

THE ANNALS of STATISTICS

ISSN (0090-5364)

AN OFFICIAL JOURNAL OF
THE INSTITUTE OF MATHEMATICAL STATISTICS

The 1984 Wald Memorial Lectures

Boundary crossing probabilities and statistical applications DAVID SIEGMUND 361

Articles

Maximum likelihood estimators and likelihood ratio criteria in multivariate components of variance	BLAIR M. ANDERSON, T. W. ANDERSON, AND INGRAM OLKIN	405
Asymptotic theory for common principal component analysis	BERNARD N. FLURY	418
Confidence sets for a multivariate distribution	R. BERAN AND P. W. MILLAR	431
Improved confidence sets for the coefficients of a linear model with spherically symmetric errors	JIUNN TZON HWANG AND JEESEN CHEN	444
Robust Bayes and empirical Bayes analysis with ϵ -contaminated priors JAMES BERGER AND L. MARK BERLINER		461
Characterization of externally Bayesian pooling operators CHRISTIAN GENEST, KEVIN J. MCCONWAY AND MARK J. SCHERVISH		487
A Bayes procedure for the identification of univariate time series models . . . D. S. POSKITT		502
Large-sample properties of parameter estimates for strongly dependent stationary Gaussian time series	ROBERT FOX AND MURAD S. TAQQU	517
Limit theory for the sample covariance and correlation functions of moving averages	RICHARD DAVIS AND SIDNEY RESNICK	533
Statistical estimation of the parameters of a moving source from array data SHEAN-TSONG CHIU		559
Estimation for a semimartingale regression model using the method of sieves IAN W. MCKEAGUE		579
The dimensionality reduction principle for generalized additive models CHARLES J. STONE		590
Time sequential estimation of the exponential mean under random withdrawals JOSEPH C. GARDINER, V. SUSARLA AND JOHN VAN RYZIN		607
Empirical processes associated with V -statistics and a class of estimators under random censoring	MICHAEL G. AKRITAS	619
Conditional empirical processes	WINFRIED STUTE	638
Large deviations of estimators	A. D. M. KESTER AND W. C. M. KALLENBERG	648
The statistical information contained in additional observations	ENNO MAMMEN	665
An approach to upper bound problems for risks of generalized least squares estimators	YASUYUKI TOYOOKA AND TAKEAKI KARIYA	679
Intergroup diversity and concordance for ranking data: An approach via metrics for permutations	PAUL D. FEIGIN AND MAYER ALVO	691
Testing for normality in arbitrary dimension	SÁNDOR CSÖRGÓ	708
Minimax variance M -estimators of location in Kolmogorov neighbourhoods DOUG WIENS		724
On optimal decision rules for signs of parameters YOSEF HOCHBERG AND MARC E. POSNER		733
Orthogonality of factorial effects	CHAND K. CHAUHAN AND A. M. DEAN	743
Short Communications		
An Efron–Stein inequality for nonsymmetric statistics	J. MICHAEL STEELE	753
Chi-square goodness-of-fit tests for randomly censored data M. G. HABIB AND D. R. THOMAS		759
Some asymptotic properties of kernel estimators of a density function in case of censored data	JAN MIELNICZUK	766
A large deviation result for signed linear rank statistics under the symmetry hypothesis	TIEE-JIAN WU	774

Vol. 14, No. 2—June 1986



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 AND EDITORS

President:

Paul Meier, Department of Statistics, University of Chicago, 5734 University Avenue, Chicago, Illinois 60637

President-Elect:

Ronald Pyke, Department of Mathematics GN-50, University of Washington, Seattle, Washington 98195

Past President:

Oscar Kempthorne, Department of Statistics, 111B Snedecor Hall, Iowa State University, Ames, Iowa 50011

Executive Secretary:

Francisco J. Samaniego, Division of Statistics, 469 Kerr Hall, University of California, Davis, California 95616

Treasurer:

Nicholas P. Jewell, Group in Biostatistics, University of California, Berkeley. *Please send correspondence to:* IMS Business Office, 3401 Investment Boulevard #7, Hayward, California 94545

Program Secretary:

Richard A. Johnson, Department of Statistics, University of Wisconsin, 1210 West Dayton Street, Madison, Wisconsin 53706

