-52 he lectured on elementary and intermediate statistics at the School of Commerce, Northwestern University, and compiled information for an analytical subject guide and index to *Econometrica*. His current research concerns the most efficient pattern for the over-all movement of empty railroad cars from points of availability to points of need and various aspects of the economics of food processing industries.

MURRAY GERSTENHABER

Murray Gerstenhaber (B.S., Yale University, 1948; M.S., 1949 and Ph.D., 1951, University of Chicago) was with the Commission as a research assistant, May to December, 1949. He held a fellowship in the Department of Mathematics while at the University of Chicago and, in addition to his association with the Commission, served as a research assistant in that Department from September, 1949, until June, 1950. Gerstenhaber received an Atomic Energy Commission predoctoral fellowship, 1950-51, and a Frank B. Jewett postdoctoral fellowship in mathematics, 1951-53. He was at Harvard University during 1951-52 and will be at the Institute for Advanced Study during the coming year. He contributed to *Activity Analysis of Production and Allocation*, 1951.

MEYER A. GIRSHICK

Meyer A. Girshick (A.B., 1932; M.A., 1934; and Ph.D. in mathematical statistics, 1946, Columbia University) served as a research consultant of the Cowles Commission during 1946 and 1947. In 1948 he entered upon his present position as professor of mathematical statistics at Stanford University. Previous to this he was a research statistician at Columbia University, 1935-37; associate statistician, Bureau of Home Economics, U. S. Department of Agriculture, 1937-39; instructor, Graduate School, U. S. Department of Agriculture, 1937-47; principal statistician, Bureau of Agricultural Economics, 1939-44, 1945-46; principal statistician, National Defense Research Committee, 1944-45; with the U. S. Bureau of the Census, 1946-47; and research mathematician, Douglas Aircraft Co., 1947-48. He was president of the Institute of Mathematical Statistics in 1952 and is a Fellow of that

Society, and of the American Statistical Association. Girshick has made numerous contributions to mathematical statistics and statistical economics and particularly to the theory of sequential analysis.

JOHN GURLAND

John Gurland (M.A. in mathematics, University of Toronto, 1942; Ph.D. in mathematical statistics, University of California, 1948) was appointed assistant professor in September, 1949, jointly in the Cowles Commission and in the Committee on Statistics of the University of Chicago. Earlier he was at the Dominion Bureau of Statistics, Ottawa, 1944, and on a war research project at the Statistical Laboratory of the University of California in 1945. During 1948-49 he was Benjamin Peirce Instructor in Mathematics at Harvard University. He is now at the Statistics Laboratory, Iowa State College. He has published an article (with E. W. Barankin) in the *University of California Publications in Statistics*, 1951.

SOPHIA GOGEK

Sophia Gogek (B.A., University of Alberta, 1943; M.A., University of Chicago, 1946) was a part-time research assistant during 1945 while she was a fellow of the Department of Economics at the University of Chicago. In 1943-44 she was awarded the Charles R. Walgreen scholarship, in 1944-45 a Marshall Field fellowship, and in 1945-46 a University fellowship. Since 1946 she has been an economic analyst with the Standard Oil Co. (New Jersey). Her current research is on the study of trade relationships between the United States and various areas of the world.

TRYGVE HAAVELMO

Trygve Haavelmo (*Cand. oecon.*, 1933 and Ph.D., 1946, University of Oslo) became associated with the Cowles Commission in July, 1943. He was in residence at Chicago as an instructor in the Department of Economics and a member of the Agricultural Economics Research Group from January, 1946, to March, 1947, at which time he returned to Norway, continuing his connection with the Commission as a research consultant. Haavelmo was a research assistant at the University Institute of Economics in Oslo, Norway, 1933-38, and lecturer in statistical theory at the University of Aarhus, Denmark, 1938-39. He studied at various European universities and in 1939-42 at American universities on an American Scandinavian Foundation fellowship and a Rockefeller Foundation fellowship. In 1942-44 he was statistician of the Norwegian Shipping and Trade Mission in New York, and in

1944-45 he was commercial secretary of the Royal Norwegian Embassy in Washington. He also served as consultant to the Norwegian Department of Commerce and vice-chairman of the Norwegian Economic Co-ordination Council. In April, 1948, he was appointed professor of economics at the University of Oslo. He also lectured at the Universities of Aarhus and Copenhagen. In January, 1950, he served as delegate to the United Nations Economic and Employment Commission, during which time he also visited the Cowles Commission and participated in staff discussions. Haavelmo is a Fellow of the Econometric Society and of the Institute of Mathematical Statistics. His contributions have been published in *Econometrica*, *Journal of Farm Economics*, *Journal of Political Economy*, *Review of Economics and Statistics*, *Review of Economic Studies*, and *Statsøkonomisk Tidsskrift*. He has also contributed to *Statistical Inference in Dynamic Economic Models*, 1950 and *Studies in Econometric Method* (forthcoming).

ANDERS HALD*

Anders Hald, professor of statistics at the University of Copenhagen, was a guest of the Commission as a Rockefeller Fellow in 1948. After his return to Copenhagen he became dean of the Faculties of Economics, Law, and Statistics at the University. He is the author of *The Decomposition of a Series of Observations Composed of a Trend, a Periodic Movement and a Stochastic Variable*, 1948.

ARNOLD C. HARBERGER

Arnold C. Harberger (M.A., 1947 and Ph.D., 1950, University of Chicago) was on the staff of the Cowles Commission as a research assistant, March through October, 1949. He studied at the Johns Hopkins University, 1941-43, and served in the army, 1943-46. He attended the University of Chicago on a scholarship, 1947-48, and on a Marshall Field fellowship, 1948-49. In 1949 he left the Commission to become an assistant professor of economics at the Johns Hopkins University. From June to September, 1950, he served as an economist for the International Monetary Fund. During 1951 he served as a staff consultant to the President's Materials Policy Commission. At the present time Harberger holds a three-year faculty research fellowship at Johns Hopkins provided by the Social Science Research Council. Articles by him have been published in the *Journal of Political Economy* and in *Resources for Freedom*, the report of the President's Materials Policy Commission.

ALBERT G. HART

Albert G. Hart (A.B., Harvard University, 1930; Ph.D., University of Chicago, 1936) was a research consultant of the Cowles Commission in 1945-46. He did graduate work in Vienna and Germany, 1930-31, and in London, 1934-35. Hart was a teaching assistant during 1932-33, and an instructor from 1934 through 1939, at the University of Chicago; an economic analyst, U. S. Treasury Department, 1934; lecturer, University of California, autumn, 1936; research director, Committee on Debt Adjustment of the Twentieth Century Fund, 1937-38; professor, Iowa State College, 1939-45; consultant in residence, U. S. Treasury Department, 1943-44; and research economist, Committee for Economic Development, 1944-46. In 1946 he went to Columbia University as a visiting professor, at which institution he is now professor of economics. From 1949 until 1952, he was the research director of the Economic Stabilization Study of the Twentieth Century Fund. Since 1949, he has been an editorial consultant in economics for Harcourt Brace & Co. He has been active in the Conference on Research in Income and Wealth and is a member of the executive committee of the American Economic Association. Papers by Hart have appeared in the *American Economic Review*, *Journal of Political Economy*, *Quarterly Journal of Economics*, *Review of Economics and Statistics*, *Review of Economic Studies*, and *Studies in Income and Wealth*. He is the author of *Debts and Recovery*, 1938; *Anticipations, Uncertainty and Dynamic Planning*, 1940; *Paying for Defense* (with E. D. Allen and others), 1941; *Social Framework of the American Economy* (with J. R. Hicks), 1945; *Jobs and Markets* (with M. de Chazeau, G. C. Means, H. Stein, and T. O. Yntema), 1946; *Money, Debt, and Economic Activity*, 1948; *Defense without Inflation*, 1951; and *Financing Defense* (with E. Cary Brown), 1951.

JACOB HARTOG*

Jacob Hartog of the Netherlands Economic Institute participated in the research of the Commission as Rockefeller Fellow in 1947-48. His research interests include models of international trade and problems of western European economic integration.

I. N. HERSTEIN

I. N. Herstein (B.Sc., University of Manitoba, 1945; M.A., University of Toronto, 1946; Ph.D. in mathematics, Indiana University, 1948) joined the staff of the Cowles Commission in late 1951 as a research associate with the complimentary rank of assistant professor,

and at the same time was appointed a research associate in the Department of Mathematics, University of Chicago. Effective July, 1952, he was appointed to the faculty of the Commission as an assistant professor. Prior to his association with the Commission he held a traveling fellowship in 1946; was an instructor at the University of Kansas, 1948-50; and a visiting lecturer at Ohio State University, 1950-51. Currently he is working on the development of mathematical tools for economists, especially in matrix theory, and is continuing his mathematical research in group and ring theory. Herstein is a member of Sigma Xi and Pi Mu Epsilon. His articles have appeared in the *American Journal of Mathematics*, *Bulletin of the American Mathematical Society*, *Canadian Journal of Mathematics*, *Det Kongelige Norske Videnskabers Selskab*, *Pacific Journal of Mathematics*, and *Publicationes Mathematicae*.

CLIFFORD HILDRETH

Clifford Hildreth (A.B., University of Kansas, 1939; M.S., 1941 and Ph.D., 1947, Iowa State College) joined the staff in January, 1949, as assistant professor in the Cowles Commission and research associate in the Department of Economics under a joint appointment with the Agricultural Economics Research Group. Prior to coming to the University of Chicago, he held appointments at Iowa State College as a graduate assistant, 1939-41; as instructor and research associate, 1941-43, and 1946-47; as assistant professor (joint appointment with the Agricultural Experimental Station and Statistical Laboratory) 1947-48; and as associate professor, Department of Economics and Sociology, and research associate professor, Statistical Laboratory, 1948. From April, 1943, to January, 1946, he was on active duty with the U. S. Navy, where he was air navigator with the Naval Air Transport Service. In July, 1950, he was promoted to associate professor in the Cowles Commission and to research associate (associate professor) in the Department of Economics. He is currently engaged in a statistical study of supply and demand for livestock products in the United States. Since June, 1950, he has consulted with the U. S. Treasury Department on estimating effects of excise taxes. His publications have appeared in the *American Economic Review*, *Journal of Farm Economics*, and *Quarterly Journal of Economics*. Contributions by Hildreth have appeared in *Paying for Defense*, 1941, and *Activity Analysis of Production and Allocation*, 1951.

WILLIAM C. HOOD

William C. Hood (Ph.D., University of Toronto, 1948) joined the Cowles Commission as research associate in September, 1949, at which

time he also became a postdoctoral fellow in political economy at the University of Chicago. He was a member of the Department of Economics of the University of Saskatchewan, 1944-46, and of the Department of Economics of the University of Toronto, 1946-49. Earlier, during the war, he served as a meteorologist attached to the Royal Canadian Air Force. In July, 1950, he returned to the University of Toronto as assistant professor of economics, at which time he became a research consultant of the Cowles Commission. His current research concerns certain problems of aggregation in economics such as the optimum degree of grouping of variables for decision-making purposes by firms. He has published in the *American Journal of Psychiatry*, the *Canadian Journal of Economics and Political Science*, and *Econometrica*. He is a contributor to and co-editor (with T. C. Koopmans) of *Studies in Econometric Method* (forthcoming).

H. S. HOUTHAKKER

H. S. Houthakker (B.A. in economics, 1947 and *Doctorandus* in economics, 1949, University of Amsterdam) was at the University of Cambridge, 1949-51, as a junior research worker and later as a research officer. He came to the Cowles Commission in January, 1952, as an assistant professor. At present he is doing empirical research on dynamic economics with special reference to futures trading. He was elected Fellow of the Econometric Society in 1952. Houthakker has published articles in *De Economist*, *Economica*, *Economic Journal*, *Review of Economic Studies*, and *Journal of the Royal Statistical Society*.

LEONID HURWICZ

Leonid Hurwicz (L.I.M., University of Warsaw, 1938) joined the Cowles Commission staff as a research associate in 1942. He studied at the London School of Economics, the Postgraduate Institute of International Studies at Geneva, the University of Chicago, and Harvard University and has held a research and teaching fellowship at Massachusetts Institute of Technology. From 1942-44, Hurwicz was a member of the faculty of the Institute of Meteorology of the University of Chicago. He was associate director under Yntema on a study of the committee on price control and rationing. At the end of 1944 he became a full-time research associate for the Cowles Commission and also served as a consultant to the United States Army Air Force. During 1945-46 he held a fellowship of the John Simon Guggenheim Foundation and at the same time was on leave of absence as associate professor of economics and statistics at Iowa State College. In 1946 he became a research consultant of the Cowles Commission and in 1949, a consultant

of the RAND Corporation. During the second half of 1948 he was a consultant with the U. S. Bureau of Standards. In 1949 Hurwicz joined the faculty of the University of Illinois as a research professor of economics and mathematical statistics. In October, 1950, he came to the Cowles Commission on a full-time basis as a research associate and visiting professor and assumed Koopmans' research leadership in the Cowles Commission and teaching duties in the Department of Economics during the latter's absence. In September, 1951, he became professor of economics and mathematics in the School of Business Administration at the University of Minnesota. In 1946, he was an associate editor of the *Journal of the American Statistical Association*. He was elected to Sigma Xi in 1946. He became a Fellow of the Econometric Society in 1949. Since 1950 he has been a consultant to the Bureau of the Budget on interindustry problems. Abstracts, papers, and reviews by Hurwicz have appeared in the *American Economic Review*, *Current Economic Comment* (University of Illinois), *Econometrica*, *Journal of the American Statistical Association*, and *Proceedings of the International Statistical Conferences*. He also contributed to *Statistical Inference in Dynamic Economic Models*, 1950.

