

# THE ANNALS of STATISTICS

AN OFFICIAL JOURNAL OF  
THE INSTITUTE OF MATHEMATICAL STATISTICS

## Articles

On rereading R. A. Fisher.....	LEONARD J. SAVAGE	441
Discussion on Professor Savage's paper by B. Efron, C. Eisenhart, B. de Finetti, D. A. S. Fraser, V. P. Godambe, I. J. Good, O. Kempthorne and Stephen Stigler		
F. Y. Edgeworth and R. A. Fisher on the efficiency of maximum likelihood estimation.....	JOHN W. PRATT	501
Optimal balanced fractional $2^m$ factorial designs of resolution VII, $6 \leq m \leq 8$ .....	TERUHIRO SHIRAKURA	515
Monotone percentile regression	ROBERT J. CASADY AND JONATHAN D. CRYER	532
Tests for independence in infinite contingency tables.....	SHINGO SHIRAHATA	542
Weak convergence of sequential linear rank statistics.....	HENRY I. BRAUN	554

## Short Communications

Asymptotic optimality of the empirical Bayes procedure	J. J. DEELY AND W. J. ZIMMER	576
Empirical Bayes estimation of a distribution function	RAMESH M. KORWAR AND MYLES HOLLANDER	581
Asymptotic sufficiency and asymptotically most powerful tests for the two sample censored situation.....	K. G. MEHROTRA AND RICHARD A. JOHNSON	589
Asymptotic expansion and a local limit theorem for a function of the Kendall rank correlation coefficient.....	ZUZANA PRÁŠKOVÁ-VÍZKOVÁ	597
Multivariate unimodality	S. W. DHARMADHIKARI AND KUMAR JOGDEO	607
Selection of largest multiple correlation coefficients: exact sample size case.....	KHURSHED ALAM, M. HASEEB RIZVI AND HERBERT SOLOMON	614
An invariance principle in regression analysis.....	P. K. BHATTACHARYA	621
On a criterion for simultaneous extrapolation in nonfull rank normal regression.....	FEDERICO J. O'REILLY	625
An improved estimator of the generalized variance	R. W. SHORROCK AND J. V. ZIDEK	629
Extensions of Milliken's estimability criterion	J. K. BAKSALARY AND R. KALA	639
Combining independent normal mean estimation problems with unknown variances.....	JAMES O. BERGER AND M. E. BOCK	642
A special property of linear estimates of the normal mean.....	GLEN MEEDEN	649
A note on paired comparison rankings.....	JAGBIR SINGH	651
Resolvability of block designs.....	SANPEI KAGEYAMA	655
An upper bound of resolution in symmetrical fractional factorial designs.....	YOSHIO FUJII	662
When are the mean and the Studentized differences independent?	LENNART BONDESSON	668

---

Vol. 4, No. 3—May 1976

# THE INSTITUTE OF MATHEMATICAL STATISTICS

(Organized September 12, 1935)

*The purpose of the Institute of Mathematical Statistics is to encourage the development, dissemination, and application of mathematical statistics.*

---

## OFFICERS

**President:**

Donald L. Burkholder, Department of Mathematics, University of Illinois, Urbana, Illinois 61801

**President-Elect:**

C. R. Rao, Indian Statistical Institute, 7, S.J.S. Sansanwal Marg, New Delhi 110001, India

**Past President**

Frederick Mosteller, Department of Statistics, Science Center, Room 603, Harvard University, One Oxford Street, Cambridge, Massachusetts 02138

**Executive Secretary:**

George J. Resnikoff, Department of Statistics, California State University, 25800 Hillary St., Hayward, California 94542

**Treasurer:**

Robert M. Elashoff, IMS Business Office, 3401 Investment Blvd., Suite 6, Hayward, California 94545

**Program Secretary:**

William L. Harkness, Pennsylvania State University, University Park, Pennsylvania 16801

**Editor: *Annals of Statistics***

I. Richard Savage, Department of Statistics, P.O. Box 2179, Yale Station, New Haven, Connecticut 06520

**Editor: *Annals of Probability***

Patrick Billingsley, Department of Statistics, University of Chicago, Chicago, Illinois 60637

**Managing Editor:**

Donald R. Truax, Department of Mathematics, University of Oregon, Eugene, Oregon 97403

---

**Membership.** Membership dues including a subscription to one *Annals* and *The Institute of Mathematical Statistics Bulletin* are \$24.00 per year for residents of the United States or Canada and \$16.00 per year for residents of other countries. Special rates of \$12.00 per year are available to students. Rates in each category are one-third higher for members who wish both *Annals* as well as the *Bulletin*. Inquiries regarding membership in the Institute should be sent to the Treasurer at the Business Office.

