THE ANNALS

of APPLIED PROBABILITY

AN OFFICIAL JOURNAL OF THE INSTITUTE OF MATHEMATICAL STATISTICS

	• _	1	_	_

The Russian option: reduced regret LARRY SHEPP AND A. N. SHIRYAEV	631
Arbitrage pricing of Russian options and perpetual lookback options	
J. Darrell Duffie and J. Michael Harrison	641
Hedging contingent claims with constrained portfolios	
Jakša Cvitanić and Ioannis Karatzas	652
Parallel and tandem fluid networks with dependent Lévy inputs Offer Kella	682
Comparison theorems for reversible Markov chains	
Persi Diaconis and Laurent Saloff-Coste	696
The asymptotic probability of a tie for first place	
Bennett Eisenberg, Gilbert Stengle and Gilbert Strang	731
First passage percolation for random colorings of \mathbb{Z}^d	
Luiz Fontes and Charles M. Newman	746
On ladder height distributions of general risk processes	
Masakiyo Miyazawa and Volker Schmidt	763
Backward-forward stochastic differential equations Fabio Antonelli	777
A matching problem and subadditive Euclidean functionals WANSOO T. RHEE	794
A selection-replacement process on the circle	
E. G. COFFMAN, Jr., E. N. GILBERT AND P. W. SHOR	802
Rates of convergence for data augmentation on finite sample spaces	
Jeffrey S. Rosenthal	819
A limit theorem for functionals of jumps of birth and death processes	
under heavy traffic condition KEIGO YAMADA AND SUNG JO HONG	840
The equivalence of the Cox process with squared radial Ornstein-Uhlenbeck	
intensity and the death process in a simple population model	
Peter Clifford and Gang Wei	863
Asymptotic properties of centered systematic sampling for predicting	
integrals of spatial processes MICHAEL L. STEIN	874
Queues in series in light traffic B. BLASZCZYSZYN AND T. ROLSKI	881
Accelerating Gaussian diffusions	
CHII-RUEY HWANG, SHU-YIN HWANG-MA AND SHUENN-JYI SHEU	897
Importance sampling for Gibbs random fields	
Paolo Baldi, Arnoldo Frigessi and Mauro Piccioni	914

Vol. 3, No. 3—August 1993

INSTITUTE OF MATHEMATICAL STATISTICS

(Organized September 12, 1935)

The purpose of the Institute is to foster the development and dissemination of the theory and applications of statistics and probability.

OFFICERS AND EDITORS

President: Lawrence D. Brown, Department of Mathematics, White Hall, Cornell University, Ithaca, New York 14853-7901

President-Elect: Stephen M. Stigler, Department of Statistics, University of Chicago, 5734 University

Avenue, Chicago, Illinois 60637

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

Executive Secretary: Diane M. Lambert, AT & T Bell Laboratories, 600 Mountain Avenue, Room 2C-256, Murray Hill, New Jersey 07974

Treasurer: Jessica Utts, Division of Statistics, University of California, Davis. Please send correspondence to: IMS Business Office, 3401 Investment Boulevard #7, Hayward, California 94545

Program Secretary: Iain M. Johnstone, Division of Biostatistics, HRP Building, Room 10, Stanford University, Stanford, California 94305-5092

Editor, The Annals of Statistics: Michael Woodroofe, Department of Statistics, Mason Hall, University of

Michigan, Ann Arbor, Michigan 48109-1027

Editor, The Annals of Probability: Burgess Davis, Departments of Mathematics and Statistics, Purdue University, West Lafayette, Indiana 47907

Editor, The Annals of Applied Probability: J. Michael Steele, Institute for Mathematics and Its Applications, University of Minnesota, 514 Vincent Hall, 206 Church Street S. E., Minneapolis, Minnesota 55455-0436

Minnesota 55455-0436
 Executive Editor, Statistical Science: Robert E. Kass, Department of Statistics, Carnegie Mellon University, Pittsburgh, Pennsylvania 15213
 Editor, The IMS Bulletin: Susan R. Wilson, Centre for Mathematics and Its Applications, Australian National University, GPO Box 4, Canberra ACT 2601, Australia
 Editor, The IMS Lecture Notes—Monograph Series: Robert J. Serfling, Department of Mathematical Sciences, Johns Hopkins University, Baltimore, Maryland 21218
 Managing Editor: John R. Collins, Department of Mathematics and Statistics, University of Calgary, 2500 University Drive NW, Calgary, Alberta, Canada T2N 1N4
 Managing Editor: Robert Smythe, Department of Statistics, George Washington University, 2201 G Street N.W., Washington, D.C. 20052