HERBERT E. JONES

Herbert E. Jones (A.B., 1926 and a degree in engineering, 1928, Stanford University) was a research fellow of the Cowles Commission from April, 1936, to September, 1937, and continued as a research associate until his death in January, 1942. While with the Commission his major studies were on cost functions associated with hydraulic pumping, the nature of regression functions in correlation analysis, statistics of time series, and differentiation between "lag hysteresis" and "skew hysteresis." Previous to coming to the Commission he had been a hydraulic engineer for the Federal Water Service Corporation in San Francisco and New York. Publications by Jones appeared in *Barron's*, *Econometrica*, and *Metron*.

GEORGE KATONA

George Katona (Ph.D., Göttingen, 1921) joined the staff in January, 1943, as co-director of the study of price control and rationing and assumed the administrative direction of the project. At the completion of this project in January, 1945, he became senior study director in the Division of Program Surveys in the U. S. Department of Agriculture. He held this position until October, 1946, at which time he became program director of the economic behavior program of the Survey Research Center, and also professor of economics and psychology, Uni-

versity of Michigan. Katona was associate editor of *Der Deutsche Volkswirt*, Berlin, 1926-33, as well as correspondent for the *Wall Street Journal*, 1929-33. He worked as an economic adviser in New York, 1934-38; was with the New School for Social Research as a research associate and then lecturer, 1935-36; conducted psychological research under grants-in-aid for the Carnegie Corporation of New York, 1938-39; and conducted investigations in war economics as a Guggenheim Fellow, 1940-42. He is author of numerous articles in economic and psychological journals and of the following books: *Zur Psychologie des Vergleichens und der Relationserfassung*, 1934; *Organizing and Memorizing, Studies in the Psychology of Learning and Teaching*, 1940; *War Without Inflation, The Psychological Approach to Problems of War Economy*, 1942; *Price Control and Business*, 1945; and *Psychological Analysis of Economic Behavior*, 1951.

CARL N. KLAHR

Carl N. Klahr (M.S. in physics, 1948, and M.S. in economics and D.Sc. in physics, 1950, Carnegie Institute of Technology) was a research consultant of the Cowles Commission, 1949-50. He was a research assistant in econometrics, Carnegie Institute of Technology, 1947-48; Atomic Energy Commission Fellow, 1948-49; and a fellow in economics in the Mellon School of Industrial Administration, Carnegie Institute of Technology, 1949-50. In August, 1950, he became a research engineer in problems of solid state physics and electronics, Westinghouse Research Laboratories. Since March, 1952, he has been a consultant to Carnegie Institute of Technology on a research project in intrafirm analysis. Currently he is engaged in research on methods of determining pricing policy for the firm. In April and May of 1952, he gave a series of lectures in the Graduate School of Industrial Administration, Carnegie Institute of Technology, on statistical determination of simultaneous equations describing intrafirm production functions, which were later mimeographed for distribution. In October, 1952, he will join Nuclear Development Associates, Inc., White Plains, New York. He has had articles published in *Physical Review*.

LAWRENCE R. KLEIN

Lawrence R. Klein (B.A., University of California, 1942; Ph.D., Massachusetts Institute of Technology, 1944) joined the staff of the Cowles Commission in November, 1944, as a research associate. Earlier, he was a George May Fellow and Teaching Fellow at the Massachusetts Institute of Technology, 1943-44. In 1945 he received a post-doctoral fellowship and in 1947 a traveling fellowship from the Social

Science Research Council. Prior to studying economic planning in Norway he spent a few months in Canada as a consultant to the Director General of the Economic Research Branch, Department of Reconstruction and Supply, Ottawa. From 1948 to 1951 Klein was a research associate of the National Bureau of Economic Research. Since 1949 he has been a research associate of the Survey Research Center at the University of Michigan, joining the Department of Economics there in 1950 as a lecturer and the Research Seminar in Quantitative Economics as a research associate in 1951. Klein's association with the Cowles Commission was again made active in May, 1951, at which time he was appointed as a research consultant. In 1948, Klein was elected a Fellow of the Econometric Society. He has had several articles published in the following journals: *American Economic Review*, *Econometrica*, *Journal of the American Statistical Association*, *Journal of Political Economy*, *Kyklos*, *Quarterly Journal of Economics*, *Review of Economic Studies*, and *Statsøkonomisk Tidsschrift*. He has written two books, *Keynesian Revolution*, 1947, and *Economic Fluctuations in the United States, 1921-1941*, 1950. Contributions by Klein appear in *Conference on Business Cycles*, 1951 and *Studies in Income and Wealth*, Vol. 14, 1951.

SONIA ADELSON KLEIN*

Sonia Adelson Klein was appointed a Sarah Frances Hutchinson Cowles Fellow in 1946. The fellowship was awarded to students preparing for advanced degrees in the fields of the social sciences and statistics, with preference to students who would be working on quantitative economics or mathematical statistics.

TJALLING C. KOOPMANS

Tjalling C. Koopmans (Ph.D., University of Leiden, 1936) lectured at the Rotterdam School of Economics and served on the staff of the Netherlands Economic Institute, 1936-37. From 1938 to 1940 he was engaged in business-cycle research at the League of Nations in Geneva. In 1940-41 he was on the staff of the Local and State Government Section of the School for Public and International Affairs, Princeton University, and also taught statistics at New York University. In 1941-42 he was economist with the Penn Mutual Life Insurance Company, and in 1942-44 he was statistician to the Combined Shipping Adjustment Board at Washington. Koopmans joined the staff of the Cowles Commission in July, 1944, as a research associate. In 1946 he also became an associate professor in the Department of Economics at the University of Chicago. In 1948 he was appointed director of research of the Commission and professor of economics at the University of Chicago. He

was elected a Fellow of the Econometric Society in 1940, of the Institute of Mathematical Statistics in 1941, of the American Statistical Association in 1949, and a member of the International Statistical Institute in 1951. He served as vice-president of the Econometric Society in 1949 and as president in 1950. He was a member of a committee of the Social Science Research Council on the Social Implications of Atomic Energy and Technological Change. From August, 1950, to January, 1951, Koopmans visited leading European centers of research and instruction in econometrics and was appointed at that time correspondent member of the Royal Dutch Academy of Sciences in Amsterdam. He has had various articles published in the *American Economic Review*, *Annals of Mathematical Statistics*, *Econometrica*, *Journal of the American Statistical Association*, *Journal of Political Economy*, *Proceedings of the International Statistical Conferences*, and *Review of Economics and Statistics*. He is editor of *Statistical Inference in Dynamic Economic Models*, 1950, and *Activity Analysis of Production and Allocation*, 1951; and co-editor of *Studies in Econometric Method* (forthcoming). Two books by Koopmans, *Linear Regression Analysis of Economic Time Series*, 1937, and *Tanker Freight Rates and Tankship Building*, 1939, have been published.

OSCAR LANGE

Oscar Lange (Ll.D., University of Cracow, 1928) became a research associate of the Cowles Commission in September, 1939. He lectured at the University of Cracow from 1931; at the Polish Free University, Warsaw, 1937; at the University of Michigan, 1936; at the University of California, 1937-38; and at Stanford University, 1938. He became an assistant professor of economics at the University of Chicago in 1938 and an associate professor the following year. He was on leave of absence as visiting professor at Columbia University during the academic year, 1942-43. He served as acting editor of *Econometrica*, 1943-45, when it was impossible to communicate with the editor, Ragnar Frisch. In 1945 he left the University of Chicago and the Cowles Commission to become ambassador of Poland to the United States. Currently, he is Rector and Professor at the School of Planning and Statistics in Warsaw. He is a Fellow of the Econometric Society and a member of the Polish Academy of Sciences. Articles by Lange have appeared in the *American Economic Review*, *Econometrica*, *Economic Mobilization*, *Encyclopaedia of Political Science*, *Journal of the American Statistical Association*, *New Leader*, *Political Science Quarterly*, *Quarterly Journal of Economics*, and *Review of Economic Studies*. He is author of the following books: *Foundations of Towns on German Law in Western Poland during the Middle Ages*, 1925; *The Statistical Investigation of Economic Fluctuations*,

1931, *Die Preisdispersion als Mittel zur statistischen Messung wirtschaftlicher Gleichgewichtsstörungen*, 1932; *On the Economic Theory of Socialism*, 1938; *Price Flexibility and Employment*, 1945; and *Theory of Statistics*, 1952.

DICKSON H. LEAVENS

Dickson H. Leavens (B. A., 1909 and M.A. in mathematics, 1915, Yale University) is a member of Phi Beta Kappa and Sigma Xi. He taught at the College of Yale in China, Changsha, 1909-28 and was treasurer from 1916 to 1928. From 1929 to 1933 he was on the research staff of the Harvard Graduate School of Business Administration. In 1934 he served in China and India as a special agent of the U. S. Treasury Department to investigate the silver situation. Leavens was a research associate of the Cowles Commission, 1936-47, and in addition served as managing editor of *Econometrica*, 1937-48. In 1943 he taught mathematics to students in the Army Specialized Training Program. Leavens has specialized in the monetary use of silver. He is now living in Colorado Springs, Colorado. Articles by him have been published in *American Economic Review*, *American Mathematical Monthly*, *American Statistician*, *Annalist*, *Annals of American Academy of Political and Social Science*, *Chinese Economic Journal*, *Econometrica*, *Engineering and Mining Journal*, *Financial News* (Bombay), *Finance and Commerce* (Shanghai), *Harvard Business Review*, *Journal of Accountancy*, *Journal of American Statistical Association*, *The Mineral Industry* (yearbook), *Popular Astronomy*, *Review of Economics and Statistics*, and *Trusts and Estates*. He is author of *Problems in Business Statistics* (with Theodore H. Brown), 1931 and *Silver Money*, 1939.

ERICH L. LEHMANN

Erich L. Lehmann (M.A., 1942 and Ph.D., 1946, University of California) has been on the teaching staff of the University of California since 1942 and is now an associate professor of mathematics in the Statistical Laboratory at that institution. He was on leave in 1944-45 as operations analyst with the U. S. Air Force; in 1950-51 to teach at Columbia University and Princeton University; and in 1951-52 as visiting associate professor at Stanford University. Lehmann was appointed a research consultant of the Cowles Commission in 1951. He has been elected as the incoming editor of the *Annals of Mathematical Statistics*. Publications by Lehmann have appeared in *Annals of Mathematical Statistics*, *Comptes Rendus des Séances de l'Académie des Sciences*, *Journal of the American Statistical Association*, *Mathematical Reviews*, *Proceedings of the First Berkeley Symposium on Mathematical Statistics and Probability*, *Proceedings of the Second Berkeley Symposium on Mathematical*

Statistics and Probability, Proceedings of the National Academy of Sciences, Sankhya, and Scripta Mathematica.

ROY B. LEIPNIK

Roy B. Leipnik (S.M., University of Chicago, 1948; Ph.D. in mathematics, University of California, 1950) was on the staff of the Commission as a research assistant, 1945-46. He was an associate in mathematics in 1946-48 at the University of California; a member of the Institute for Advanced Study at Princeton in 1948-50; and since 1950 has been an assistant professor of mathematics at the University of Washington. His current research interests include distribution of serial correlation in a continuous stochastic process, operational calculus, inversion of nonlinear operators and distribution of quotients. In 1949-50 he was chairman of the Princeton Chapter, Federation of American Scientists. Papers by Leipnik have been published in the *Annals of Mathematical Statistics, Bulletin of American Mathematical Society, and Proceedings of the American Mathematical Society.* He has also contributed to *Statistical Inference in Dynamic Economic Models, 1950.*

JULES LEVEUGLE*

Jules Leveugle, Institut National de la Statistique, Paris, participated in the research discussions of the Commission in 1949-50. His current research is in estimates of national income for French Colonies.

HAROLD GREGG LEWIS

Harold Gregg Lewis (A.B., 1936 and Ph.D., 1947, University of Chicago) came to the Commission as a research associate in 1939. From 1943 to 1945 he was on leave of absence to act as executive secretary and later assistant wage stabilization director of the Chicago Regional Office of the War Labor Board. In 1945 he served in the army, resumed his teaching at the University of Chicago in the autumn quarter, and became a research consultant of the Cowles Commission, continuing in that capacity through 1946. He is now an associate professor of economics at the University of Chicago. Earlier Lewis was a university fellow in economics at the University of Chicago, 1937-38; fellow of the Brookings Institution, 1938-39; instructor in economics, University of Chicago 1939-46. His current research interests include a study of the scientific content of various theories of the labor market. Papers by Lewis have been published in the *American Economic Review, Econometrica, Journal of the American Statistical Association, Journal of Business, Journal of Political Economy, and Review of Economic Studies.* He is co-author (with Paul H. Douglas) of *Studies in Consumer Expenditures, 1947.*

SIRO LOMBARDINI*

Siro Lombardini came to the Cowles Commission through the cooperation of the Fulbright fellowship program and the Institute of International Education. He maintained contact with the work of the Commission from his arrival in October, 1950, until June, 1951, at which time he returned to Italy to join the faculty of the University of Milan.