**Subscription Rates.** Current volumes (six issues per calendar year) of the *Annals of Probability* and the *Annals of Statistics* are each \$30.00. Members of the Institute of Mathematical Statistics pay different rates (see above). Single issues are \$6.00. Back numbers of both *Annals* and the *Annals of Mathematical Statistics* (Volume 1 through 43) may be purchased from the Treasurer.

**The Annals of Statistics**, Volume 4, Number 3, May 1976. Published bimonthly in January, March, May, July, September, and November by The Institute of Mathematical Statistics, IMS Business Office, 3401 Investment Blvd., Suite 6, Hayward, California 94545

---

Mail to the *Annals of Statistics* should be addressed to either the Editor, Managing Editor or the Treasurer, as described above. It should *not* be addressed to Waverly Press.

---

PRINTED AT THE

WAVERLY PRESS, INC., BALTIMORE, MARYLAND 21202 U.S.A.

Second-class postage paid at Hayward, California and at additional mailing offices

Copyright © 1976 by the Institute of Mathematical Statistics

## EDITORIAL STAFF

### EDITOR

I. RICHARD SAVAGE

### ASSOCIATE EDITORS

RICHARD E. BARLOW  
ROBERT H. BERK  
DONALD A. BERRY  
PETER J. BICKEL  
DAVID R. BRILLINGER  
LARRY BROWN  
ARTHUR DEMPSTER  
ROGER H. FARRELL  
PETER C. FISHBURN  
J. K. GHOSH  
DAVID L. HANSON

A. HEDAYAT  
AGNES M. HERZBERG  
SØREN JOHANSEN  
JOSEPH B. KADANE  
CHARLES H. KRAFT  
ROSS LEADBETTER  
PI-ERH LIN  
ROBERT M. LOYNES  
MICHAEL D. PERLMAN  
JOHANN PFANZAGL

J. N. K. RAO  
J. SETHURAMAN  
DAVID O. SIEGMUND  
CHARLES J. STONE  
HOWARD L. TAYLOR  
CONSTANCE VAN EEDEN  
WILLIAM R. VAN ZWET  
GRACE WAHBA  
ROY E. WELSCH  
DONALD YLVISAKER  
JAMES V. ZIDEK

### MANAGING EDITOR

D. R. TRUAX

### PAST EDITORS OF THE ANNALS OF MATHEMATICAL STATISTICS

H. C. CARVER, 1930-1938

S. S. WILKS, 1938-1949

T. W. ANDERSON, 1950-1952

E. L. LEHMANN, 1953-1955

T. E. HARRIS, 1955-1958

WILLIAM KRUSKAL, 1958-1961

J. L. HODGES, JR., 1961-1964

D. L. BURKHOLDER, 1964-1967

Z. W. BIRNBAUM, 1967-1970

INGRAM OLKIN, 1970-1972

### PAST EDITOR OF THE ANNALS OF STATISTICS

INGRAM OLKIN, 1972-1973

---

## EDITORIAL POLICY

The main purpose of the *Annals of Statistics* and the *Annals of Probability* is to publish contributions to the theory of statistics and probability and to their applications. The emphasis is on importance and interest, not formal novelty and correctness. Especially appropriate are authoritative expository papers and surveys of areas in vigorous development. All papers are refereed.

