

By action of the Council of the Institute of Mathematical Statistics the 1978 volume of the Annals of Statistics is dedicated to the memory of

HAROLD HOTELLING

in recognition of his many contributions to mathematical economics and the theory, practice and teaching of statistics.



HAROLD HOTELLING 1895–1973

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Harold Hotelling was born on September 29th, 1895, in Fulda, Minnesota, where his father, Clair Alberta Hotelling, was engaged in the trade of selling hay. His parents were to have six children and Harold was their first. It is said that even when quite young he exhibited an unusual degree of curiosity. He read, for example, every book about electricity on which he could lay his young hands, to gain an understanding of that novel mystery: electric lighting. Another technological novelty in those early years was the internal combustion engine, whose steady usurpation of the horse finally ruined the hay business of his father. At this juncture the parents decided on a move to Seattle, a move that involved a train journey with, not only the five children they now had, but also forty horses salvaged from the abandoned business in Fulda! It is possible that, had the family been able to stay in Fulda, Harold might never have attended university. As it was, the move brought him to the doorstep of the University of Washington where his remarkable career would, in the ripeness of time, begin.

His family was not without some claims to distinction. On the side of his mother, Lucy Amelia Rawson Hotelling, it descended from an Edward Rawson who was Secretary of the Massachusetts Bay colony in its early days. On visits to Cambridge, England, in later years, it gave Harold pleasure to trace family connections also with Andrew Perne, who was the Master of Peterhouse in 1554 and made Dean of Ely in 1557, and with Edmund Grindal, who was Archbishop of Canterbury from 1575 until his death in 1583.

At the University of Washington he chose journalism as his major subject, worked on various newspapers in Washington state while a student, and was awarded his Bachelor of Arts degree in journalism in 1919. Fortunately, he took one or two mathematics courses as part of his degree program and these gave Eric Temple Bell the opportunity to detect in him a remarkable mathematical talent. Bell persuaded him to turn from journalism to mathematics. Thus it was that he gained a Master of Science degree in mathematics, also at the University of Washington, in 1921. Journalism undoubtedly lost an outstanding personality, but mathematical statistics and mathematical economics were enriched forever with his pioneering spirit.

He had been a summer student at the University of Chicago in the summer of 1920, but it was to Princeton University that he went for his doctoral studies, and there gained the Doctor of Philosophy degree, in 1924, for work in mathematics.

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His thesis was written under the guidance of James W. Alexander; it was a contribution to the field of topology and titled "3-dimensional manifolds of states of motion." This work was published in 1925 in the *Transactions of the American Mathematical Society*.

His first job as a Ph.D. was at Stanford University where he went in 1924 as a research associate in the Food Research Institute. In 1927 he became an Associate Professor in the Mathematics Department at Stanford University, and held this position until 1931. It seems that he taught his first course, "The theory of probability and statistical inference" in the year 1925–26, and it is interesting to note that in the following year he was offering "Determinants and probability" and "The mathematics of statistical inference," as well as "Analysis situs" and "Differential geometry." Thus, even at this early stage in his career, he gave a strong indication of areas in which he would make his mark and of the tools he would use in doing so. But at that time it was in England that statistical theory was receiving its most exciting developments, and it was natural, therefore, that Harold Hotelling should look in that direction for inspiration.

The dominant figure in mathematical statistics in the twenties and thirties was that of Ronald A. Fisher. Most of Fisher's work in those years was done at the Rothamsted Agricultural Station at Harpenden in England. Harold Hotelling managed to spend the six months from June to December of 1929 at Rothamsted with Fisher and it was during this sojourn that mathematical statistics, already one of his several scholarly interests, became a life-long and consuming passion. During these months in England he also made friends with many British statisticians who were, like himself, to rise to international prominence. These friendships were preserved to the end of his life and were to provide him and them with many congenial occasions and to produce valuable exchanges of ideas.