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

Individual and Organizational Memberships. All individual members pay basic membership dues of \$50. Each regular member must elect to receive at least one scientific journal for an additional amount, as follows: The Annals of Applied Probability (\$10), The Annals of Probability (\$20), The Annals of Statistics (\$20), or Statistical Science (\$10). Of the total due dues paid, \$24 is allocated to The IMS Bulletin and the remaining amount is allocated equally among the scientific journal(s) received. Reduced membership dues are available to full-time students, permanent residents of countries designated by the IMS Council and retired members. Retired members may elect to receive the Bulletin only for \$20. Organizational memberships are available to nonprofit organizations at \$425 per year and to for-profit organizations at \$700 per year. Organizational 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. 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 1993 are available to The Annals of Applied Probability (\$70), The Annals of Probability (\$80), The Annals of Statistics (\$80), The IMS Bulletin (\$45) and Statistical Science (\$70). General subscriptions are for libraries, institutions and any multiple-readership use. General subscriptions for 1993 are available to the *The Annals of Applied Probability* (\$70), *The Annals of Probability* (\$130). *The Annals of Statistics* (\$130), *The IMS Bulletin* (\$50) and *Statistical Science* (\$75). Air mail rates for delivery outside North America are \$80 per title (excluding the *The IMS* Bulletin).

Correspondence. Mail to IMS should be sent to the IMS Business Office (membership, subscriptions, claims, copyright permissions, advertising, back issues), and Editor of the appropriate journal (submissions, editorial content) or the Production Editor, Patrick Kelly, Department of Statistics, University of Pennsylvania, Philadelphia, Pennsylvania 19104-6302.

The Annals of Applied Probability (ISSN 1050-5164), Volume 3, Number 3, August, 1993. Published quarterly 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 Applied Probability, Institute of Mathematical Statistics, 3401 Investment Boulevard #7, Hayward, California 94545.

EDITORIAL STAFF

EDITOR
J. MICHAEL STEELE
ASSOCIATE EDITORS

DAVID ALDOUS VENKAT ANANTHARAM J. DARRELL DUFFIE STEWART N. ETHIER CHARLES M. GOLDIE J. MICHAEL HARRISON PETER JAGERS IOANNIS KARATZAS ANDREW W. LO James McKenna Robin A. Pemantle Michael J. Phelan Sidney I. Resnick Joel Spencer Lawrence M. Wein Walter Willinger Wojbor A. Woyczynski

EDITORIAL ASSISTANT RUTH STOOLMAN

Managing Editor Robert Smythe

PRODUCTION EDITOR
PATRICK KELLY

EDITORIAL POLICY

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

NOTICE

Manuscripts submitted for publication in *The Annals of Applied Probability* should be sent to the Editor at the following address:

J. Michael Steele Institute for Mathematics and Its Applications University of Minnesota 514 Vincent Hall 206 Church Street, S.E. Minneapolis, Minnesota 55455-0436

IMS CORPORATE MEMBERS

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

IMS INSTITUTIONAL MEMBERS

ACADEMIA SINICA Inst of Statistical Science Taipei, Taiwan

AMERICAN UNIVERSITY Dept of Mathematics and Statistics Washington, DC

ARIZONA STATE UNIVERSITY Committee on Statistics Dept of Mathematics and Dept of Decision and Information Systems 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 Dept of Mathematics Fullerton, California

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

CHINESE UNIVERSITY OF HONG KONG Statistical Unit Shatin, Hong Kong

CORNELL UNIVERSITY Dept of Mathematics Ithaca, New York

DALHOUSIE UNIVERSITY Killam Memorial Library Halifax, Nova Scotia, Canada

FLORIDA STATE UNIVERSITY Dept of Statistics Tallahassee, Florida

GEORGE WASHINGTON UNIVERSITY Dept of Statistics Washington, DC

HARVARD UNIVERSITY Cabot Science Library Cambridge, Massachusetts

HARVARD UNIVERSITY Dept of Biostatistics Boston, Massachusetts

HARVARD UNIVERSITY Dept of Statistics Cambridge, Massachusetts

INDIANA UNIVERSITY Dept of Mathematics Bloomington, Indiana

INSTITUTE FOR DEFENSE ANALYSIS Cent for Communications Research La Jolla, California

INSTITUTO MEXICANO DEL PETROLEO Mexico, DF, Mexico IOWA STATE UNIVERSITY Dept of Stat and Statistical Lab Ames. Iowa

JOHNS HOPKINS UNIVERSITY Depts of Biostatistics and Mathematical Sciences Baltimore, Maryland

KANSAS STATE UNIVERSITY Dept of Statistics Manhattan, Kansas

MARA INSTITUTE OF TECHNOLOGY Selangor, Malaysia

MASSACHUSETTS INSTITUTE OF TECHNOLOGY Dept of Mathematics Cambridge, Massachusetts

