



**Statistical Inference**  
Second Edition  
**George Casella**  
**Roger L. Berger**

DUXBURY ADVANCED SERIES

---

## Contents

---

|   |           |
|---|-----------|
| <b>1 Probability Theory</b>                         | <b>1</b>  |
| 1.1 Set Theory                                      | 1         |
| 1.2 Basics of Probability Theory                    | 5         |
| 1.2.1 Axiomatic Foundations                         | 5         |
| 1.2.2 The Calculus of Probabilities                 | 9         |
| 1.2.3 Counting                                      | 13        |
| 1.2.4 Enumerating Outcomes                          | 16        |
| 1.3 Conditional Probability and Independence        | 20        |
| 1.4 Random Variables                                | 27        |
| 1.5 Distribution Functions                          | 29        |
| 1.6 Density and Mass Functions                      | 34        |
| 1.7 Exercises                                       | 37        |
| 1.8 Miscellanea                                     | 44        |
| <br>  |           |
| <b>2 Transformations and Expectations</b>           | <b>47</b> |
| 2.1 Distributions of Functions of a Random Variable | 47        |
| 2.2 Expected Values                                 | 55        |
| 2.3 Moments and Moment Generating Functions         | 59        |
| 2.4 Differentiating Under an Integral Sign          | 68        |
| 2.5 Exercises                                       | 76        |
| 2.6 Miscellanea                                     | 82        |
| <br>  |           |
| <b>3 Common Families of Distributions</b>           | <b>85</b> |
| 3.1 Introduction                                    | 85        |
| 3.2 Discrete Distributions                          | 85        |
| 3.3 Continuous Distributions                        | 98        |
| 3.4 Exponential Families                            | 111       |
| 3.5 Location and Scale Families                     | 116       |

CONTENTS

xiv

- 3.6 Inequalities and Identities
  - 3.6.1 Probability Inequalities
  - 3.6.2 Identities
- 3.7 Exercises
- 3.8 Miscellanea

**4 Multiple Random Variables**

- 4.1 Joint and Marginal Distributions
- 4.2 Conditional Distributions and Independence
- 4.3 Bivariate Transformations
- 4.4 Hierarchical Models and Mixture Distributions
- 4.5 Covariance and Correlation
- 4.6 Multivariate Distributions
- 4.7 Inequalities
  - 4.7.1 Numerical Inequalities
  - 4.7.2 Functional Inequalities
- 4.8 Exercises
- 4.9 Miscellanea

**5 Properties of a Random Sample**

- 5.1 Basic Concepts of Random Samples
- 5.2 Sums of Random Variables from a Random Sample
- 5.3 Sampling from the Normal Distribution
  - 5.3.1 Properties of the Sample Mean and Variance
  - 5.3.2 The Derived Distributions: Student's  $t$  and Snedecor's  $F$
- 5.4 Order Statistics
- 5.5 Convergence Concepts
  - 5.5.1 Convergence in Probability
  - 5.5.2 Almost Sure Convergence
  - 5.5.3 Convergence in Distribution
  - 5.5.4 The Delta Method
- 5.6 Generating a Random Sample
  - 5.6.1 Direct Methods
  - 5.6.2 Indirect Methods
  - 5.6.3 The Accept/Reject Algorithm
- 5.7 Exercises
- 5.8 Miscellanea

**6 Principles of Data Reduction**

- 6.1 Introduction
- 6.2 The Sufficiency Principle
  - 6.2.1 Sufficient Statistics
  - 6.2.2 Minimal Sufficient Statistics
  - 6.2.3 Ancillary Statistics
  - 6.2.4 Sufficient, Ancillary, and Complete Statistics

## CONTENTS

xv

|       |  |     |
|-------|--|-----|
| 6.3   | The Likelihood Principle                                 | 290 |
| 6.3.1 | The Likelihood Function                                  | 290 |
| 6.3.2 | The Formal Likelihood Principle                          | 292 |
| 6.4   | The Equivariance Principle                               | 296 |
| 6.5   | Exercises  | 300 |
| 6.6   | Miscellanea  | 307 |
| 7     | Point Estimation   | 311 |
| 7.1   | Introduction   | 311 |
| 7.2   | Methods of Finding Estimators                            | 312 |
| 7.2.1 | Method of Moments  | 312 |
| 7.2.2 | Maximum Likelihood Estimators                            | 315 |
| 7.2.3 | Bayes Estimators   | 324 |
| 7.2.4 | The EM Algorithm   | 326 |
| 7.3   | Methods of Evaluating Estimators                         | 330 |
| 7.3.1 | Mean Squared Error                                       | 330 |
| 7.3.2 | Best Unbiased Estimators                                 | 334 |
| 7.3.3 | Sufficiency and Unbiasedness                             | 342 |
| 7.3.4 | Loss Function Optimality                                 | 348 |
| 7.4   | Exercises  | 355 |
| 7.5   | Miscellanea  | 367 |
| 8     | Hypothesis Testing                                       | 373 |
| 8.1   | Introduction   | 373 |
| 8.2   | Methods of Finding Tests                                 | 374 |
| 8.2.1 | Likelihood Ratio Tests                                   | 374 |
| 8.2.2 | Bayesian Tests   | 379 |
| 8.2.3 | Union–Intersection and Intersection–Union Tests          | 380 |
| 8.3   | Methods of Evaluating Tests                              | 382 |
| 8.3.1 | Error Probabilities and the Power Function               | 382 |
| 8.3.2 | Most Powerful Tests                                      | 387 |
| 8.3.3 | Sizes of Union–Intersection and Intersection–Union Tests | 394 |
| 8.3.4 | p-Values   | 397 |
| 8.3.5 | Loss Function Optimality                                 | 400 |
| 8.4   | Exercises  | 402 |
| 8.5   | Miscellanea  | 413 |
| 9     | Interval Estimation                                      | 417 |
| 9.1   | Introduction   | 417 |
| 9.2   | Methods of Finding Interval Estimators                   | 420 |
| 9.2.1 | Inverting a Test Statistic                               | 420 |
| 9.2.2 | Pivotal Quantities                                       | 427 |
| 9.2.3 | Pivoting the CDF   | 430 |
| 9.2.4 | Bayesian Intervals                                       | 435 |