C. B. McGUIRE

C. B. McGuire (B.A. in economics and political science, University of Minnesota, 1949) became a research assistant at the Cowles Commission in January, 1952. Earlier he served in the Navy, 1943-46, and attended the University of Minnesota, 1946-49, and the University of Chicago, 1949-52. Currently McGuire is working on problems of highway capacity and utilization.

FRANCIS McINTYRE

Francis McIntyre (A.B., Stanford University, 1931; Ph.D., University of Chicago, 1941) was a research associate of the Cowles Commission from 1937-40. He was a research assistant of the Social Science Research Committee, 1931-32, and a university fellow in economics, 1932-34, University of Chicago. He was an instructor in statistics and economics at Stanford University, 1934-37, and associate professor of economics at Colorado College, 1937-39. In 1939-40 he was on leave of absence as assistant professor of economics at Stanford University, resigning from the Commission in 1940 to become assistant professor of economics and statistics, Indiana University. In 1942 he was made associate professor, but was on leave of absence to serve as program officer, Lend Lease Administration, 1942-43, and program officer and chief, Program Coordination Staff, Foreign Economic Administration, 1943-45. In 1945 he served as member of the United States Delegation, UNRRA Conference, London. McIntyre was deputy director, Requirements and Supply Branch (later director, Export Control Branch), Office of International Trade, U. S. Department of Commerce, 1946-47. In 1947-49, he was assistant director and later acting director of the Office of International Trade, U. S. Department of Commerce. Since 1949 he has been director of economic research, California Texas Oil Company, Ltd., New York.

PIERRE MAILLET*

Pierre Maillat (Ingénieur Ecole Polytechnique, 1946; Ingénieur Civil des Mines, 1948) Stagiaire de Recherches au Centre National de la

Recherche Scientifique, Paris, participated in the research discussions of the Commission during 1949-50. At present he is associated with Professor F. Divisia of the Ecole Polytechnique in the development of an input-output research project. He has had papers published in the *Revue d'économie politique*.

EDMOND MALINVAUD*

Edmond Malinvaud of the Institut National de la Statistique et des Etudes Economiques, Paris, was at the Commission as a Rockefeller Fellow from July, 1950 through June, 1951. Currently he is an active participant in the econometric seminars conducted in Paris by Professors Allais and Roy. In March, 1952, he was appointed as an associate editor of *Econometrica*. His research is concerned with the theory of econometric models and the principles which should underly the aggregation of variables and relations when a model is built for use in economic policy.

STEN MALMQUIST*

Sten Malmquist, Statistical Institute of the University of Uppsala, Sweden, was in residence at the Commission as a guest from November 1950 through March, 1951. His research interests include the study of demand for rationed commodities and econometric methods in general.

HARRY MARKOWITZ

Harry Markowitz (M.A., University of Chicago, 1950) became a research assistant of the Cowles Commission in October, 1949. In 1950 he held a University of Chicago fellowship in the Department of Economics. In 1950-51 he was a research fellow of the Cowles Commission and a fellow of the Social Science Research Council. Currently he is with the RAND Corporation. He has published articles in the *Journal of Finance* and the *Journal of Political Economy*.

JACOB MARSCHAK

Jacob Marschak (Ph.D., University of Heidelberg, 1922; M.A. by decree from the University of Oxford, 1935) studied at the Technological Institute at Kiev, and at the Universities of Berlin and Heidelberg. Marschak accepted appointment as research director of the Cowles Commission and as professor of economics in the University of Chicago in January, 1943. His past teaching positions include assistant professor at the University of Heidelberg, 1930-33; Chichele lecturer in economics at All Souls College, Oxford University, 1933-35; reader in statistics and director of the Institute of Statistics, Oxford University,

1935-39; professor of economics, Graduate Faculty of Social and Political Science, New York, 1939-42. He is a Fellow of the Econometric Society, served as vice-president in 1944 and 1945 and as president in 1946, and continued on the Council of the Society through 1949. He served on the executive committee of the Conference on Research on Income and Wealth from 1943 to 1947 and was its chairman in 1948. He was a vice-president of the American Statistical Association, a director of its Chicago Chapter, a collaborating editor of the *Journal of the American Statistical Association*, and was elected Fellow of that Association in 1947. Marschak was elected a member of the International Statistical Institute in 1948. He served on the Committee on Social Aspects of Atomic Energy of the Social Science Research Council in 1946-49 and was co-director of the study on economic aspects of atomic power. He served as a member of the organizing and editorial committees of the Universities-National Bureau Conference on Business Cycles Research in the fall of 1949. He has been a member of the editorial board of *Econometrica*, 1943-46, and *Human Relations* since 1948, a member of the editorial board of *Metroeconomica* since 1951, and cooperates in the editing of the *Journal of Political Economy*. During the winter quarter of 1948 Marschak was visiting professor at the National University of Mexico and at the University of Buffalo. Marschak resigned as director of research in June, 1948, but continued as senior research associate of the Commission and as professor of economics at the University of Chicago. In 1950 he became a consultant of the RAND Corporation and a member of an inter-society committee on the mathematical training of social scientists. In 1951 he became principal investigator of the project on decision-making under uncertainty; he participated in the Colloquium on Risk and Uncertainty convened by the Centre National de la Recherche Scientifique, Paris. Since Marschak joined the Cowles Commission, he has published articles and papers in *American Economic Review*, *Bulletin of Atomic Scientists*, *Econometrica*, *Journal of Political Economy*, *Mathematical Reviews*, *Metroeconomica*, and *Review of Economics and Statistics*. He is author of *Die Lohndiskussion*, 1931; author of *Die Elastizität der Nachfrage*, 1931; co-author of *Kapitalbildung*, 1936; co-editor of *Management in Russian Industry and Agriculture*, and author of the Introduction, 1944; co-author of *Economic Aspects of Atomic Power*, 1950; wrote the introduction to *Statistical Inference in Dynamic Economic Models*, 1950; and is a contributor to *Studies in Econometric Method* (forthcoming).

ANDREW MARSHALL*

Andrew Marshall as a graduate student in the Department of Economics at the University of Chicago, worked closely with the Com-

mission from September, 1948 to March, 1949, in a study of the Klein model, the subject of his M.A. thesis in economics. He is at present an economist at the RAND Corporation.

KENNETH O. MAY

Kenneth O. May (A.B., 1936; M.A., 1937; Ph.D., 1946, all in mathematics, University of California) was associated with the Commission as a research consultant in 1946 and 1947. He was a fellow in mathematics at the University of California, 1936-37 and 1939-40. During the interim he was a traveling fellow of the Institute of Current World Affairs, studying at the University of London and University of Paris. May served in the 87th Mountain Infantry in the Aleutians, 1943, and in Italy, 1945. He was an instructor at the University Study Center, Florence, Italy. In the summer of 1947, he taught at the University of Minnesota. Since 1946 he has been a professor at Carleton College, becoming a full professor and chairman of the Department of Mathematics and Astronomy in 1952. At present he is interested in theory of choice, production function, theory of value, and mathematics for economists. He is an associate editor of *Econometrica*. May is a member of Sigma Xi and Phi Beta Kappa. Articles by him have been published in the *Bulletin of the American Mathematical Society*, *Econometrica*, *Economic Journal*, *Mathematics Magazine*, *Mathematical Monthly*, and *Review of Economic Studies*. He is the author of *Elementary Analysis*, 1952.

HORST MENDERSHAUSEN

Horst Mendershausen (Ph.D., University of Geneva, 1937) joined the staff as a research fellow in November, 1938. Between the years 1930 and 1937 he studied at the Universities of Freiburg, Heidelberg, Berlin, and Geneva, and the Graduate Institute of International Studies at Geneva. During 1937-38 he held a fellowship of the Rockefeller Foundation. He left the staff of the Commission in September, 1939, to join the Faculty of Colorado College. Since that time he has been associated with the National Bureau of Economic Research and with Bennington College; assistant chief of price control of the U. S. Military Government of Germany, 1946-48; joined the Federal Reserve Bank of New York, 1949; visiting professor, University of Minnesota, 1950; staff member of the President's Materials Policy Commission, 1951-52; and is now a member of the Currie mission to Caldas, Colombia. He is the author of two books: *Changes of Seasonality in the Building Industry*, 1937, and *The Economics of War*, 1940. He has also published several papers on economic and statistical topics.

FRANCO MODIGLIANI

Franco Modigliani (D.Jr., University of Rome, 1939; D.Soc.Sc., New School for Social Research, 1944) joined the Cowles Commission as a research associate in September, 1948, at which time he also became a fellow in political economy at the University of Chicago. During 1941-42, he held the Halle fellowship at the New School. He was interim instructor in economics and statistics, New Jersey College for Women, (Rutgers University), in the spring of 1942; instructor at Bard College of Columbia University, summer, 1942, and associate until 1945. At that time he returned to the New School for Social Research and remained there until coming to the University of Chicago. In November, 1948, he became an associate professor in the Bureau of Economic and Business Research, a member of the Department of Economics of the University of Illinois, and continued his association with the Cowles Commission as a research consultant. He is now serving on the executive committee for the National Conference on Income and Wealth of the National Bureau of Economic Research. In the fall of 1952 he will leave the University of Illinois to assume teaching duties at Carnegie Institute of Technology. He was elected a Fellow of the Econometric Society in 1949. Papers by Modigliani have appeared in *Econometrica*, *Proceedings Supplement of the American Economic Review*, and *Studies in Income and Wealth*.

JACOB L. MOSAK

Jacob L. Mosak (A.B., 1935 and Ph.D., 1941; University of Chicago) joined the staff of the Cowles Commission as a research associate in September, 1939. He was a research assistant to Henry Schultz at the University of Chicago, 1935-38; Social Science Research Council Fellow, 1938-39; instructor in economics at the University of Chicago, 1939-41. In 1941 he was on leave of absence, and held various positions in the Research Division of the Office of Price Administration, resigning from the Commission's staff at the end of 1945. He was chief of the Stabilization Division of the Office of War Mobilization and Reconversion, 1946-47. In 1947 he became an economic affairs officer with the United Nations and has been visiting lecturer in economics at Columbia University since 1948. He is a Fellow of the Econometric Society. His articles have appeared in *American Economic Review*, *Econometrica*, and *Journal of the American Statistical Association*. Mosak is the author of *General-Equilibrium Theory in International Trade*, 1944.

WILLIAM F. C. NELSON

William F. C. Nelson (A.B., University of Toronto, 1921), from 1932 until his death in May, 1936, was a research associate of the

Cowles Commission. He also served as assistant editor of *Econometrica*, and was a lecturer in statistics at Colorado College. He is a co-author of *Elements of Statistics*, 1937.

WILLIAM PARRISH

William Parrish (A.B., Dartmouth College) came to the University of Chicago for graduate work in statistics. In 1949 he joined the computation staff of the Cowles Commission, becoming computation leader in July, 1951. Later that year he left the Commission to become statistician in the Market Analysis Department of General Mills, Inc. As computation leader, he devised methods and procedures for numerical development and testing of research projects of the staff.

DON PATINKIN

Don Patinkin (B.A., 1943; A.M., 1945; Ph.D., 1947; University of Chicago) joined the staff as a research assistant in May, 1946. In July, 1947, he was appointed research associate in the Cowles Commission and assistant professor of economics in the University of Chicago. He held these positions until June, 1948, when he became associate professor of economics at the University of Illinois. Since February, 1949, he has been on the economics faculty at the Hebrew University in Jerusalem. Patinkin held the Harper fellowship at the University of Chicago in 1945-46, and a predoctoral fellowship of the Social Science Research Council in 1946-47. His articles have been published in the *American Economic Review*, *Econometrica*, *Economic Journal*, *Jewish Social Studies*, *Metroeconomica*, *Quarterly Journal of Economics*, and *Review of Economic Studies*.

GEORGE PERAZICH

George Perazich (B.S. in electrical engineering, University of California, 1933) joined the staff in March, 1947, as a research associate on the study of the economics of atomic energy. In October, 1947, he left Chicago but continued as a part-time research consultant until the end of the year. Perazich was with the National Research Project, Philadelphia, as engineer in charge of studies in technology and industrial techniques, 1935-40. For two years he was assistant director and consulting engineer, Research Advisory Service, Buffalo, New York. From 1944 to 1947 he served overseas with the United Nations Relief and Rehabilitation Administration as director of industrial rehabilitation and deputy chief of supply. He is senior author of *Industrial Research and Changing Technology*, *Industrial Instruments and Changing Technology*, and *Mechanization in the Cement Industry*, and author of

several technical articles and special surveys. He contributed to *Economic Aspects of Atomic Power*, 1950.

ALAN PREST*

Alan Prest of the Department of Applied Economics, University of Cambridge, was at the Commission as a Rockefeller Fellow in the Fall of 1948. Among his research interests are the econometric theory of demand over long periods.