McGill University Dept of Mathematics and Statistics Montreal, Quebec, Canada

MIAMI UNIVERSITY LIBRARY Oxford, Ohio

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

NATIONAL SECURITY AGENCY Fort George G. Meade, Maryland

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

NORTH CAROLINA STATE UNIVERSITY Dept of Statistics Raleigh, North Carolina

NORTH DAKOTA STATE UNIVERSITY LIBRARY Fargo, North Dakota

NORTHERN ILLINOIS UNIVERSITY Div of Statistics DeKalb, 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 LIBRARY Houston, Texas

THE ROCKEFELLER UNIVERSITY LIBRARY New York, New York

SCOTT AIR FORCE BASE Air Weather Service Technical Library Scott AFB, Illinois

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

STANFORD UNIVERSITY Dept of Statistics Stanford, California

SYRACUSE UNIVERSITY Dept of Mathematics Syracuse, New York

TECHNISCHE UNIVERSITÄT Inst für Math Stochastik Braunschweig, Germany

TEMPLE UNIVERSITY
Dept of Mathematics
Philadelphia, Pennsylvania

TEXAS TECH UNIVERSITY Dept of Mathematics Lubbock, Texas

UNIVERSITY OF ALBERTA
Dept of Statistics
and Applied Probability
Edmonton, Alberta, Canada

University of Arizona Dept of Mathematics Tucson, Arizona

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

UNIVERSITY OF CALGARY Dept of Mathematics and Statistics Calgary, Alberta, Canada

UNIVERSITY OF CALIFORNIA Dept of Statistics Berkeley, California

UNIVERSITY OF CALIFORNIA Div of Statistics Davis, California

UNIVERSITY OF CALIFORNIA Main Library Irvine, California

UNIVERSITY OF CONNECTICUT Dept of Statistics Storrs, Connecticut

University of Florida Dept of Statistics Gainesville, Florida

University of Georgia Dept of Statistics Athens, Georgia

University of Illinois Dept of Statistics Champaign, 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 MARYLAND Dept of Mathematics College Park, Maryland UNIVERSITY OF MASSACHUSETTS Dept of Mathematics and Statistics Amherst, Massachusetts

UNIVERSITY OF MINNESOTA School of Statistics Minneapolis, Minnesota

University of Missouri Ellis Library Columbia, Missouri

UNIVERSITY OF MONTREAL Dept of Mathematics Montreal, Quebec, Canada

UNIVERSITY OF NEBRASKA Dept of Mathematics and Statistics Lincoln, Nebraska

UNIVERSITY OF NEW BRUNSWICK LIBRARY Fredericton, New Brunswick, Canada

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 PENNSYLVANIA Dept of Statistics Philadelphia, Pennsylvania

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 VICTORIA Dept of Mathematics Victoria, British Columbia, Canada

UNIVERSITY OF VIRGINIA Dept of Mathematics Charlottesville, Virginia

University of Washington Dept of Statistics Seattle, Washington

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

VIRGINIA COMMONWEALTH UNIVERSITY Dept of Mathematical Sciences Richmond, Virginia

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

WAKE FOREST UNIVERSITY Z. Smith Reynolds Library Winston-Salem, North Carolina

WAYNE STATE UNIVERSITY Dept of Mathematics Detroit, Michigan

YORK UNIVERSITY Dept of Mathematics Downsview, Ontario, Canada

THE ANNALS OF APPLIED PROBABILITY

INSTRUCTIONS FOR AUTHORS

Submission of Papers. Papers to be submitted for publication should be sent to the Editor of *The Annals of Applied Probability*. (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.

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. Two 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 "A Limit Theorem for Conditioned Recurrent Random Walk Attracted to a Stable Law" could have 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.

Affiliation. Indicate your present institutional affiliation as you would like it to appear. List your permanent mailing address after the references.

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 1991 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*-1991. 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 hand-written 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 $\dfrac{a+b}{c+d},$ 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:

Révész, P. (1982). On the increments of Wiener and related processes. *Ann. Probab.* 10 613-622.

In textual material, the format "... Révész (1982)..." should be used. Multiple references can be distinguished as "... Révész (1982a)...". 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.

Copyright, Page Charges and Offprints. Page charges are \$45 per printed page. Payment of some or all of the estimated page charges associated with articles is strongly encouraged. The editorial review of articles and administration of page charges are completely separate activities. Manuscripts are reviewed and accepted prior to determining whether page charges will be paid.

Corresponding authors receive 25 gratis offprints. Offprints of discussion articles include the main article(s), discussion(s) and rejoinder(s) as a package. Corresponding authors of main articles receive 25 gratis offprints; corresponding discussants receive 10 gratis offprints. Additional offprints may be purchased by using the IMS Offprint Purchase Order Form accompanying the galleys.

Copyright transfer, page charges and offprints are the responsibility of the IMS Business Manager.

Galley Proofs. The author will ordinarily receive galley proofs. Corrected galley proofs should be sent to: AAP Redactory, Technical Typesetting Inc., 1510 Caton Center Drive, Suite E, Baltimore, MD 21227.