In 1925 he had already published the first of a long series of scholarly papers. His earliest applications of mathematics concerned journalism and political science; from these subjects he turned to population and food supply, and from these to theoretical economics, in which he was one of the initiators of the modern theories of imperfect competition and welfare economics. At the same time as he was developing these applications of mathematics, he was producing a series of publications in theoretical statistics which were often of such originality and importance that they provoked a considerable amount of later research by many scholars in many lands. In particular, he published in 1931 in the *Annals of Mathematical Statistics* his paper "The generalization of Student's ratio," a paper which Professor Jerzy Neyman considers to be Hotelling's most important contribution to statistics. In that same year, 1931, he moved to Columbia University as Professor of Economics. He was to stay there for fifteen fruitful years, which were to establish him internationally, in both mathematical economics and mathematical statistics, as a teacher and researcher of the front rank.

He was indefatigable and always active on several fronts. He urged Columbia University to accept Russian as an appropriate language for doctoral requirements,

a suggestion which not only Columbia University but many other graduate schools in the United States have adopted. In the dark years following Hitler's accession to power, Harold Hotelling assisted various refugee scholars of central Europe who had fled to the United States. In particular, he played an important part in helping the late Abraham Wald and in providing him with the opportunity to pursue his research at Columbia University. During World War II Harold Hotelling was actively engaged in statistical work of a military character and in that connection organized, at Columbia University, the Statistical Research Group and recruited a number of outstanding talents into it, including, in addition to Abraham Wald, W. Allen Wallis and Jacob Wolfowitz. From this fertile group came, in particular, Wald's theory of sequential estimation.

In 1946 the University of North Carolina at Chapel Hill had, in Dr. Frank Porter Graham, an exceptional and prescient president. Graham was convinced of the desirability of developing at Chapel Hill a department of theoretical statistics which would complement the applied statistics group then growing in nearby Raleigh, in the Agriculture School of what was then called North Carolina State College, under the energetic leadership of that most remarkable of women, Professor Gertrude Cox. Graham was also advised that the right man to start this new department was Harold Hotelling. Thus it was that in the summer of 1946, Harold Hotelling was persuaded to leave Columbia University and accept the challenge of creating a wholly new department of statistics. He was then fifty years old.

In a surprisingly short space of time he had gathered a faculty of merit, including R. C. Bose, W. Hoeffding, W. G. Madow, G. E. Nicholson, H. E. Robbins, and P. L. Hsu who, however, was to return to his homeland, China, after a few years and was succeeded by S. N. Roy. Harold Hotelling was able to attract distinguished visitors for periods of a semester or less; these included M. S. Bartlett, E. J. G. Pitman, and J. Wolfowitz. Those first years in Chapel Hill were exciting and rewarding, and there was an air of pleasant informality about the department. For example, Ingram Olkin recalls arriving with his family, as a research student, in the summer of 1948 and, to his delight and surprise, being driven around in a search for suitable family housing by none other than Mrs. Hotelling!

Harold Hotelling had married Floy Tracy in 1920 and a son and daughter were born to them. But in November 1932 she died, not long after their move from Stanford to Columbia. The blow of his wife's death fell at the beginning of his most creative period, and the burden of caring for two young children in addition to his new responsibilities at Columbia University must have been considerable. Fortunately he was destined to meet Susanna P. Edmondson and, in due course, they were married in June 1934. Seldom can a professor have had a more capable, witty and intelligent help-mate. She relieved him of much of the tedious but necessary trivia that encumber the lives of most family men, and ensured that he could devote himself whole-heartedly to his scholarly work. She bore him five sons and a daughter, who, to their great sadness, died in infancy. But the responsibilities and demands of her maternity in no way diminished her energetic involvement in the

life of Harold's department, not only as a frequent hostess to distinguished visitors but, as we have seen, in giving timely help to students.

When the Hotellings arrived in Chapel Hill in 1946 they started, doubtless with the obvious pun intended, their monthly "Hotelling Teas," which quickly became a vital institution in the life of the department. For the afternoon of the second Sunday of every month the Hotelling home was declared "open house" for all who cared to come, and this included faculty, graduate students, visiting scholars, wives, and children of *all* ages, not only from the Statistics Department but also from the departments of Biostatistics, Economics, Psychology and others. Often a considerable press developed, and a respectful circle would surround Harold Hotelling and benefit from his observations and reminiscences, while Mrs. Hotelling, aided by faculty wives and that dedicated departmental secretary, Miss Martha Jordan, would dispense tea and an elaborate array of comestibles. For the many who were associated with Chapel Hill Statistics Department and who took part in those "Hotelling Teas," those occasions must be among their most poignant memories. These teas were, in fact, a continuation of a practice the Hotellings had begun years earlier, in 1934, while Harold Hotelling was at Columbia University.