ROY RADNER

Roy Radner (Ph.B., 1945, and M.S., 1951; University of Chicago) studied under a William Cook scholarship at the University of Chicago, 1944-45. After three years in the armed forces, he returned to the University to complete his studies. He became a research assistant of the Commission in March, 1951, and a research associate in November of that year. He is currently conducting research in the theory of statistical decision-making.

GEORGE RASCH*

George Rasch, statistician of the State Serum Institute, University of Copenhagen, was on the staff of the Commission and a fellow of the University of Chicago in 1947. He collaborated with Koopmans and Reiersøl in a comparative study of problems of specification and identification, arising in econometrics, psychology, and biology.

OLAV REIERSØL

Olav Reiersøl (M.A., University of Oslo, 1935; Ph.D., University of Stockholm, 1945) joined the Commission as a research fellow for the summer of 1949 after serving as visiting professor of mathematics at Purdue University, 1948-49. He is now assistant professor of mathematics at the University of Oslo. Reiersøl was a research assistant to Professor Frisch at the University Institute of Economics in Oslo, 1936-37, and the instructor in mathematical statistics at the University of Oslo, 1938-46, except for the latter part of the war when he took refuge in Sweden. In the spring of 1946 he studied at the University of Cambridge as a fellow of the British Council. After that he received a Rockefeller fellowship under which he studied at Columbia University, University of North Carolina, University of Chicago, and University of California, Berkeley. He was elected a Fellow of the Institute of Mathematical Statistics in 1950, and a Fellow of the Econometric Society in 1952. Articles by him have appeared in *Annals of Mathematical Statistics*, *Arkiv för Matematik, Astronomi och Fysik*, *Econometrica*, *Portugaliae Mathematica*, *Psychometrika*, and *Skandinavisk Aktuarietidskrift*.

STANLEY REITER

Stanley Reiter (A. B., Queens College, 1947; M.A., University of Chicago, 1950) assisted the Cowles Commission, summer of 1948, while a graduate student in economics at the University of Chicago, and re-joined the Commission as a research assistant in March, 1949. Earlier he was at Queens College, 1941-43, and again from 1945-47, following service in the army. In December, 1949, Reiter became a research associate of the Commission in which capacity he remained until joining the economics staff at Stanford University in September, 1950, at which institution he is now an assistant professor. He contributed to *Activity Analysis of Production and Allocation*, 1951.

CHARLES F. ROOS

Charles F. Roos (B.A., 1921; M.A., 1924; Ph.D., 1926; Rice Institute) was director of research of the Cowles Commission from September, 1934, to January, 1937. He was National Research Council Fellow in mathematics 1926-28; assistant professor of mathematics at Cornell University, 1928-31; secretary of Section K (economics, sociology, and statistics), American Association for the Advancement of Science, 1928-31, and permanent secretary and member of the executive committee of that organization, 1931-33; fellow of the John Simon Guggenheim Memorial Foundation, 1933; director of research, National Recovery Administration, 1933-34; and professor of econometrics, Colorado College, 1934-37. He was one of the founders of the Econometric Society; secretary-treasurer, 1931-32; secretary, 1932-36; vice-president, 1947; and president, 1948. He is a Fellow and has been a member of the council of the Society. He is a member of the International Statistical Institute and a Fellow of both the American Statistical Association and the Institute of Mathematical Statistics. He resigned from the staff of the Commission in January, 1937, to accept a business research position and later organized the Institute of Applied Econometrics, Inc., now called The Econometric Institute, Inc. He is now president of that organization. Approximately 60 papers on economics, statistics, and mathematics have been published in the *American Journal of Mathematics*, *Bulletin of the American Mathematical Society*, *Commercial and Financial Chronicle*, *Econometrica*, *Metron*, *Journal of Political Economy*, *Proceedings of the National Academy of Sciences*, and *Transactions of the American Mathematical Society*. He is author of the following books: *Dynamic Economics*, 1934; *NRA Economic Planning*, 1937; *Economic Measures*, 1938; *Dynamics of Automobile Demand*, 1939; and *Charting the Course of Your Business*, 1948.

HERMAN RUBIN

Herman Rubin (B.S., 1944; M.S., 1945; Ph.D., 1948; University of Chicago) joined the staff as a research assistant in July, 1944; he served in the U. S. Army from March to December, 1945, returning to the staff in January, 1946. He became a research associate in November, 1946. In September, 1947, he became a research fellow with the Institute for Advanced Study, Princeton, continuing his association with the Cowles Commission as a research consultant. The following year he was in residence at the Commission as a research associate and concurrently taught at Illinois Institute of Technology. In September, 1949, he joined the faculty at Stanford University as acting assistant professor of statistics and again became a research consultant. Publications by Rubin have appeared in *Annals of Mathematical Statistics*, *Bulletin of the American Mathematical Society*, *Econometrica*, and *Review of Economic Studies*. He has also contributed to *Statistical Inference in Dynamic Economic Models*, 1950; and *Studies in Econometric Method* (forthcoming).

ERIK RUIST*

Erik Ruist, of the Swedish Institute for Industrial, Economic, and Social Research, was a guest from January to May, 1949. His research interests include the statistical aspects of the theory of production and allocation of resources, and the econometric study of demand over long periods.

SAM H. SCHURR

Sam H. Schurr (B.A., 1938 and M.A., 1939, Rutgers University) joined the staff of the Cowles Commission in the autumn of 1946 as co-director (with the rank of assistant professor) of the study of the economics of atomic energy. In December, 1948, he became a research consultant of the Commission, remaining in that capacity until the report on the project was brought into publication in 1950. Schurr was on the research staff of the National Bureau of Economic Research, 1939-43; economist, Office of Strategic Services, 1943-45; economic adviser to U. S. Representative, Allied Commission on Reparations, 1945-46; and chief, Manufacturing and Mining Branch, Division of Interindustry Economics, Bureau of Labor Statistics, 1949-50; and associate director of the Teaching Institute of Economics, American University, 1949-50. In June, 1950, he became chief economist of the U. S. Bureau of Mines. He is co-author of *The Mining Industries, 1899-1939: A Study of Output, Employment and Productivity*, 1944, and co-editor of *Economic Aspects of Atomic Power*, 1950.

MILTON F. SEARL

Milton F. Searl was a research consultant in the Cowles Commission project on economic aspects of atomic power. He received a degree in economics from the Illinois Institute of Technology in 1948. He is the author of Chapter XII, "Residential Heating," *Economic Aspects of Atomic Power*, 1950. Searl is employed as an economist by the Stanolind Oil and Gas Company, Tulsa, Oklahoma.

HERBERT A. SIMON

Herbert A. Simon (A.B., 1936, and Ph.D., 1943, University of Chicago) has been a research consultant of the Cowles Commission since April, 1947. He was a research assistant at the University of Chicago, 1937-38; with the Bureau of Public Administration, University of California, 1939-42; and with Illinois Institute of Technology as assistant professor of political science, 1942-45, associate professor, 1945-47, chairman of the Department of Political and Social Science, 1946-49, and full professor, 1947-49. He served as a consultant for the U. S. Bureau of the Budget, 1946-49, for the U. S. Bureau of the Census, 1947, and for the Economic Cooperation Administration, 1948. Since 1949, he has been at Carnegie Institute of Technology as professor of administration and head of the Department of Industrial Management. Simon is a member of Phi Beta Kappa and Sigma Xi. His principal area of research is organization theory. He is author of articles published in the *American Sociological Review*, *Annals of Mathematical Statistics*, *Econometrica*, *Journal of the American Statistical Association*, *Philosophical Magazine*, *Public Administration Review*, *Public Management*, and *Quarterly Journal of Economics*. He is the author of *Fiscal Aspects of Metropolitan Consolidation*, 1943, and *Administrative Behavior*, 1947, and co-author of the following: *Measuring Municipal Activities*, 1938; *Determining Work Loads for Professional Staff in a Public Welfare Agency*, 1941; *Fire Risks and Fire Losses*, 1943; *Technique of Municipal Administration*, 1945; and *Public Administration*, 1950. He has contributed to *Economic Aspects of Atomic Power*, 1950; *Activity Analysis of Production and Allocation*, 1951; and *Studies in Econometric Method*, (forthcoming).

WILLIAM B. SIMPSON

William B. Simpson (A.B. in mathematics, 1942, Reed College; M.A. in mathematical economics and mathematical statistics, 1943, Columbia University) joined the staff of the Cowles Commission as research associate and assistant director of research in May, 1948. He served as acting director of research from August, 1950 through January, 1951, and in July, 1951, was appointed executive director of

the Commission. Prior to his association with the Commission he was successively Fletcher Scholar, Kerr Scholar, and Whitcomb Scholar in economics and statistics at Reed College, 1938-42; was elected to Phi Beta Kappa, 1942; and was graduate resident scholar in economics, 1942-43, and on leave from university fellowship, 1943-46, Columbia University. He was research assistant in statistics, 1940-41 and teaching assistant in economics and statistics, 1941-42 at Reed College; prepared comparative wage studies in the lumber industry for the National Defense Mediation Board, winter, 1941; and revised the statistical techniques employed in forest management administration for the General Land Office of the Department of Interior, summer, 1942. During the war, he was a special agent for the Military Intelligence Division of the War Department, serving among other things as head of the banking and economic section of the Manila Counter Intelligence Office. In late 1945 and 1946 he had responsibilities in Japan in connection with the War Department and the War Crimes Commission and was a special representative of the Supreme Commander of Allied Powers on political affairs and labor relations in northern Honshu. From September, 1946, until joining the Cowles Commission in 1948, he was engaged in research in economics as a fellow of the Social Science Research Council at the University of Chicago, except for temporary duty during late 1947 with the Legal Section in Tokyo as consultant to the Secretary of the Army. In September, 1948, Simpson was elected secretary of the Econometric Society by the Council of the Society, and was re-elected to that position in subsequent years. In May, 1952, he submitted his resignation as secretary of the Society, to become effective in October. In addition he has served as managing editor of *Econometrica* from January, 1949, and as co-editor of that journal since June, 1951.

MORTON L. SLATER

Morton L. Slater (B.A., Swarthmore College, 1941; M.A., University of Wisconsin, 1942; Ph.D., Harvard University, 1949) was with the Cowles Commission as a research associate (with the rank of assistant professor) from January, 1950 through July, 1951. Earlier he was employed by Westinghouse Electric and Manufacturing Co. as a statistician in late 1942, after which he served in the U. S. Naval Reserve until May, 1946. Prior to joining the Commission he was with Ordnance Research Group, No. 1 in Chicago as senior mathematician from September, 1948 to December, 1949. In addition, he taught mathematics at Illinois Institute of Technology in the fall of 1949. Slater is now with the Cornell Aeronautical Laboratory. Abstracts and

papers have appeared in the *Bulletin of the American Mathematical Society* and *Econometrica*.

JOHN H. SMITH

John H. Smith (Ph.D., University of Chicago, 1941) joined the staff as a research associate in September, 1940. He was research and teaching assistant in the School of Business, 1936-41, and instructor in statistics, 1941-42, the University of Chicago. In 1942 he resigned from the Commission to accept a position as statistical consultant in the office of the chief statistician, Bureau of Labor Statistics. This position he held until June, 1947, when he entered upon his present position as professor of statistics and chairman of the Department of Statistics of the American University. He is now a member of the Committee on Mathematical Training of Social Scientists, and the Committee on Training of Statisticians. Smith is author of two books, *Tests of Significance and How to Use Them*, 1939 and *Statistical Deflation in the Analysis of Economic Series*, 1941.

GERHARD STOLTZ

Gerhard Stoltz (*Cand. oecon.*, University of Oslo, 1947) became a research assistant of the Cowles Commission in October, 1949, in connection with the study of resource allocation. Concurrently he held a fellowship from the Norwegian Department of Education and the Nationalgaven til Chr. Michelsen Foundation, 1949-50. Earlier he engaged in research at the Chr. Michelsen Institute, Bergen, Norway, 1947-48, and at the Institute of Sociology, Oslo, 1948-49. He completed his work for the Commission on resource allocation in the summer of 1950 and moved to Stanford University. In the summer of 1951 he returned to the University of Oslo, Norway.

ROBERT H. STROTZ

Robert H. Strotz (A.B., 1942 and Ph.D., 1951; University of Chicago) became a research consultant of the Cowles Commission in 1951. He is associate professor of economics at Northwestern University and is currently engaged in research in welfare economics and the use of analog computing in economics. Strotz is program chairman for the winter meeting of the Econometric Society in 1952. Papers by him have been published in *Econometrica*, *Southern Economic Journal*, and *Transactions of the American Institute of Electrical Engineers*. He is co-author of *Problems for Economic Analysis*, 1948.

ERLING SVERDRUP

Erling Sverdrup (*Cand. act.*, University of Oslo, 1945) was a Rockefeller Fellow for the years 1949 and 1950, during which time he visited Columbia University and the Universities of California and Chicago. In addition he was a research fellow of the Cowles Commission, January through November, 1950. Since that time he has been acting professor of actuarial mathematics and mathematical statistics at the University of Oslo, where earlier he worked on problems in mathematical statistics under Professor Frisch in 1946, and later taught, first as a lecturer, 1946-48, and then as an acting professor, 1948-49. He has published articles in *Skandinavisk Aktuarietidskrift* and *Arbiv för Matematik og Naturvidenskab*.