---

## IMS INSTITUTIONAL MEMBERS

- AEROSPACE CORPORATION  
El Segundo, California
- ARIZONA STATE UNIVERSITY  
Tempe, Arizona
- ARTHUR D. LITTLE, INC.  
Cambridge, Massachusetts
- BELL TELEPHONE LABORATORIES, TECHNICAL LIBRARY  
Murray Hill, N. J.
- BOWLING GREEN STATE UNIVERSITY, DEPT. OF MATHEMATICS  
Bowling Green, Ohio
- CALIFORNIA STATE UNIVERSITY, FULLERTON, DEPARTMENT OF MATHEMATICS  
Fullerton, California
- CALIFORNIA STATE UNIVERSITY, HAYWARD, DEPARTMENT OF STATISTICS  
Hayward, California
- CASE WESTERN RESERVE UNIVERSITY, DEPARTMENT OF MATHEMATICS  
Cleveland, Ohio
- CORNELL UNIVERSITY, DEPARTMENT OF MATHEMATICS  
Ithaca, New York
- FLORIDA STATE UNIVERSITY, DEPARTMENT OF STATISTICS  
Tallahassee, Florida
- FORD MOTOR COMPANY, ENGINEERING AND RESEARCH LIBRARY  
Dearborn, Michigan
- GENERAL MOTORS CORPORATION, RESEARCH LABORATORIES  
Warren, Michigan
- GEORGE WASHINGTON UNIVERSITY, DEPARTMENT OF STATISTICS  
Washington, D.C.
- INDIANA UNIVERSITY, MATHEMATICS DEPT.  
Bloomington, Indiana
- INSTITUTE FOR DEFENSE ANALYSES  
Arlington, Virginia
- INTERNATIONAL BUSINESS MACHINES CORPORATION  
Armonk, New York
- IOWA STATE UNIVERSITY, STATISTICAL LABORATORY  
Ames, Iowa
- JOHNS HOPKINS UNIVERSITY, DEPARTMENT OF BIostatISTICS, DEPARTMENT OF MATHEMATICAL SCIENCES  
Baltimore, Maryland
- KANSAS STATE UNIVERSITY, DEPARTMENT OF STATISTICS  
Manhattan, Kansas
- MIAMI UNIVERSITY, DEPARTMENT OF MATHEMATICS  
Oxford, Ohio
- MICHIGAN STATE UNIVERSITY, DEPARTMENT OF STATISTICS AND PROBABILITY  
East Lansing, Michigan
- NATIONAL INSTITUTE FOR THE DEAF, OFFICE FOR PROGRAM ANALYSIS  
Rochester, New York
- NATIONAL SECURITY AGENCY  
Fort George G. Meade, Maryland
- NEW MEXICO STATE UNIVERSITY, DEPARTMENT OF MATHEMATICAL SCIENCES  
Las Cruces, New Mexico
- NORTHWESTERN UNIVERSITY, DEPARTMENT OF MATHEMATICS  
Evanston, Illinois
- OHIO STATE UNIVERSITY, DIVISION OF STATISTICS  
Columbus, Ohio
- OREGON STATE UNIVERSITY, DEPARTMENT OF STATISTICS  
Corvallis, Oregon
- PENNSYLVANIA STATE UNIVERSITY, DEPARTMENT OF STATISTICS  
University Park, Pennsylvania
- PRINCETON UNIVERSITY, DEPARTMENT OF STATISTICS  
Princeton, New Jersey
- PURDUE UNIVERSITY LIBRARIES  
Lafayette, Indiana
- QUEEN'S UNIVERSITY DEPT. OF MATHEMATICS, KINGSTON  
Ontario, Canada
- RICE UNIVERSITY, DEPARTMENT OF MATHEMATICAL SCIENCES  
Houston, Texas
- THE ROCKEFELLER UNIVERSITY  
New York, New York
- SANDIA CORPORATION, SANDIA BASE  
Albuquerque, New Mexico
- SOUTHERN ILLINOIS UNIVERSITY, MATHEMATICAL STUDIES  
Edwardsville, Illinois
- SOUTHERN METHODIST UNIVERSITY, DEPARTMENT OF STATISTICS  
Dallas, Texas
- STANFORD UNIVERSITY, GIRSHICK MEMORIAL LIBRARY  
Stanford, California
- STATE UNIVERSITY OF NEW YORK, BUFFALO, DEPARTMENT OF STATISTICS  
Amherst, New York
- TEMPLE UNIVERSITY, MATHEMATICS DEPARTMENT  
Philadelphia, Pennsylvania
- TEXAS A & M UNIVERSITY, DEPT. OF MATHEMATICS  
College Station, Texas

TEXAS TECH UNIVERSITY, DEPARTMENT OF  
 MATHEMATICS  
 Lubbock, Texas 79409

THE TOBACCO INSTITUTE  
 Washington, D.C.