Editor: *The Annals of Statistics*

Willem R. van Zwet, Department of Mathematics, University of Leiden, P.O. Box 9512, 2300 RA Leiden, The Netherlands

Editor: *The Annals of Probability*

Thomas M. Liggett, Department of Mathematics, University of California, Los Angeles, California 90024

Executive Editor: *Statistical Science*

Morris H. DeGroot, Department of Statistics, Carnegie-Mellon University, Pittsburgh, Pennsylvania 15213

Editor: *The IMS Bulletin*

William C. Guenther, Department of Statistics, University of Wyoming, Laramie. *Please send correspondence to:* Box 3332 University Station, Laramie, Wyoming 82071

Editor: *The IMS Lecture Notes—Monograph Series*

Shanti S. Gupta, Department of Statistics, Purdue University, West Lafayette, Indiana 47907

Managing Editor:

Paul Shaman, Department of Statistics, University of Pennsylvania, Philadelphia, Pennsylvania 19104

Journals. The scientific journals of the Institute are *The Annals of Statistics*, *The Annals of Probability*, and *Statistical Science*. The news organ of the Institute is *The Institute of Mathematical Statistics Bulletin*.

Individual, Institutional, and Corporate Memberships. All *individual members* receive *Statistical Science* and *The IMS Bulletin* for a basic annual dues rate of \$30. Individual members may elect to receive one *Annals* for an additional \$10 or both *Annals* for an additional \$20. Dues allocations to each journal are set by Council resolution. Of the total dues paid, \$8 is allocated to *The IMS Bulletin* and the remaining amount is allocated equally among the scientific journals received. Memberships are available at a reduced rate (40% of regular rates) for full-time students, permanent residents of developing countries, and retired members. Retired members may also elect to receive the *Bulletin* only for \$10. *Institutional memberships* are available to nonprofit organizations at \$225 per year and *corporate memberships* are available to other organizations at \$500 per year. Institutional and corporate memberships include two multiple-readership copies of all IMS journals in addition to other benefits specified for each category (details available from the IMS Business Office).

Individual and General Subscriptions. Subscriptions are available on a calendar-year basis. For 1986, all subscriptions to one or both *Annals* automatically include one subscription to *Statistical Science*. *Individual subscriptions* are for the personal use of the subscriber and must be in the name of, paid directly by, and mailed to an individual. Individual subscriptions for 1986 are available to both *Annals* and *Statistical Science* (\$79), one *Annals* and *Statistical Science* (\$52), *Statistical Science* only (\$25), and *The IMS Bulletin* (\$15). *General subscriptions* are for libraries, institutions, and any multiple-readership use. General subscriptions for 1986 are available to both *Annals* and *Statistical Science* (\$155), *The Annals of Statistics* and *Statistical Science* (\$85), *The Annals of Probability* and *Statistical Science* (\$80), *Statistical Science* only (\$40), and *The IMS Bulletin* (\$20). Air mail rates for overseas delivery of general subscriptions are \$40 per title.

Correspondence. Mail to IMS should be sent to the IMS Business Office (membership, subscriptions, claims, copyright permissions, advertising, back issues), the Editor of the appropriate journal (submissions, editorial content), or the Managing Editor (production).

The Annals of Statistics (ISSN 0090-5364), Volume 14, Number 2, June 1986. Published in March, June, September, and December by the Institute of Mathematical Statistics, 3401 Investment Boulevard #7, Hayward, California 94545. Second-class postage paid at Hayward, California and at additional mailing offices. **Postmaster:** Send address changes to *The Annals of Statistics*, Institute of Mathematical Statistics, 3401 Investment Boulevard #7, Hayward, California 94545.