SAMI TEKINER

Sami Tekiner, was fellow of the Department of Economics at the University of Chicago in 1944 and a research assistant for the Cowles Commission from July, 1944 to June, 1945. He participated in the studies on models for manufacturing industries and firms in the United States. Currently he is with European Steamship and Airways Agency in New York.

JAMES G. C. TEMPLETON

James G. C. Templeton (B.A., in applied mathematics University of Toronto, 1947; M.A. in mathematics, Princeton University, 1949) joined the staff in July, 1950, as a research associate with responsibility for supervising the computational work of the Commission. Prior to this he spent three years at Princeton University as a graduate student in mathematical physics and mathematical statistics and as an assistant in instruction and research. In the summer of 1949 he attended the Institute for Numerical Analysis at Los Angeles. In July, 1951, he left the Commission to become assistant professor of mathematics, University of Manitoba, at which institution he is now assistant professor of statistics.

GERHARD TINTNER

Gerhard Tintner (Ph.D., University of Vienna, 1929) studied as a postgraduate student at Harvard University, Columbia University, University of California, Stanford University, Institut Henri Poincaré, and Cambridge University. He was on the staff of the Austrian Institute of Trade Cycle Research, 1936; research fellow in economics and statistics at the Cowles Commission, 1936-37; and instructor in econometrics at Colorado College, 1937. In 1937 he joined the staff of Iowa

State College as assistant professor of economics and mathematics and now holds the rank of professor of economics, mathematics, and statistics. Tintner has also served as consultant to the Office of Strategic Services, 1942; as an associate of the Office of European Economic Research, 1943; and as a statistician with the Department of Agriculture, 1944. In 1948 he became a research associate in the Department of Applied Economics at Cambridge University. He lectured at several European universities while abroad and returned to Iowa State College in September, 1949. He was elected a Fellow of the Econometric Society, 1940; of the Institute of Mathematical Statistics, 1947; and of the American Statistical Association, 1951. He was a member of the editorial board, and is now an associate editor and book review editor of *Econometrica*. In addition, he is a member of the editorial board of *Metroeconomica*. Currently Tintner is interested in foundations of probability and statistical inference, multivariate analysis, computational problems in regression analysis and stochastic linear programming. Among the journals in which his articles have appeared are: *Annals of Mathematical Statistics*, *Econometrica*, *Iowa State College Journal of Science*, *Journal of the American Statistical Association*, *Journal of Farm Economics*, *Journal of Political Economy*, *Journal of the Royal Statistical Society*, *Metroeconomica*, *Quarterly Journal of Economics*, *Review of Economics and Statistics*, *Revue d'economie politique*, *Schmoller's Jahrbuch*, *Statistical and Social Inquiry Society of Ireland*, *Statistische Vierteljahresschrift*, and *Zeitschrift für Nationalökonomie*. Three books have been published by Tintner: *Prices in the Trade Cycle*, 1935; *The Variate Difference Method*, 1940; and *Econometrics*, 1952.

JAROSLAV TUZAR*

Jaroslav Tuzar, (M.A., 1945 and D.Sc., 1948; Charles University, Prague) a Rockefeller Fellow from Charles University, Prague, came to the Commission in November, 1948, and remained until January, 1950. He was assistant professor, State Technical School, Prague, 1945-48 and research assistant in economics, State College for Social and Political Sciences, Prague, 1946-48. Currently he is engaged in research on statistical control of food manufacturing process and mathematical method in physics and economics. At present he is director of research for the Salerno Megowen Biscuit Co., Chicago.

ABRAHAM WALD

Abraham Wald (Ph.D. in mathematics, University of Vienna, 1930) joined the staff as a research fellow for one year in July, 1938, but went on leave of absence in September to accept a Carnegie fellow-

ship at Columbia University, where he continued as lecturer in statistics. He was a native of Cluj, Rumania, and for several years a collaborator of Karl Menger at the University of Vienna and also of Oskar Morgenstern at the Institute for Business Cycle Research in Vienna. Before coming to the United States he held a fellowship from the Geneva Research Center in Switzerland, where he was engaged in the study of economic problems. His special topic of investigation during his connection with the Commission was index numbers and family incomes. In 1939 Wald was elected a Fellow of the Econometric Society. In 1948 he was president of the Institute of Mathematical Statistics and vice-president of the American Statistical Association. Wald taught at Columbia University for many years, becoming professor of mathematical statistics and head of the Department there. In 1950 he was invited by the Indian Government to lecture at Indian universities, but he met tragic death in an airplane crash in India. During his life he published more than 90 articles and books. Some of his articles have been published in *American Mathematical Monthly*, *Econometrica*, *Ergebnisse eines Mathematischen Kolloquiums*, and *Zeitschrift für Nationalökonomie*. Among his books are *Berechnung und Ausschaltung von Saisonschwankungen*, 1936; *Sequential Analysis*, 1945; *Statistical Decision Functions*, 1950. He contributed to *Statistical Inference in Dynamic Economic Models*, 1950.

DICK VAN DONGEN TORMAN*

Dick van Dongen Torman was a guest of the Commission as a Rockefeller Fellow from Rotterdam in late 1947 and early 1948 while working on the measurement of production functions.

DANIEL WATERMAN

Daniel Waterman (B.A., Brooklyn College, 1947; M.A., Johns Hopkins University, 1948) became a research associate of the Cowles Commission in July, 1951, while completing his work for the Ph.D. degree at the University of Chicago. He is responsible for the direction of the computation laboratory of the Commission. Prior to joining the Commission he was an instructor at Brooklyn College, 1947; junior instructor at the Johns Hopkins University and University Scholar, 1947-48; and teaching assistant and Strong Fellow at the University of Chicago, 1948-51. During the summers of 1948 and 1949 he served as a mathematician in the Ballistics Research Laboratory. He is a member of Sigma Xi. In 1952-53 Waterman will be at the University of Vienna as a Fulbright Scholar. A paper by him has been published in the *Transactions of the American Mathematical Society*.

HAROLD H. WEIN

Harold H. Wein was a research consultant in the Cowles Commission project on the economics of atomic power. He is the author of Chapter X, "Iron and Steel," *Economic Aspects of Atomic Power*, 1950. He is a member of the U. S. Department of Justice.

ISAMU YAMADA*

Isamu Yamada was a guest of the Cowles Commission, March-April, 1951. Yamada was commissioned by the Japanese government to study recent developments in econometrics and in social accounting in the United States. While he was at the Cowles Commission, he participated in staff seminars and meetings. He is professor of economics at Hitotsubashi University, Tokyo, Japan.

THEODORE O. YNTEMA

Theodore O. Yntema (A.B., Hope College, 1921; A.M., 1922 and C.P.A., 1924, University of Illinois; Ph.D., University of Chicago, 1929) became director of research of the Cowles Commission at the time of the move to Chicago in September, 1939. He joined the faculty of the University of Chicago in 1923, and was professor of statistics in the School of Business, 1930-1944, and professor of business and economic policy, 1944-49. He was economic consultant in the National Recovery Administration, 1934-35; head of economics and statistics in the Division of Industrial Materials of the Defense Commission, 1940; consulting economist and statistician for the United States Steel Corporation, 1938-40; consultant in the War Shipping Administration, 1942; director of research of the Committee for Economic Development, 1942-49; consulting economist for Stein Roe & Farnham, 1945-49; consulting economist, Lord, Abnett & Co., 1946-49; consulting economist, Ford Motor Company, 1947-49; and consultant for the Economic Stabilization Agency, 1951. Since 1940 Yntema has been a director of the National Bureau of Economic Research. In 1949 Yntema joined Ford Motor Company as vice president-finance and since 1950 a director of the Company. He is a Fellow of the Econometric Society and of the American Statistical Association. He is author of *A Mathematical Reformulation of the Theory of International Trade*, 1932, and co-author of *Jobs and Markets*, 1946. Yntema also directed most of the research leading to Volume I of *TNEC Studies*, published by the United States Steel Corporation, and from 1942-49 also planned and directed most of the research leading to the Research Reports of the Committee for Economic Development.

STAFF PUBLICATIONS AND ADDRESSES

July 1, 1951-June 30, 1952

STEPHEN G. ALLEN

"Cost Analysis in the Design of Acceptance Sampling Plans," presented August 22, 1951, at the Sampling Inspection Conference sponsored by the Office of Naval Research and Applied Mathematics and Statistics Laboratory, Stanford University.

"Testing of Hypotheses from the Viewpoint of Statistical Decision Theory," presented April 2, 1952, at the School of Business Administration, University of Minnesota.

"On Acceptance Sampling Procedures," presented April 3, 1952, School of Business Administration, University of Minnesota.

For contribution to *Studies in Econometric Method*, Cowles Commission Monograph 14, see Appendix IV.

T. W. ANDERSON

"Estimating Linear Restrictions on Regression Coefficients for Multivariate Normal Distributions," *Annals of Mathematical Statistics*, Vol. 22, September, 1951, pp. 327-351. (Reprinted as Cowles Commission Papers, New Series, No. 50.)

"Probability Models for Analyzing Time Changes in Attitudes," presented September 7, 1951, before the Institute of Mathematical Statistics, Minneapolis, Minnesota. (Abstract in *Annals of Mathematical Statistics*, Vol. 22, December, 1951, p. 607.)

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Course Lectures on Statistical Inference, Theory of Multivariate Statistical Analysis, Correlation Theory and Elementary Multivariate Analysis, and Time Series Analysis, 1951-52, Columbia University.

Discussant on "Content and Methods of the Social Sciences," 1951-52, at the University Seminar, Columbia University.

KENNETH J. ARROW

"Optimal Inventory Policy" (with T. E. Harris and J. Marschak), *Econometrica*, Vol. 19, July, 1951, pp. 250-272. (Reprinted as Cowles Commission Papers, New Series, No. 44.)

Review of "Anticipations, Uncertainty, and Dynamic Planning" by Albert G. Hart, *Econometrica*, Vol. 19, July, 1951, pp. 353-354.

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"Reduction of Constrained Maxima to Saddle-Point Problems," presented October 16, 1951, at Joint Statistics Colloquium, University of California and Stanford University.

"The Theory of Games," presented October 24, 1951, at the San Francisco Chapter of the American Statistical Association.

"Alternative Approaches to the Theory of Choice in Risk-Taking Situations," *Econometrica*, Vol. 19, October, 1951, pp. 404-437. (Reprinted as Cowles Commission Papers, New Series, No. 51.)

Review of "A Regression Problem" by D. V. Lindley, *Mathematical Reviews*, Vol. 12, November, 1951, pp. 842-843.

"Little's Critique of Welfare Economics," *American Economic Review*, Vol. 41, December, 1951, pp. 923-934.

"Mathematical Models in the Social Sciences," *The Policy Sciences* (D. Lerner and H. D. Lasswell, eds.), Stanford: Stanford University Press, 1951, pp. 129-154. (Reprinted as Cowles Commission Papers, New Series, No. 48.)

"An Extension of the Basic Theorems of Classical Welfare Economics," *Proceedings of the Second Berkeley Symposium on Mathematical Statistics and Probability* (J. Neyman, ed.), Berkeley and Los Angeles: University of California Press, 1951, pp. 507-532. (Reprinted as Cowles Commission Papers, New Series, No. 54.)

Review of "Uses of Leontief's Open Input-Output Models" by H. M. Smith, *Mathematical Reviews*, Vol. 13, March, 1952, p. 262.

Review of "The Problem of Integrability in Utility Theory" by P. A. Samuelson, *Mathematical Reviews*, Vol. 13, March, 1952, p. 262.

Review of "The Aggregate Linear Production Function and Its Application to von Neumann's Model" by N. Georgescu-Roegen, *Mathematical Reviews*, Vol. 13, March, 1952, p. 262.

"Dynamic Problems in the Optimal Allocation of Resources," presented April 30, 1952, before a seminar of the Department of Applied Economics, Cambridge University and presented May 2, 1952, at Nuffield College, Oxford University.

"The Role of Securities in the Optimal Allocation of Risk-Bearing," presented May 13, 1952, before the Colloqué sur les Fondements et Applications de la Théorie du Risque en Econometrie, Centre Nationale de la Recherche Scientifique, Paris.

"The Principle of Rationality in Collective Decision-Making," presented May 6, 1952, at Oxford University and presented June 6, 1952, at the Institute des Sciences Economiques Appliquées, Paris.

Course Lectures on Price and Allocation Theory (mathematical) and Statistical Analysis, 1951-52, Stanford University.

MARTIN BECKMANN

"Models of Transportation and Location," presented September 7, 1951, at the Minneapolis meeting of the Econometric Society. (To be published in *Econometrica*, Vol. 20, October, 1952, pp. 643-660.)

Review of "Einfuehrung in die Wirtschafts Theorie" by E. Schneider, *Econometrica*, Vol. 19, October, 1951, pp. 483-484.

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GEORGE H. BORTS

"Production Relations in the Railway Industry," *Econometrica*, Vol. 20, January, 1952, pp. 71-79. (Reprinted as Cowles Commission Papers, New Series, No. 56.)