UNION OIL COMPANY OF CALIFORNIA, UNION  
 RESEARCH CENTER  
 Brea, California

UNITED STATES ARMY RESEARCH AND DE-  
 VELOPMENT CENTER  
 Aberdeen Proving Ground, Maryland

UNIVERSITY OF ALBERTA, DEPARTMENT OF  
 MATHEMATICS  
 Edmonton, Alberta, Canada

UNIVERSITY OF ARIZONA, DEPARTMENT OF  
 MATHEMATICS  
 Tucson, Arizona

UNIVERSITY OF BRITISH COLUMBIA, DE-  
 PARTMENT OF MATHEMATICS  
 Vancouver, B.C., Canada

UNIVERSITY OF CALGARY, MATHEMATICS  
 DEPARTMENT  
 Calgary 44, Alberta, Canada

UNIVERSITY OF CALIFORNIA, BERKELEY,  
 STATISTICAL LABORATORY  
 Berkeley, California

UNIVERSITY OF CINCINNATI, DEPARTMENT  
 OF MATHEMATICAL SCIENCES  
 Cincinnati, Ohio

UNIVERSITY OF GUELPH, MATHEMATICS AND  
 STATISTICS DEPARTMENT  
 Guelph, Ontario, Canada

UNIVERSITY OF ILLINOIS AT CHICAGO  
 CIRCLE, DEPARTMENT OF MATHEMATICS  
 Chicago, Illinois

UNIVERSITY OF ILLINOIS, MATHEMATICS  
 DEPT.  
 Urbana, Illinois

UNIVERSITY OF IOWA, DIVISION OF MATHE-  
 MATICAL SCIENCES  
 Iowa City, Iowa

UNIVERSITY OF MANITOBA, DEPARTMENT  
 OF STATISTICS  
 Winnipeg, Manitoba, Canada

UNIVERSITY OF MARYLAND, DEPARTMENT  
 OF MATHEMATICS  
 College Park, Maryland

UNIVERSITY OF MICHIGAN, DEPARTMENT OF  
 STATISTICS  
 Ann Arbor, Michigan

UNIVERSITY OF MINNESOTA, SCHOOL OF  
 STATISTICS  
 Minneapolis, Minnesota

UNIVERSITY OF MISSOURI, DEPARTMENT OF  
 STATISTICS  
 Columbia, Missouri

UNIVERSITY OF MISSOURI AT ROLLA, DE-  
 PARTMENT OF MATHEMATICS  
 Rolla, Missouri

UNIVERSITY OF MONTREAL, DEPARTMENT  
 OF MATHEMATICS  
 Montreal, Quebec, Canada

UNIVERSITY OF NEW MEXICO, DEPARTMENT  
 OF MATHEMATICS AND STATISTICS  
 Albuquerque, New Mexico

UNIVERSITY OF NORTH CAROLINA, DEPART-  
 MENT OF STATISTICS  
 Chapel Hill, North Carolina

UNIVERSITY OF OREGON, MATHEMATICS DE-  
 PARTMENT  
 Eugene, Oregon

UNIVERSITY OF OTTAWA, DEPARTMENT OF  
 MATHEMATICS  
 Ottawa, Ontario, Canada

UNIVERSITY OF SOUTH CAROLINA, DEPART-  
 MENT OF MATHEMATICS AND COMPUTER  
 SCIENCE  
 Columbia, South Carolina

UNIVERSITY OF TEXAS, DEPARTMENT OF  
 MATHEMATICS  
 Austin, Texas

UNIVERSITY OF UTAH, DEPT. OF MATHEMAT-  
 ICS  
 Salt Lake City, Utah

UNIVERSITY OF VICTORIA, DEPT. OF MATH-  
 EMATICS  
 Victoria, British Columbia, Canada

UNIVERSITY OF WASHINGTON, DEPARTMENT  
 OF MATHEMATICS  
 Seattle, Washington

UNIVERSITY OF WISCONSIN, MADISON, DE-  
 PARTMENT OF STATISTICS  
 Madison, Wisconsin

UNIVERSITY OF WISCONSIN, MILWAUKEE,  
 DEPARTMENT OF MATHEMATICS  
 Milwaukee, Wisconsin

VIRGINIA COMMONWEALTH UNIVERSITY, DE-  
 PARTMENT OF MATHEMATICAL SCIENCES  
 Richmond, Virginia

WAYNE STATE UNIVERSITY, DEPARTMENT  
 OF MATHEMATICS  
 Detroit, Michigan

WEST CHESTER STATE COLLEGE  
 West Chester, Pennsylvania

WESTINGHOUSE ELECTRIC CORPORATION,  
 RESEARCH LABORATORIES  
 Pittsburgh, Pennsylvania

YALE UNIVERSITY, STATISTICS DEPART-  
 MENT  
 New Haven, Connecticut

# THE ANNALS OF STATISTICS

## INSTRUCTIONS FOR AUTHORS

**Submission of Papers.** Papers to be submitted for publication should be sent to the Editor of the *Annals of Statistics*. (For current address, see the latest issue of the *Annals*.) The original (or xerox copy) should be submitted with three additional copies on paper that will take ink corrections. The manuscript will *not* normally be returned to the author; when expressly requested by the author, one copy of the manuscript will be returned.