Harold Hotelling was no dry-as-dust, solemn pedant; he had a dry humor and a keen sense of fun. The Chapel Hill Statistics Department held a Christmas party every year at which he played, with apparent relish, the role of Santa Claus. All coming to the party were obliged to bring small gifts which were placed in a large container and suitably randomized. These gifts were then redistributed by him, in accordance with rules of Eleusinian strangeness, with a Dickensian drollery and charm.

He impressed one as a man totally convinced of the importance of intellectual activity and discovery; he was, it seemed, genuinely puzzled when bureaucrats acted as though they did not share his convictions and, incredibly, would divert his energies to more mundane matters. He was imbued with an optimism that nothing would impede the progress of his academic enterprises, arising, one felt, from a firm belief that whatever forces ruled the universe shared his views. He invariably spoke well of others, never exhibited envy, and he charmed with a courtly, old-world manner that was entirely natural to him and free from guile. His conversation was fascinating, ranging over many fields and revealing astonishing powers of recall. He once explained to the writer how he could play "Monopoly" in his head, maintaining a faultless memory of the information necessary to render that somewhat involved diversion a Markov process; he further explained what a wonderful relaxant this practice could be on hot Chapel Hill nights, though, he said, sleep sometimes did not come until two complete games had been played.

Since the 1930's, mathematical statistics in the United States has gone through a period of spectacular growth, both in volume and quality of research work, in the extent and standards of academic instruction, and in the demand for experts in the field. Mathematical economics, after decades of stagnation, experienced a sudden revival in the late 1920's. In both of these developments Harold Hotelling's part

was of first-rate importance. In statistical theory he has been a leader in the field of multivariate analysis, contributing some of the basic ideas and tools in the treatment of vector-valued observations. His first important contribution has come to be called "Hotelling's generalized T^2 ." In developing his T^2 , Hotelling was perhaps the first statistician to be guided by the idea of invariance, later recognized as a principle of wide applicability in statistics. To mention only two of his other discoveries in the field of multivariate analysis, the methods of principal components and of canonical correlations have left a lasting imprint of Hotelling's name on statistics. His investigations on matrix calculations, also inspired by multivariate problems, are of importance outside of statistics as well.

Hotelling did pioneering work in other branches of mathematical statistics. His study of differential equations subject to error (in 1927) was one of the first papers in a field of great current research interest. His papers on rank correlation, on statistical prediction, and on the experimental determination of the maximum of a function also stimulated much further research in the succeeding decades.

Hotelling's contribution to economic theory has assured him a role of honor in the history of economic thought. His papers on demand theory, the incidence of taxation and welfare economics are already recognized as classics that form the basis of much that has been done in economics since they were written.

In demand theory he was one of a small number of pioneers in the world to revolutionize the basis of that theory and to extend its applications. Working in the 1930's, he was a major figure in a complete reformulation of micro theory which took place in that decade. In addition, his work on the incidence of taxation has achieved a permanent place in the literature of public finance. Perhaps worthy of special mention are his contributions to the theory of welfare economics. He was the first to prove rigorously the marginal cost-pricing theorem, which forms the basis of a great deal of the modern theory of welfare economics.

Some of his work on economics was largely ignored when published, only to be recognized in more recent times as of fundamental importance in the study of problems which only lately have become of wider interest. In particular, his works on location theory and on the economics of exhaustible resources, completed in the 1920's, have been rediscovered and found to be of considerable usefulness in contemporary economic thinking.

Those familiar with Harold Hotelling's substantial contributions to statistical theory are seldom fully cognizant of the scope and importance of his work in economic theory. Paul Samuelson in his 1970 Nobel Prize acceptance speech declared "Economics . . . has its heroes, and the letter H that I used in my mathematical equations was not there to honor Sir William Hamilton, but rather Harold Hotelling."