HERMAN CHERNOFF

Discussant on "Statistical Decision Problems," September 4, 1951, at the Minneapolis meeting of the Econometric Society.

"A Property of Some Type A Regions," *Annals of Mathematical Statistics*, Vol. 22, September, 1951, pp. 472-474.

"An Extension of a Result of Liapounoff on the Range of a Vector Measure," *Proceedings of the American Mathematical Society*, Vol. 2, October, 1951, pp. 722-726.

"A Generalization of the Neyman-Pearson Fundamental Lemma" (with Henry Scheffé), *Annals of Mathematical Statistics*, Vol. 23, June, 1952, pp. 213-225.

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CARL CHRIST

"A Test of an Econometric Model for the United States 1921-1947," *Conference on Business Cycles*, New York: National Bureau of Economic Research, 1951, pp. 35-105. (Reprinted as Cowles Commission Papers, New Series, No. 49.)

Course Lectures on Income and Employment, Statistics, Mathematical Economics, and Econometrics, 1951-52, Johns Hopkins University.

"History of the Cowles Commission, 1932-1952," *Cowles Commission Twentieth Year Report*.

HAROLD T. DAVIS

"Numerical Representation of Technological Change," presented April 7, 1951, at the Conference on Quantitative Description of Technological Change, Princeton University. (Not included in previous report.)

"Proof of the Law of Mass-Energy," presented October 9, 1951, before the Chicago Physics Club, Chicago.

"Alexandria, the Golden City," presented November 29, 1951, before the Science Forum of Mundelein College, Chicago, Illinois.

"The Influence of Interest Rates on Time Series of Price," presented December 29, 1951, at the Boston meeting of the Econometric Society. (Abstract in *Econometrica*, Vol. 20, July, 1952, p. 501.)

"Quantitative Aspects of the Carcinogenic Radiations," presented February 6, 1952, before the Physics Colloquium, Northwestern University. (To be published in the Fall, 1952.)

"Number Magic," presented May 5, 1952, before Etta Kappa Nu (Electrical Engineering), Evanston.

"The Curse of the Ibis," presented May 29, 1952, before Etta Sigma Phi (Classical), Evanston.

GERARD DEBREU

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

"The Coefficient of Resource Utilization," *Econometrica*, July, 1951, Vol. 19, pp. 273-292. (Reprinted as Cowles Commission Papers, New Series, No. 45.)

"A Classical Tax-Subsidy Problem," presented September 6, 1951, at the Minneapolis meeting of the Econometric Society.

Discussant on "Symposium on the Theory of Games, Decision Problems, and Related Topics," September, 1951, before the Minneapolis meeting of the Econometric Society.

"Definite and Semi-Definite Quadratic Forms," *Econometrica*, Vol. 20, April, 1952, pp. 295-300. (Reprinted as Cowles Commission Papers, New Series, No. 58.)

A. DVORETZKY

"The Inventory Problem: I. Case of Known Distributions of Demand" (with J. Kiefer and J. Wolfowitz), *Econometrica*, Vol. 20, April, 1952, pp. 187-222. (Part II to appear in the July, 1952, issue of *Econometrica*.)

KIRK FOX

"Mathematics for Agricultural Economists," presented April 2, 1952, before the Agricultural Economics Staff-Graduate Seminar, University of Illinois.

"Possibilities for Application of Activity Analysis (Linear Programming) to Agricultural Economics Problems," presented May 23, 1952, before the Agricultural Economics Staff-Graduate Seminar, University of Illinois.

Course Lectures on Elementary and Intermediate Statistics, 1951-52, School of Commerce, Northwestern University.

JOHN GURLAND

"Distribution of Ratios of Quadratic Forms," presented September, 1951, at the Minneapolis meeting of the Institute of Mathematical Statistics. (Abstract in *Annals of Mathematical Statistics*, Vol. 22, December, 1951, p. 607.)

"Autocorrelation of Disturbances in Linear Regression," presented December, 1951, at the Boston meeting of the Econometric Society. (Abstract in *Econometrica*, Vol. 20, July, 1952, p. 477.)

"Generalization of the Theory of Minimum χ^2 ," presented February, 1952, at Iowa State College Seminar.

Course Lectures on Theory of Estimation and Testing Hypotheses, and Time Series, 1951-52, University of Chicago.

TRYGVE HAAVELMO

"Begrepsapparatet i Moderne Inflasjonsteori" (Conceptual Framework of Modern Theories of Inflation), *Økonomisk Tidsskrift*, October, 1951, pp. 161-175.

"Contribution to the Theory of Economic Evolution with Particular Reference to the Problem of Backward Areas," mimeographed, Oslo, 1952, 99 pp.

Course Lectures on Dynamic Theory of Prices, mimeographed notes, 1952, University of Oslo.

Course Lectures on Econometric Methods and Economic Theory, 1951-52, University of Oslo.

ARNOLD HARBERGER

Review of "The Economic Theory of Cost of Living Index Numbers" by Melville J. Ulmer, *Journal of American Statistical Association*, Vol. 46, September, 1951, pp. 395-396.

"Monetary Policy and Devaluation," presented March 17, 1952, before the Graduate Seminar, Harvard University.

"Projection of 1975 Materials Demand," *The Outlook for Key Commodities*, Vol. II of *Resources for Freedom* (the report of the President's Materials Policy Commission) Washington: Government Printing Office, June, 1952.

Course Lectures in Monetary Theory and Econometrics, 1951-52, Johns Hopkins University.

I. N. HERSTEIN

"Selection from 'Algebraic Function' by Chevalley," presented Summer, 1951, at the Algebra Seminar, University of Chicago.

"A Generalization of a Theorem of Jacobson," *American Journal of Mathematics*, Vol. 73, October, 1951, pp. 756-763. (Abstract No. 326 in *Bulletin of the American Mathematical Society*, July, 1951, p. 284.)

"The Commutativity of Certain Rings," presented November 27, 1951, before the Senior Mathematics Club, University of Chicago.

"Some Results in Ring Theory," presented November 27, 1951, before the Graduate Mathematics Club, Indiana University.

"Recursions Connected with Symmetric Groups" (with S. Chowla and W. K. Moore), *Canadian Journal of Mathematics*, Vol. 3, 1951, pp. 328-335.

"A Generalization of a Theorem of Jacobson II," presented February 23, 1952, before the New York meeting of the American Mathematical Society.

"Finite Multiplicative Subgroups in Division Rings," presented February 23, 1952, before the New York meeting of the American Mathematical Society. (Accepted for publication by the *Pacific Journal of Mathematics*.)

"A Theorem on Rings," presented April 25, 1952, before the Chi-

icago meeting of the American Mathematical Society. (Accepted for publication by the *Canadian Journal of Mathematics*.)

"The Solutions of $x^2 = 1$ in Symmetric Groups" (with S. Chowla and W. R. Scott), *Det Kongelige Norske Videnskabers Selskab*, Vol. 25, 1952, pp. 29-31.

"A Note on the Automorphism Group of a Finite Group" (with J. E. Adney), *American Mathematical Monthly*, Vol. 59, May, 1952, pp. 309-310.

CLIFFORD HILDRETH

"An Alternative Approach to Welfare Functions," presented September 4, 1951, at the Minneapolis meeting of the Econometric Society.

Course Lectures for Economics 313, "Statistical Methods of Measuring Economic Relations," Winter, 1951, University of Chicago.

"Aggregation of Preferences," presented April 14 and April 21, 1952, before the Seminar on Social Choice, University of Chicago.

"Training for Statistical Research in Agricultural Economics," presented May 7, 1952, at the Agricultural Economics Faculty Seminar, Michigan State College.

"Relations Affecting Livestock Production and Price," (with Frank Jarrett) presented by Jarrett, June 19, 1952, at the Eugene meeting of the Econometric Society.

"A Re-Examination of the Arrow Conditions," presented June 25, 1952, before the Seminar on Measurement of Value sponsored by the University of Michigan, Santa Monica, California.

WILLIAM C. HOOD

"Autocorrelation of Disturbances in Economic Behavior Equations," "Economic Time Series and the Testing of Hypotheses," (discussion of papers by J. Gurland and G. H. Orcutt) on December 26, 1951, at the Boston meeting of the Econometric Society.

"Linear Programming and the Theory of the Firm," a review article on Robert Dorfman's "Application of Linear Programming to the Theory of the Firm," *Canadian Journal of Economics and Political Science*, Vol. 18, May, 1952, pp. 208-212.

"Some Problems of Aggregation with Special Reference to Consumer Behavior," presented June, 1952, at the annual meeting of the Canadian Political Science Association.

Course Lectures on Mathematical Economics, Statistical Analysis, and Money and Banking, 1951-52, University of Toronto.

For contribution to *Studies in Econometric Method*, Cowles Commission Monograph 14, see Appendix IV.

H. S. HOUTHAKKER

"Quality Variations in Family Budgets" (with S. J. Prais), presented September, 1951, at the European meeting of the Econometric Society, Louvain, Belgium. (Accepted for publication in *Economie Appliquée*.)

"The Application of an Electronic Computer to Statistical Work," presented September, 1951, at the Conference of the Royal Statistical Society, Cambridge, England.

"Some Implications of Empirical Research for Consumption Theory," presented December, 1951, at the Boston meeting of the Econometric Society.

"The Effects of Rationing on Demand Elasticities" (with James Tobin), *Review of Economic Studies*, Vol. 18, 1950-51, pp. 140-153.

"Some Calculations on Electricity Consumption in Great Britain," *Journal of the Royal Statistical Society*, Series A, Vol. 114, 1951, pp. 359-371.

Review of "Grondslagen en Techniek der Marktanalyse," by P. J. Verdoorn, *Economic Journal*, Vol. 61, 1951, pp. 610-611.

"The Free Demand for Rationed Foodstuffs in Britain," presented March 6, 1952, at a Cowles Commission Seminar, University of Chicago.

"A Proposed Inquiry into Some Markets with Forward Trading," presented March 21, 1952, at Cowles Commission Staff Meeting and Agricultural Economics Meeting, University of Chicago.

"Estimates of the Free Demand for Rationed Foodstuffs" (with James Tobin), *Economic Journal*, Vol. 62, March, 1952, pp. 103-118.

Review of "Social Choice and Individual Values" by K. J. Arrow, *Economic Journal*, Vol. 62, June, 1952, pp. 355-358.

"The Econometrics of Family Budgets," *Journal of the Royal Statistical Society*, Series A, 1952, pp. 103-118.

"Compensated Changes in Quantities and Qualities Consumed," *Review of Economic Studies*, Vol. 19, 1952, pp. 155-164.

LEONID HURWICZ

Discussant on "Probability and Statistical Inference," September, 1951, at the Minneapolis meeting of the Econometric Society.

"Decision-Making and the Theory of Organization," presented September, 1951, before the Minneapolis meeting of the Econometric Society.

"Aggregation in Macroeconomic Models," presented December, 1951, at the Boston meeting of the Econometric Society. (Abstract in *Econometrica*, Vol. 20, July, 1952, pp. 489-490.)

"Recent Developments in Decision Theory," presented December, 1951, at the Statistics Group, University of Minnesota.

"Dynamic Aspects of Achieving Optimal Allocation of Resources" (with Kenneth J. Arrow), presented August, 1951, at the Santa Monica meeting of the Econometric Society. (Abstract in *Econometrica*, Vol. 20, January, 1952, pp. 86-87.)

Discussion on "Necessary and Sufficient Conditions for Consistent Estimability," December 27, 1951, at the Boston meeting of the Econometric Society. (Abstract in *Econometrica*, Vol. 20, July, 1952, p. 481.)

"Measurement in the Social Sciences," presented January 30, 1952, at the Sociology Club, University of Minnesota.

"Lagrangian Problems and Saddle Points," presented February 26, 1952, at Mathematics Colloquium, University of Minnesota.

Discussant on "Research Design and Methodology in Studies of Labor Mobility," May 23, 1952, at the 8th Annual Conference on Research in Industrial Relations, University of Minnesota.

Lecture Courses in Foundations of Mathematics for Social Scientists, Econometrics I and II, and Topics in Mathematical Economics, 1951-52, University of Minnesota.

LAWRENCE R. KLEIN

"The Life of John Maynard Keynes," *Journal of Political Economy*, Vol. 59, October, 1951, pp. 443-451.

"Estimating Patterns of Savings Behavior from Sample Survey Data," *Econometrica*, Vol. 19, October, 1951, pp. 438-454. (Reprinted as Cowles Commission Papers, New Series, No. 55.)

Review of "Expectations in Economics" by G. L. S. Shackle, *Review of Economics and Statistics*, Vol. 33, November, 1951, pp. 355-356.

"Results of Alternative Statistical Treatments of Sample Survey Data" (with J. N. Morgan), *Journal of the American Statistical Association*, Vol. 46, December, 1951, pp. 442-460.

"Some Findings on Consumer Behavior from the Surveys of Consumer Finances," presented December 10, 1951, before the Economics Club, University of Michigan.

"The Econometric Approach to Forecasting," presented December 27, 1952, before the Boston meeting of the Econometric Society. (Abstract in *Econometrica*, Vol. 20, July, 1952, p. 492.)

"Studies in Investment Behavior," *Conference on Business Cycles*, New York: National Bureau of Economic Research, 1951, pp. 233-304.