**Preparation of Manuscripts.** Manuscripts should be typewritten, entirely double-spaced, including references, with wide margins at sides, top and bottom. Dittoed or mimeographed papers are acceptable only if completely legible; xerox copies are preferable. When technical reports are submitted, all extraneous sheets and covers should be removed.

**Submission of Reference Papers.** Copies (preferably two) of unpublished or not easily available papers cited in the manuscript should be submitted with the manuscript.

**Title and Abbreviated Title.** The title should be descriptive and as concise as is feasible, i.e., it should indicate the topic of the paper as clearly as possible, but every word in it should be pertinent. An abbreviated title to be used as a running head is also required, and should be given below the main title. This should normally not exceed 35 characters. For example, a title might be "A Limit Theorem for Conditioned Recurrent Random Walk Attracted to a Stable Law," with the running head "Limit Theorem for Recurrent Random Walk" or possibly "Recurrent Random Walk Attracted to a Stable Law," depending on the emphasis to be conveyed.

**Summary.** Each manuscript is required to contain a summary, which will be printed immediately after the title, clearly separated from the rest of the paper. Its main purpose is to inform the reader quickly of the nature and results of the paper; it may also be used as an aid in retrieving information. The length of a summary will clearly depend on the length and difficulty of the paper, but in general it should not exceed 150 words. It should be typed on a separate page, under the heading "Summary," followed by the title of the paper. Formulas should be used as sparingly as possible. The summary should not make reference to results or formulas in the body of the paper—it should be self-contained.

**Footnotes.** Footnotes should be reduced to a minimum and, where possible, should be replaced by remarks in the text or in the references; formulas in footnotes should be avoided. Footnotes in the text should be identified by superscript numbers and typed together, double-spaced, on a separate page.

**Key Words.** Included as the first footnote on page 1 should be the headings:

American Mathematical Society 1970 subject classifications. Primary—; Secondary—.

Key words and phrases.

The classification numbers representing the primary and secondary subjects of the article may be found with instructions for its use, as an Appendix to *Mathematical Reviews* Index to Volume 39, June 1970. (See, also, *The Notices of the American Mathematical Society*, June 1970, pp. 616–618, for more details.) The key words and phrases should describe the subject matter of the article; generally they should be taken from the body of the paper.

**List of Symbols.** A completely typewritten list of symbols, identified typographically, not mathematically, should be attached to the manuscript on a separate page. Distinguish between "oh" and "zero"; "ell" and "one"; "kappa" and "kay," etc. Indicate also when special type is required (Greek, German, script, boldface, etc.); other letters will be set in italics.

**Figures and Tables.** Figures, charts, and diagrams should be prepared in a form suitable for photographic reproduction and should be professionally drawn twice the size they are to be printed. (These need not be submitted until the paper has been accepted for publication.) Tables should be typed on separate pages with accompanying footnotes immediately below the table.

**Formulas.** Fractions in the text are preferably written with the solidus or negative exponent; thus,  $(a + b)/(c + d)$  is preferred to  $\frac{a + b}{c + d}$ , and

$(2\pi)^{-1}$  or  $1/(2\pi)$  to  $\frac{1}{2\pi}$ . Also,  $a^{b(c)}$  and  $a_{b(c)}$  are preferred to  $a^{bc}$  and  $a_{bc}$ , respectively.

Complicated exponentials should be represented with the symbol exp. A fractional exponent is preferable to a radical sign.

**References.** References should be typed double-spaced and should follow the style:

- [5] Wilks, S. S. (1938). The large-sample distribution of the likelihood ratio for testing composite hypotheses. *Ann. Statist.* 1 60–62.

In textual material, the format "... Wilks (1938) ..." is normally preferred to "... Wilks [5] ..." Multiple references can be distinguished as "... Wilks (1938a) ...". Abbreviations for journals should be taken from *Mathematical Reviews* Index to Volume 40, 1970, pp. 1683–1702.

**Proofs.** Author will ordinarily receive galley proofs. Corrected galley proofs should be sent to the Managing Editor of the *Annals of Statistics*. (For current address, see the latest issue of the *Annals*.)