Harold Hotelling had the gift of detecting talent in others and of attracting that talent to the sphere of his interests; thus he played a vital role in the raising of standards in statistical research work and in transforming mathematical statistics into a respected academic discipline. His persistent and vigorous advocacy of

competence in the teaching of statistics had a great impact on the academic community and contributed to the establishment of some of the first departments of statistics in American universities. At a meeting of the Institute of Mathematical Statistics held in September 1940, Harold Hotelling delivered his famous paper "The teaching of statistics." It was received with enthusiasm and, by a unanimous vote, the audience decided to have it published in the *Annals* as an expression of the way the Institute felt on this vital subject.

In class, Harold Hotelling spoke as he was wont to write, in well-rounded paragraphs with a perfect syntax that few for whom English is the mother-tongue seem able to emulate. His style, it must be confessed, did not suit all students. But he encouraged questions and discussion and a student was soon aware that he was in the presence of a remarkable man for whom scholarship was all-important. Harold Hotelling never tired of helping others, especially younger workers, as many of today's leaders in the fields of statistics and economics will gratefully attest. At professional meetings he frequently found ways of drawing attention to work done by students from Chapel Hill.

Already by 1952 he had established the Department of Statistics at Chapel Hill as one of the front-rank international centers for statistical research. He passed the departmental chairmanship over to a young man who had recently obtained his doctor's degree, George E. Nicholson Jr., and devoted his remaining years to his students and his research; the latter being mainly concerned with exploring consequences of his earlier work of the 1930's and 1940's. In 1955 he was awarded an honorary LL.D. by the University of Chicago in a ceremony that also honored Walter Lippmann and Arnold Toynbee. In 1963 he was awarded an honorary D.Sc. by the University of Rochester on an occasion when Dwight D. Eisenhower also received an honorary degree. The University of North Carolina promoted him to a Kenan Professorship in 1961.

He was an Honorary Fellow of the Royal Statistical Society, a Distinguished Fellow of the American Economic Association, and a Fellow of the Econometric Society, the Institute of Mathematical Statistics, and the Royal Economic Society. He was also elected a member of the International Statistical Institute. He served as President of the Econometric Society in 1936-37 and of the Institute of Mathematical Statistics in 1941.

On the occasion of his 65th birthday, in 1960, the *American Statistician* published "Three papers in honor of Harold Hotelling". In addition, two commemorative volumes were published. One was "Contributions to probability and statistics: essays in honor of Harold Hotelling;" the other, reflecting the other side of his interests, was "Essays in economics and econometrics: a volume in honor of Harold Hotelling". Nonetheless, he did not retire, but continued as a faculty member of the department, teaching a full course load. However, early in 1965 he set off on a special project for the Institute of Statistics in the University of Buenos Aires, to help in the development of a suitable statistics program. While in Buenos Aires ill-health struck and he was obliged, after an operation, to return to Chapel

Hill before he could complete his mission. He was never quite the same man again, although he continued to attend all departmental meetings, colloquia and social functions.

He returned in 1966 at the age of 72 and, at a dinner in the Carolina Inn, his colleagues presented him with two beautifully bound volumes containing 38 of his more outstanding papers. Even then he continued to hold an office in the department and, though he now occasionally exhibited a fatigue that had never been there before, he was frequently in the department, giving his friendship and advice to new generations of students.

The flow of honors had not stopped for him. In May 1970 he was elected to the National Academy of Sciences, and in 1972 he received the North Carolina Award for Science. The Accademia Nazionale dei Lincei, in Rome, a scholarly society of which Galileo was once a member, elected him to membership in July 1973.

It was typical of Harold Hotelling that he should undertake a tiring outing to Duke University campus, eight miles from his home, one hot Saturday evening in May 1972, to see a younger colleague perform in an amateur production of “The Mikado.” The effort was probably unwise. During family lunch the next day he experienced a serious stroke from which he never recovered. He was nursed and sustained by his wife, with signal devotion for nineteen months. On December 26th, 1973 he died.

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