|           |   |            |
|-----------|---|------------|
| 9.3       | Methods of Evaluating Interval Estimators               | 440        |
| 9.3.1     | Size and Coverage Probability                           | 440        |
| 9.3.2     | Test-Related Optimality                                 | 444        |
| 9.3.3     | Bayesian Optimality                                     | 447        |
| 9.3.4     | Loss Function Optimality                                | 449        |
| 9.4       | Exercises   | 451        |
| 9.5       | Miscellanea   | 463        |
| <b>10</b> | <b>Asymptotic Evaluations</b>                           | <b>467</b> |
| 10.1      | Point Estimation  | 467        |
| 10.1.1    | Consistency   | 467        |
| 10.1.2    | Efficiency  | 470        |
| 10.1.3    | Calculations and Comparisons                            | 473        |
| 10.1.4    | Bootstrap Standard Errors                               | 478        |
| 10.2      | Robustness  | 481        |
| 10.2.1    | The Mean and the Median                                 | 482        |
| 10.2.2    | M-Estimators  | 484        |
| 10.3      | Hypothesis Testing                                      | 488        |
| 10.3.1    | Asymptotic Distribution of LRTs                         | 488        |
| 10.3.2    | Other Large-Sample Tests                                | 492        |
| 10.4      | Interval Estimation                                     | 496        |
| 10.4.1    | Approximate Maximum Likelihood Intervals                | 496        |
| 10.4.2    | Other Large-Sample Intervals                            | 499        |
| 10.5      | Exercises   | 504        |
| 10.6      | Miscellanea   | 515        |
| <b>11</b> | <b>Analysis of Variance and Regression</b>              | <b>521</b> |
| 11.1      | Introduction  | 521        |
| 11.2      | Oneway Analysis of Variance                             | 522        |
| 11.2.1    | Model and Distribution Assumptions                      | 524        |
| 11.2.2    | The Classic ANOVA Hypothesis                            | 525        |
| 11.2.3    | Inferences Regarding Linear Combinations of Means       | 527        |
| 11.2.4    | The ANOVA <i>F</i> Test                                 | 530        |
| 11.2.5    | Simultaneous Estimation of Contrasts                    | 534        |
| 11.2.6    | Partitioning Sums of Squares                            | 536        |
| 11.3      | Simple Linear Regression                                | 539        |
| 11.3.1    | Least Squares: A Mathematical Solution                  | 542        |
| 11.3.2    | Best Linear Unbiased Estimators: A Statistical Solution | 544        |
| 11.3.3    | Models and Distribution Assumptions                     | 548        |
| 11.3.4    | Estimation and Testing with Normal Errors               | 550        |
| 11.3.5    | Estimation and Prediction at a Specified $x = x_0$      | 557        |
| 11.3.6    | Simultaneous Estimation and Confidence Bands            | 559        |
| 11.4      | Exercises   | 563        |
| 11.5      | Miscellanea   | 572        |

|  | CONTENTS   | xvii |
|--|------------|------|
| <b>12 Regression Models</b>                    | <b>577</b> |      |
| 12.1 Introduction                              | 577        |      |
| 12.2 Regression with Errors in Variables       | 577        |      |
| 12.2.1 Functional and Structural Relationships | 579        |      |
| 12.2.2 A Least Squares Solution                | 581        |      |
| 12.2.3 Maximum Likelihood Estimation           | 583        |      |
| 12.2.4 Confidence Sets                         | 588        |      |
| 12.3 Logistic Regression                       | 591        |      |
| 12.3.1 The Model                               | 591        |      |
| 12.3.2 Estimation                              | 593        |      |
| 12.4 Robust Regression                         | 597        |      |
| 12.5 Exercises                                 | 602        |      |
| 12.6 Miscellanea                               | 608        |      |
| <b>Appendix: Computer Algebra</b>              | <b>613</b> |      |
| <b>Table of Common Distributions</b>           | <b>621</b> |      |
| <b>References</b>                              | <b>629</b> |      |
| <b>Author Index</b>                            | <b>645</b> |      |
| <b>Subject Index</b>                           | <b>649</b> |      |