"Assets, Debts, and Economic Behavior," *Studies in Income and Wealth*, Vol. 14, Conference on Research in Income and Wealth, New York: National Bureau of Economic Research, 1951, pp. 197-228.

Review of "The Role of Measurement in Economics" by Richard Stone, *Econometrica*, Vol. 20, January, 1952, pp. 104-105.

"Evaluation of Consumers' Expenditures Survey Data," presented February 7, 1952, at a Cowles Commission Seminar, University of Chicago.

"Savings Concepts and their Relation to Economic Policy," presented May 16, 1952, before the Savings Conference, University of Minnesota.

Course Lectures, Graduate Seminar in Econometrics, 1951-52, University of Michigan.

TJALLING C. KOOPMANS

"Efficient Allocation of Resources," *Econometrica*, Vol. 19, October, 1951, pp. 445-465. (Reprinted as Cowles Commission Papers, New Series, No. 52.)

Discussant of "An Econometric Model of Interindustry Material Flows" by Ronald Shephard, December 28, 1951, at the Boston meeting of the Econometric Society. (Abstract in *Econometrica*, Vol. 20, July, 1952, pp. 490-491.)

Discussant of "Planning and Scheduling Production Processes" by Melvin E. Salvesson and report of "Transportation on a Network" by Martin Beckmann, January 2, 1952, before the Third Annual Logistics Conference of George Washington University and the Office of Naval Research.

"Theory of Allocation of Resources," presented January 10, 1952, before the Research Seminar in Econometrics of the University of Michigan.

"The Problem of Identification in Social Science Models," presented January 11, 1952, before the Seminar on Application of Mathematics to the Social Sciences of the University of Michigan.

Course Lectures on Allocation of Resources in Production, Winter and Spring, 1952, University of Chicago.

For contributions to *Studies in Econometric Method*, Cowles Commission Monograph 14, see Appendix IV.

ERICH L. LEHMANN

Review of "On the Independence of Quadratic Forms in a Non-Central Normal System" by J. Ogawa, *Mathematical Reviews*, Vol. 12, July-August, 1951, p. 509.

Review of "Estimators of the Probability of the Zero Class in Poisson and Certain Related Populations" by N. L. Johnson, *Mathematical Reviews*, Vol. 12, September, 1951, p. 622.

"Testing Multiparameter Hypotheses," presented October, 1951, at the Washington meeting of the Institute of Mathematical Statistics.

Review of "On the Theory of Unbiased Tests of Simple Statistical Hypotheses Specifying the Values of Two or More Parameters" by S. L. Isaacson, *Mathematical Reviews*, Vol. 12, November, 1951, p. 842.

"A General Concept of Unbiasedness," *Annals of Mathematical Statistics*, Vol. 22, December, 1951, pp. 587-592.

"Some Applications of the Cramér-Rao Inequality" (with J. L. Hodges, Jr.), *Proceedings of the Second Berkeley Symposium on Mathematical Statistics and Probability* (J. Neyman, ed.), Berkeley and Los Angeles: University of California Press, 1951, pp. 13-22.

Review of "Statistical Decision Functions" by A. Wald, *Scripta Mathematica*, Vol. 18, March, 1952, pp. 77-78.

Review of "Test Criteria for Hypotheses of Symmetry of a Regression Matrix" by U. Chand, *Mathematical Reviews*, Vol. 13, April, 1952, p. 367.

"On the Power of Rank Tests," presented May 12, 1952, at the Statistics Seminar of the University of California, Berkeley.

Review of "Un test séquentiel unilatéral" by C. Dresselaers and P. Gillis, *Mathematical Reviews*, Vol. 13, May, 1952, p. 479.

Review of "Asymptotically Subminimax Solutions of Compound Statistical Decision Problems" by Herbert Robbins, *Mathematical Reviews*, Vol. 13, May, 1952, p. 480.

Courses Lectures on the Theory of Testing Hypotheses, Sequential Analysis, Non-Parametric Inference, and Theory of Probability, 1951-52, Stanford University.

EDMOND MALINVAUD

Review of "Sur L'Econométrie" by B. Chait, *Econometrica*, Vol. 19, July, 1951, pp. 355-356.

"Efficient Accumulation of Capital," presented September, 1951, at the Minneapolis meeting of the Econometric Society.

HARRY MARKOWITZ

"Stocks and Flows in Monetary Analysis" (with Karl Brunner), presented December 29, 1951, before the Boston meeting of the Econometric Society.

"Portfolio Selection," *Journal of Finance*, Vol. 7, March, 1952, pp. 77-91. (Reprinted as Cowles Commission Papers, New Series, No. 60.)

"The Utility of Wealth," *Journal of Political Economy*, Vol. 60, April, 1952, pp. 151-158. (Reprinted as Cowles Commission Papers, New Series, No. 57.)

JACOB MARSCHAK

"Optimal Inventory Policy" (with K. Arrow and T. Harris), *Econometrica*, Vol. 19, July, 1951, pp. 250-272. (Included as Cowles Commission Papers, New Series, No. 44.)

"Criteria for Planning under Incomplete Information" (with Roy Radner), presented August 2, 1951, before the Santa Monica meeting of the Econometric Society. (Abstract in *Econometrica*, Vol. 20, January, 1952, p. 81.)

"Optimal Communication within Teams," presented October 31, 1951, at the Chicago Conference on Decision-Making organized by the Cowles Commission.

"Some Remarks on Goals for the Study of Mathematics by Social Scientists," presented December 28, 1951, at the Round Table Meeting of the American Statistical Association, the Econometric Society, and the Institute of Mathematical Statistics, Boston.

"Some Aspects of Inventory Control," presented December 29, 1951, at the Boston meeting of the Econometric Society. (Abstract in *Econometrica*, Vol. 20, July, 1952, p. 499.)

"Comments on Wesley Mitchell's 'What Happens During Business Cycles,'" *Conference on Business Cycles*, New York: National Bureau of Economic Research, 1951, pp. 14-24.

"Why 'Should' Statisticians and Businessmen Maximize 'Moral Expectation?'" *Proceedings of the Second Berkeley Symposium on Mathematical Statistics and Probability* (J. Neyman, ed.), Berkeley and Los Angeles: University of California Press, 1951, pp. 493-506. (Reprinted as Cowles Commission Papers, New Series, No. 53.)

Review of "Note sur un problème fondamental de la théorie de l'équilibre économique" by Jiri Seitz, *Mathematical Reviews*, Vol. 12, No. 7, 1951, p. 471.

"Optimal Choice of Weapons" (with M. R. Mickey), presented

January 3, 1952, at the Annual Logistics Conference, George Washington University.

"Inventory Rules for Business and Nonprofit Organizations," presented February 14, 1952, at the Econometric Seminar of the University of Michigan.

"Teams and Organizations," presented February 15, 1952, at the Inter-Disciplinary Seminar of the University of Michigan.

"Organized Decision-Making" (with M. Beckmann), presented April 10, 1952, at the Conference on Business Decision-Making organized jointly by the Bureau of Business and Economic Research, University of Illinois, the Cowles Commission, and the School of Industrial Administration, Carnegie Institute of Technology.

"Equipes et Organisations," presented May, 1952, at the Colloquium on Risk and Uncertainty, Centre Nationale de la Recherche Scientifique, Paris. (To be published in *Proceedings of the Colloquium*.)

"Mensurations économiques: prévisions et décisions," presented May 27, 1952, at the Economic Seminar of the Ecole des Mines, Paris.

"Monnaie et liquidité dans des modèles micro-économiques et macro-économiques," presented May 29, 1952, at the Econometric Seminar of the Centre Nationale de la Recherche Scientifique, Paris.

"Comments on Ruth Mack's 'Economics of Consumption,' " *Survey of Contemporary Economics*, Vol. 2, (Bernard F. Haley, ed.) Homewood, Illinois: Richard D. Irwin, Inc., 1952, pp. 80-83.

Course Lectures on Economics of Uncertainty, Spring, 1952, University of Chicago.

"The Communication Problem in an Arbitrage Firm," presented June 4, 1952, at the London School of Economics.

"Experimental Team Models," presented June 30, 1952, at the Summer Seminar on Decision-Making organized at Santa Monica, California by the University of Michigan.

"Assets, Prices, and Monetary Theory" (with Helen Makower), (republished with some corrections from *Econometrica*, 1938) in *Readings in Price Theory*, selected by a Committee of the American Economic Association (A. Stigler and K. Boulding), Homewood, Illinois: Richard D. Irwin, Inc., 1952, pp. 283-310.

FRANCO MODIGLIANI

"Economic Expectations and Plans of Firms in Relation to Short-Run Forecasting" (with Owen H. Sauerlender), presented September, 1951, at the Midwest Conference on Research in Income and Wealth, Ann Arbor. (To be published in *Proceedings of the Conference on Research in Income and Wealth*.)

"Statistical Problems in the Study of Economic Expectations and Plans," presented Fall, 1951, at the Statistical Seminar, University of Illinois.

"The Role of Economic Expectations and Plans in the Economy of the Firm," presented Fall, 1951, before the Economics Faculty Seminar, Pennsylvania State College.

"The Measurement of Economic Expectations," presented December, 1951, at the Boston meeting of the Econometric Society. (Abstract in *Econometrica*, Vol. 20, July, 1952, pp. 481-483.

"Expectations, Plans, and Economic Forecasting," presented February, 1952, before the Graduate Economic Seminar, University of Minnesota.

"Uses of Taxation as a Substitute for Direct Controls," presented February, 1952, before the graduate economic class on taxation, University of Minnesota. (Abstract in *Econometrica*, Vol. 20, January, 1952, p. 81.)

"Some Empirical Results of an Analysis of Expectations and Plans of Firms," presented May 22, 1952, at a Cowles Commission Seminar.

Course Lectures on Introduction to Econometrics, Spring, 1952, University of Illinois.

ROY RADNER

"Criteria for Planning under Incomplete Information" (with J. Marschak), presented August 2, 1951, at the Santa Monica meeting of the Econometric Society.

"Theory of Statistical Decision Functions," presented Fall, 1951, at the Junior Mathematics Club, University of Chicago.

HERMAN RUBIN

"Systems of Nonlinear Stochastic Difference Equations," presented December 27, 1951, before the Boston meeting of the Econometric Society.

Review of "Contributions to the Theory of Games" (H. W. Kuhn and A. W. Tucker, eds.) *Econometrica*, Vol. 20, January, 1952, pp. 112-113.

"A Bayes Approach to a Quality Control Mode" (with M. A. Girshick), *Annals of Mathematical Statistics*, Vol. 23, March, 1952, pp. 114-125.

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HERBERT A. SIMON

"A Formal Theory of the Employment Relationship," *Econometrica*, Vol. 19, July, 1951, pp. 292-305. (Reprinted as Cowles Commission Papers, New Series, No. 47.)

Review of "Mathematical Biology of Social Behavior" by Nicholas Rashevsky, *Econometrica*, Vol. 19, July, 1951, pp. 357-358.

"Mathematical Models in the Social Sciences," presented September, 1951, before the American Sociological Society, Chicago and presented November 15, 1951, before a Cowles Commission Seminar, University of Chicago.

"Decision-Making in Organization," presented March 10, 1952, at the Seminar on Organization, Columbia University.

"On the Application of Servomechanism Theory in the Study of Production Control," *Econometrica*, Vol. 20, April, 1952, pp. 247-268. (Reprinted as Cowles Commission Papers, New Series, No. 59.)

"A Formal Theory of Interaction in Social Groups," *American Sociological Review*, Vol. 17, April, 1952, pp. 202-211.

"The Logic of Causality," presented April 10, 1952, at the Conference on Business Decision-Making sponsored jointly with Carnegie Institute of Technology and the University of Illinois.

"Development of Theory of Democratic Administration: Reply," *American Political Science Review*, Vol. 46, June 1952, pp. 494-496.

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ROBERT STROTZ

"Long-Run Marginal Costs and Fluctuating Output" (with H. M. Oliver), *Southern Economic Journal*, Vol. 18, October, 1951, pp. 160-172.

"Analog Computing Techniques Applied to Economics" (with J. F. Calvert and N. F. Morehouse), *Transactions of the American Institute of Electrical Engineers*, Vol. 70, Part I, 1951, pp. 557-563.

"Problems on the Pure Theory of Income Redistribution," presented December 13, 1951, at a Cowles Commission Seminar.

"An Analog Solution of Goodwin's Nonlinear Cycle Theory," presented April 8, 1952, at the School of Business Administration, University of Minnesota.

Course Lectures on Statistics and Economic Theory, 1951-52, Northwestern University.

ERLING SVERDRUP

"Weight Functions and Minimax Procedures in the Theory of Statistical Inference," *Arkiv för Matematik og Naturvidenskab*, Summer, 1952.

"The Limit Distribution of a Continuous Function of Random Variables," *Skandinavisk Aktuarietidskrift*, 1952, No. 1-2, pp. 1-10.

Several expository papers about statistical problems have been published in *Memorandum fra Universitetets Socialøkonomiske Institutt*.

DANIEL WATERMAN

"On Farey Functions," presented Fall, 1951, at Junior Mathematics Club, University of Chicago.