EDITORIAL STAFF

EDITOR

WILLEM R. VAN ZWET

ASSOCIATE EDITORS

JAMES O. BERGER
PETER J. BICKEL
LAWRENCE D. BROWN
RAYMOND J. CARROLL
CHING-SHUI CHENG
DENNIS D. COX
MORRIS L. EATON

DAVID F. FINDLEY
RICHARD D. GILL
PIET GROENEBOOM
PETER HALL
R. Z. HASMINSKII
NIELS KEIDING
STEFFEN L. LAURITZEN

BRUCE G. LINDSAY
DAVID POLLARD
DAVID O. SIEGMUND
A. F. M. SMITH
TERRY SPEED
JON A. WELLNER
MICHAEL WOODROOFE

EDITORIAL ASSISTANT
LUCIE W. VAN ZWET

MANAGING EDITOR
PAUL SHAMAN

EDITORIAL ASSISTANT
TAMMY MORROW

PAST EDITORS

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

THE ANNALS OF STATISTICS

INGRAM OLKIN, 1972–1973
I. R. SAVAGE, 1974–1976
RUPERT G. MILLER, JR., 1977–1979
DAVID V. HINKLEY, 1980–1982
MICHAEL D. PERLMAN, 1983–1985

THE ANNALS OF PROBABILITY

RONALD PYKE, 1972–1975
PATRICK BILLINGSLEY, 1976–1978
R. M. DUDLEY, 1979–1981
HARRY KESTEN, 1982–1984

EDITORIAL POLICY

The main purpose of *The Annals of Statistics* and *The Annals of Probability* is to publish significant contributions to the theory of statistics and probability and their applications. The emphasis is on importance and interest; formal novelty and mathematical correctness alone are not sufficient for publication. Especially appropriate are authoritative expository papers and surveys of areas in vigorous development. Because statistics is an evolving discipline, the Editors of *The Annals of Statistics* take a broad view of its domain and welcome papers in interface areas. Contributors to *The Annals of Statistics* should review the editorial in the January 1980 issue. All papers are refereed.

NOTICE

Manuscripts submitted for *The Annals of Statistics* should be sent to the Editor at the following address:

Willem R. van Zwet
Department of Mathematics
University of Leiden
P. O. Box 9512
2300 RA Leiden
The Netherlands

IMS CORPORATE MEMBERS

THE AEROSPACE CORPORATION
Los Angeles, California

AT & T BELL LABORATORIES
Murray Hill, New Jersey

BELL COMMUNICATIONS RESEARCH
Morristown, New Jersey

GENERAL MOTORS CORPORATION
Research Laboratories
Warren, Michigan

INTERNATIONAL BUSINESS MACHINES CORP
Thomas J. Watson Research Center
Yorktown Heights, New York

SPRINGER-VERLAG NEW YORK INCORPORATED
New York, New York

UNION OIL COMPANY OF CALIFORNIA
Brea, California

IMS INSTITUTIONAL MEMBERS

ARIZONA STATE UNIVERSITY
Dept of Mathematics
Tempe, Arizona

AUSTRALIAN NATIONAL UNIVERSITY
Canberra, ACT, Australia

BOWLING GREEN STATE UNIVERSITY
Dept of Mathematics and Statistics
Bowling Green, Ohio

**CALIFORNIA STATE UNIVERSITY
AT FULLERTON**
Depts of Math and Management Science
Fullerton, California

CASE WESTERN RESERVE UNIVERSITY
Dept of Mathematics and Statistics
Cleveland, Ohio

CENTERS FOR DISEASE CONTROL
Atlanta, Georgia

CORNELL UNIVERSITY
Dept of Mathematics
Ithaca, New York

FLORIDA STATE UNIVERSITY
Dept of Statistics
Tallahassee, Florida

GEORGE WASHINGTON UNIVERSITY
Dept of Statistics
Washington, DC

INDIANA UNIVERSITY
Dept of Mathematics
Bloomington, Indiana

IOWA STATE UNIVERSITY
Dept of Stat and Statistical Lab
Ames, Iowa

JOHNS HOPKINS UNIVERSITY
Dept of Biostatistics
Baltimore, Maryland

KANSAS STATE UNIVERSITY
Dept of Statistics
Manhattan, Kansas

MARA INSTITUTE OF TECHNOLOGY
Selangor, West Malaysia

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Dept of Mathematics
Cambridge, Massachusetts

MIAMI UNIVERSITY
Dept of Mathematics and Statistics
Oxford, Ohio

MICHIGAN STATE UNIVERSITY
Dept of Statistics and Probability
East Lansing, Michigan

NATIONAL SECURITY AGENCY
Fort George G. Mead, Maryland

NEW MEXICO STATE UNIVERSITY
Dept of Mathematical Sciences
Las Cruces, New Mexico

NORTH CAROLINA STATE UNIVERSITY
Dept of Statistics
Raleigh, North Carolina

NORTHERN ILLINOIS UNIVERSITY
Dept of Mathematical Sciences
DeKalb, Illinois

NORTHWESTERN UNIVERSITY
Dept of Mathematics
Evanston, Illinois

OHIO STATE UNIVERSITY
Dept of Statistics
Columbus, Ohio

OREGON STATE UNIVERSITY
Dept of Statistics
Corvallis, Oregon

PENNSYLVANIA STATE UNIVERSITY
Dept of Statistics
University Park, Pennsylvania

PRINCETON UNIVERSITY LIBRARY
Princeton, New Jersey

PURDUE UNIVERSITY LIBRARY
West Lafayette, Indiana

QUEEN'S UNIVERSITY
Dept of Mathematics and Statistics
Kingston, Ontario, Canada

RICE UNIVERSITY
Dept of Mathematical Sciences
Houston, Texas

THE ROCKEFELLER UNIVERSITY LIBRARY
New York, New York

SIMON FRASER UNIVERSITY
Dept of Mathematics and Statistics
Burnaby, British Columbia, Canada

SOUTHERN ILLINOIS UNIVERSITY
Dept of Math, Stat, and Comp Sci
Edwardsville, Illinois

SOUTHERN METHODIST UNIVERSITY
Dept of Statistics
Dallas, Texas

STANFORD UNIVERSITY
Dept of Statistics
Stanford, California

TEMPLE UNIVERSITY
Dept of Mathematics
Philadelphia, Pennsylvania

TEXAS TECH UNIVERSITY
Dept of Mathematics
Lubbock, Texas

UNIVERSITY OF ARIZONA
Dept of Mathematics
Tucson, Arizona

UNIVERSITY OF BRITISH COLUMBIA
Dept of Statistics
Vancouver, British Columbia, Canada

UNIVERSITY OF CALGARY
Division of Statistics
Calgary, Alberta, Canada

UNIVERSITY OF CALIFORNIA
Dept of Statistics
Berkeley, California

UNIVERSITY OF CALIFORNIA
Division of Statistics
Davis, California

UNIVERSITY OF GUELPH
Dept of Mathematics and Statistics
Guelph, Ontario, Canada

UNIVERSITY OF ILLINOIS
Department of Statistics
Urbana, Illinois

UNIVERSITY OF ILLINOIS AT CHICAGO
Dept of Math, Stat, and Comp Sci
Chicago, Illinois

UNIVERSITY OF IOWA
Dept of Statistics and Actuarial Sci
Iowa City, Iowa

UNIVERSITY OF MANITOBA
Dept of Statistics
Winnipeg, Manitoba, Canada

UNIVERSITY OF MARYLAND
Dept of Mathematics
College Park, Maryland

UNIVERSITY OF MASSACHUSETTS
Dept of Mathematics and Statistics
Amherst, Massachusetts

UNIVERSITY OF MICHIGAN
Dept of Statistics
Ann Arbor, Michigan

UNIVERSITY OF MINNESOTA
School of Statistics
Minneapolis, Minnesota

UNIVERSITY OF MISSOURI AT COLUMBIA
Dept of Statistics
Columbia, Missouri

UNIVERSITY OF MONTREAL
Dept of Mathematics
Montreal, Quebec, Canada

UNIVERSITY OF NEBRASKA
Dept of Mathematics and Statistics
Lincoln, Nebraska

UNIVERSITY OF NEW MEXICO
Dept of Mathematics and Statistics
Albuquerque, New Mexico

UNIVERSITY OF NORTH CAROLINA
Dept of Statistics
Chapel Hill, North Carolina

UNIVERSITY OF OREGON
Dept of Mathematics
Eugene, Oregon

UNIVERSITY OF OTTAWA
Dept of Mathematics
Ottawa, Ontario, Canada

UNIVERSITY OF SOUTH CAROLINA
Dept of Statistics
Columbia, South Carolina

UNIVERSITY OF STOCKHOLM
Inst of Actuarial Math and Math Stat
Stockholm, Sweden

UNIVERSITY OF TEXAS AT AUSTIN
Dept of Mathematics
Austin, Texas

UNIVERSITY OF TEXAS AT SAN ANTONIO
Div of Math, Comp Sci, and Systems Design
San Antonio, Texas