"On an Integral of Marcinkiewicz," presented April, 1952, at the American Mathematical Society, Chicago. (Abstract to be published in the *Bulletin of American Mathematical Society*.)

"A Convergence Theorem for Dirichlet Series," presented April, 1952, at the American Mathematical Society, Chicago. (Abstract to be published in the *Bulletin of American Mathematical Society*.)

COWLES COMMISSION PAPERS, 1943-1952

NEW SERIES

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

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

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

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

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

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

* ALFRED COWLES, "Can Stock Market Forecasters Forecast?" *Econometrica*, Vol. 1, July, 1933, pp. 309-324.

* ALFRED COWLES AND HERBERT E. JONES, "Some A Posteriori Probabilities in Stock Market Action," *Econometrica*, Vol. 5, July, 1937, pp. 280-294.

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

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

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

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

* Single copies available on request. (Of the papers not marked with an asterisk, those which are reprinted from *Econometrica* may be obtained by purchasing the back issues in which they appear from the Econometric Society, University of Chicago, Chicago 37, Illinois. Price \$3.00 per issue.)

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

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

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

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

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

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

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

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

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

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

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

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

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

No. 24. M. A. GIRSHICK AND TRYGVE HAAVELMO, "Statistical

Analysis of the Demand for Food: Examples of Simultaneous Estimation of Structural Equations," *Econometrica*, Vol. 15, April, 1947, pp. 79-110.

No. 25. Two Review Articles: TJALLING C. KOOPMANS, "Measurement without Theory," and JACOB MARSCHAK, "On Mathematics for Economists," *Review of Economic Statistics*, Vol. 29, August, 1947, pp. 161-172; November, 1947, pp. 269-273.

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

No. 27. Two Papers on Econometric Models: TRYGVE HAAVELMO, "Quantitative Research in Agricultural Economics: The Interdependence between Agriculture and the National Economy," and GERSHON COOPER, "The Role of Econometric Models in Economic Research," *Journal of Farm Economics*, Vol. 29, November, 1947, pp. 910-924; Vol. 30, February, 1948, pp. 101-116.

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

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

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

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

No. 32. JACOB MARSCHAK, "Statistical Inference from Nonexperimental Observations: Economic Example," *Proceedings of the International Statistical Conferences*, Vol. 3, pp. 289-298.

* No. 33. EVSEY DOMAR, "Capital Accumulation and the End of Prosperity," *Proceedings of the International Statistical Conferences*, Vol. 5 (reprinted as a Supplement to *Econometrica*, Vol. 17, July, 1949, pp. 307-314).

* No. 34. TJALLING C. KOOPMANS, "Optimum Utilization of the Transportation System," *Proceedings of the International Statistical Con-*

ferences, Vol. 5 (reprinted as a Supplement to *Econometrica*, Vol. 17 July, 1949, pp. 136-146).

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

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

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

* No. 38. Two Papers on Involuntary Economic Decisions: TRYGVE HAAVELMO, "The Notion of Involuntary Economic Decisions," *Econometrica*, Vol. 18, January, 1950, pp. 1-8; DON PATINKIN, "Involuntary Unemployment and the Keynesian Supply Function," *Economic Journal*, Vol. 59, September, 1949, pp. 360-383.

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

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

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* No. 43. Papers on the Theory of Choice: JACOB MARSCHAK, "Rational Behavior, Uncertain Prospects, and Measurable Utility," and

abstracts of papers presented at Boulder by TJALLING C. KOOPMANS AND JACOB MARSCHAK, *Econometrica*, Vol. 18, April, 1950, pp. 111-141; pp. 174-175.

* No. 44. KENNETH J. ARROW, THEODORE HARRIS, AND JACOB MARSCHAK, "Optimal Inventory Policy," *Econometrica*, Vol. 19, July, 1951, pp. 250-272.

* No. 45. GERARD DEBREU, "The Coefficient of Resource Utilization," *Econometrica*, Vol. 19, July, 1951, pp. 273-292.

* No. 46. JACOB MARSCHAK, "The Rationale of the Demand for Money and of 'Money Illusion,'" *Metroeconomica*, Vol. 2, 1950, pp. 71-100; abstract, *Econometrica*, Vol. 18, July, 1950, pp. 273-274.

No. 47. HERBERT A. SIMON, Two Papers on Organization Problems and Economic Theory: "A Formal Theory of the Employment Relationship," *Econometrica*, Vol. 19, July, 1951, pp. 293-305; "A Comparison of Organization Theories," (Forthcoming in *Review of Economic Studies*, October, 1952.)

* No. 48. KENNETH J. ARROW, "Mathematical Models in the Social Sciences," in *The Policy Sciences in the United States*, (H. D. Lasswell and D. T. Lerner, eds.), Stanford: Stanford University Press, 1951, pp. 129-154.

* No. 49. CARL CHRIST, "A Test of an Econometric Model for the United States, 1921-1947," *Proceedings of the Conference on Business Cycles*, New York: National Bureau of Economic Research, 1951, pp. 35-129.

* No. 50. T. W. ANDERSON, "Estimating Linear Restrictions on Regression Coefficients for Multivariate Normal Distributions," *Annals of Mathematical Statistics*, Vol. 22, September, 1951, pp. 327-351.

* No. 51. KENNETH J. ARROW, "Alternative Approaches to the Theory of Choice in Risk-Taking Situations," *Econometrica*, Vol. 19, October, 1951, pp. 404-437.

* No. 52. TJALLING C. KOOPMANS, "Efficient Allocation of Resources," *Econometrica*, Vol. 19, October, 1951, pp. 455-465.

* No. 53. JACOB MARSCHAK, "Why 'Should' Statisticians and Businessmen Maximize Moral Expectation?" *Proceedings of the Second Berkeley Symposium on Mathematical Statistics and Probability*, 1951, pp. 493-506.

* No. 54. KENNETH J. ARROW, "An Extension of the Basic Theorems of Classical Welfare Economics," *Proceedings of the Second Berkeley Symposium on Mathematical Statistics and Probability*, 1951, pp. 507-532.

* No. 55. LAWRENCE R. KLEIN, "Estimating Patterns of Savings Behavior from Sample Survey Data," *Econometrica*, Vol. 19, October, 1951, pp. 438-454.

* No. 56. GEORGE H. BORTS, "Production Relations in the Railway Industry," *Econometrica*, Vol. 20, January, 1952, pp. 71-79.

* No. 57. HARRY MARKOWITZ, "The Utility of Wealth," *Journal of Political Economy*, Vol. 60, April, 1952, pp. 151-158.

* No. 58. GERARD DEBREU, "Definite and Semi-Definite Quadratic Forms," *Econometrica*, Vol. 20, April, 1952, pp. 295-300.

* No. 59. HERBERT A. SIMON, "On the Application of Servomechanism Theory in the Study of Production Control," *Econometrica*, Vol. 20, April, 1952, pp. 247-268.

* No. 60. HARRY MARKOWITZ, "Portfolio Selection," *Journal of Finance*, Vol. 7, March, 1952, pp. 77-91.

SPECIAL PAPERS

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

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

COWLES COMMISSION MONOGRAPHS, 1934-1952*

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.

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

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

No. 8. *Price Flexibility and Employment*, by OSCAR LANGE, 1944. Evanston, Ill.: Principia Press. 114 pages. Price \$2.75. A clarification of important concepts that have had much currency in the practical discussion of depressions and wars but remained too vague to allow useful treatment.

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

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

No. 10. *Statistical Inference in Dynamic Economic Models*, edited by 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. *Contents:*

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

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

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

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

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

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

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

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

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

No. 11. *Economic Fluctuations in the United States, 1921-1941*, by LAWRENCE R. KLEIN. 1950. New York: John Wiley and Sons. 174 pages. Price \$4.00. The methodology of econometric model construction is applied to business cycle analysis with possible implications for prediction and policy making. *Contents:*

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

No. 12. *Social Choice and Individual Values*, by KENNETH J. ARROW. 1951. New York: John Wiley and Sons. 99 pages. Price \$2.50. Methods

of symbolic logic are applied to the question whether a social valuation of alternatives can be consistently derived from given, partly conflicting, individual valuations. *Contents:*

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

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

Introduction, *Tjalling C. Koopmans*.

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

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PART THREE. MATHEMATICAL PROPERTIES OF CONVEX SETS: XVII. Theory of Convex Polyhedral Cones, *Murray Gerstenhaber*; XIX. Linear Programming and the Theory of Games, *David Gale, Harold W. Kuhn, and Albert W. Tucker*; XX. A Proof of the Equivalence of the Programming Problem and the Game Problem, *George B. Dantzig*.

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

No. 14. *Studies in Econometric Method*, by COWLES COMMISSION RESEARCH STAFF, edited by WM. C. HOOD AND T. C. KOOPMANS. New York:

John Wiley and Sons. Presents and extends methods developed in Monograph 10 in an expository style addressed primarily to the user of methodology. *Contents:*

I. Economic Measurements for Policy and Prediction, *Jacob Marschak*; II. Identification Problems in Economic Model Construction, *Tjalling C. Koopmans*; III. Causal Ordering and Identifiability, *Herbert A. Simon*; IV. Methods of Measuring the Marginal Propensity to Consume, *Trygve Haavelmo*; V. Statistical Analysis of the Demand for Food: Examples of Simultaneous Estimation of Structural Equations, *M. A. Girshick and Trygve Haavelmo*; VI. The Estimation of Simultaneous Linear Economic Relationships, *Tjalling C. Koopmans and Wm. C. Hood*; VII. Asymptotic Properties of Limited-Information Estimates Under Generalized Conditions, *Herman Chernoff and Herman Rubin*; VIII. An Example of Loss of Efficiency in Structural Estimation, *S. G. Allen, Jr.*; IX. Sources and Size of Least-Squares Bias in a Two-Equation Model, *Jean Bronfenbrenner*; X. The Computation of Maximum-Likelihood Estimates of Linear Structural Equations, *Herman Chernoff and Nathan Divinsky*.

* * *

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

Preface.

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

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

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

Income, Employment, and the Price Level, notes on lectures by JACOB MARSCHAK at The University of Chicago, Autumn, 1948 and 1949. Cowles Commission for Research in Economics, The University of Chicago, Chicago 37, Illinois. 1951. 95 pp. Price \$1.75.

COWLES COMMISSION SEMINARS 1951-1952

1951

October 18. MELVILLE J. HERSKOVITS, Northwestern University, "Rational Behavior and Cultural Relativism."

November 1. HOWARD RAIFFA, University of Michigan, "Arbitration Schemes for Generalized Two-Person Games," presented at the Cowles Commission Conference on the Problem of Decision-Making.

November 15. HERBERT A. SIMON, "Some Mathematical Models in Social Sciences."

November 29. KARL MENGER, Illinois Institute of Technology, "Probabilistic Theory of Relations."

December 13. ROBERT H. STROTZ, "Problems in the Pure Theory of Income Redistribution."

1952

January 10. MILTON FRIEDMAN, University of Chicago, "Price, Income, and Monetary Changes in Three Wartime Periods."

January 24. KARL FAXÉN, University of Stockholm, "Games with Nonmeasurable Utilities."

February 7. LAWRENCE R. KLEIN, "Evaluation of Consumers' Expenditures Survey Data."

February 21. HERBERT D. LANDAHL, University of Chicago, "A Neurobiophysical Interpretation of Certain Aspects of the Problem of Risks."

March 6. H. S. HOUTHAKKER, "The Free Demand for Rationed Foodstuffs in Britain."

March 27. CLYDE H. COOMBS, University of Michigan, "Measurement of Individual and Social Utility."

April 10. HERBERT A. SIMON, "The Logic of Causality," presented at the Conference on Business Decision-Making sponsored jointly with Carnegie Institute of Technology and the University of Illinois.

April 24. ROBERT M. THRALL, University of Michigan, "A General Theory of Measurement and the Michigan Interdisciplinary Training Program."

May 8. JAMES G. MILLER, University of Chicago, "The Executive of the Personality and Decision-Making."

May 22. FRANCO MODIGLIANI, "Some Empirical Results of an Analysis of Expectations and Plans of Firms."

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

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

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

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

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

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

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

* Not all of these courses are offered in any one academic year.

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

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

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

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

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

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

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

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

STATISTICAL PROBLEMS OF MODEL CONSTRUCTION. Discussion of problems arising when inference processes are directed to a postulated structure underlying the probability distribution of observed variables. Problems of identification of structural characteristics in a given model, of estimation of identifiable parameters, of estimation bias arising from incorrectly specified models, and of testing the specifications that define a model. Examples are drawn from econometrics, factor analysis, latent attribute analysis, and from the study of errors of observation.

STATISTICAL METHODS OF MEASURING ECONOMIC RELATIONS.

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

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

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

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

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

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

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

MATHEMATICAL STATISTICS. An introduction to the theories of mathematical statistics that include discussions of point estimation, set estimation, and the testing of hypotheses.

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

MULTIVARIATE ANALYSIS. The multivariate normal distribution. Related distributions such as the Wishart distribution and its noncentral analogue, and the distribution of the roots of determinantal equations. Hotelling's canonical correlations. Associated tests and estimation functions and the problem of classification.

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

NON-PARAMETRIC INFERENCE.

ECONOMETRICS SEMINAR. Reports by staff members, students, and visitors.

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