UNIVERSITY OF VICTORIA
Dept of Mathematics
Victoria, British Columbia, Canada

UNIVERSITY OF VIRGINIA
Dept of Mathematics
Charlottesville, Virginia

UNIVERSITY OF WASHINGTON
Depts of Statistics and Mathematics
Seattle, Washington

UNIVERSITY OF WATERLOO
Dept of Statistics and Actuarial Sci
Waterloo, Ontario, Canada

UNIVERSITY OF WISCONSIN AT MILWAUKEE
Dept of Mathematical Sciences
Milwaukee, Wisconsin

VIRGINIA COMMONWEALTH UNIVERSITY
Dept of Mathematical Sciences
Richmond, Virginia

**VIRGINIA POLYTECHNIC INSTITUTE
AND STATE UNIVERSITY**
Dept of Statistics
Blacksburg, Virginia

WAYNE STATE UNIVERSITY
Dept of Mathematics
Detroit, Michigan

YORK UNIVERSITY
Dept of Mathematics
Downsview, Ontario, Canada

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*.) **Four copies** should be submitted 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. All manuscripts should be accompanied by a cover letter.

Preparation of Manuscripts. Manuscripts should be typewritten, entirely double-spaced, including references, with wide margins at sides, top and bottom. All copies must be completely legible. When technical reports are submitted, all extraneous sheets and covers must be removed. Typists should check an issue of the *Annals* for style.

Submission of Reference Papers. Four copies of unpublished or not easily available papers cited in the manuscript should be submitted with the manuscript.

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.

Abbreviated Title. An abbreviated title to be used as a running head is also **required**. This should normally not exceed 35 characters. For example, an article with the title "The Curvature of a Statistical Model, with Applications to Large-Sample Likelihood Methods," could have the running head, "Curvature of Statistical Model" or possibly "Asymptotics of Likelihood Methods," depending on the emphasis to be conveyed.

Affiliation. Indicate your present institutional affiliation as you would like it to appear.

Summary. Each manuscript is required to contain a summary, clearly separated from the rest of the paper, which will be printed immediately after the title. 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. Formulas should be used as sparingly as possible within the summary. The summary should not make reference to results or formulas in the body of the paper—it should be self-contained.

Footnotes. Footnotes should not be used, except as described under Title Page Footnotes below. Such information should be included within the text.

Title Page Footnotes. Included as a footnote on page 1 should be the headings:

American Mathematical Society 1980 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 in the *Mathematical Reviews Annual Subject Index-1980*. The key words and phrases should describe the subject matter of the article; generally they should be taken from the body of the paper.

Acknowledgment of support. Grants and contracts should also be included in this footnote.

Identification of Symbols. Manuscripts for publication should be clearly prepared to insure that all symbols are properly identified. Distinguish between "oh" and "zero"; "ell" and "one"; "epsilon" and "element of"; "summation" and "capital sigma," etc. Indicate also when special type is required (Greek, German, script, boldface, etc.); unless indicated otherwise, formula letters will be set in italics. Acronyms should be introduced sparingly. Any handwritten symbols should be clearly identified.

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.) The printer does not improve upon the quality of the figures submitted. 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^{b^c} and a_{b^c} , 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:

Keifer, J. C. (1976). Admissibility of conditional confidence procedures. *Ann. Statist.* 4 836–865.

In textual material, the format "... Keifer (1976)..." should be used. Multiple references can be distinguished as "... Keifer (1976a)..." Abbreviations for journals should be taken from a current index issue of *Mathematical Reviews*.

Addresses. The permanent address of each author should be typed following the references.

Galley Proofs. The author will ordinarily receive galley proofs. Corrected galley proofs should be sent to AOS Redactory, Science Typographers, Inc., 15 Industrial Boulevard, Medford, NY 11763.

Correspondence. All correspondence with the Editor must refer to the manuscript number of the paper. This number will be on the card sent to the author acknowledging receipt of the article.