# **Contents**

### FOREWORD vii

## PREFACE ix

## CHAPTER 1 MATHEMATICAL PRELIMINARIES 1

1.1 Introduction. 1.2 Sample space and events. 1.2.1 Probability. 1.2.2 Random variables. 1.2.3 Illustrations. 1.3 Expected value. 1.4 Variance and covariance. 1.5 Variance of products. 1.6 Conditional expectation. 1.6.1 Conditional variance and covariance. 1.7 The Tchebycheff inequality. 1.8 An example. 1.9 Intraclass correlation coefficient. 1.10 The best weight function. 1.11 Minimum variance unbiased estimation. 1.12 Two limit theorems. References.

# CHAPTER 2 SAMPLE SURVEY BACKGROUND 19

2.1 Introduction.
2.2 The main problem.
2.2.1 Characteristics of interest.
2.3 Sample versus complete enumeration.
2.4 The role of the sampling method.
2.5 Planning and execution of sample surveys.
2.6 Judgment sampling.
2.7 Probability sampling.
2.8 Formation of estimators.
2.9

Unbiased estimation. 2.10 Precision of estimators. 2.11 Biased estimators. 2.11 Confidence intervals. 2.12 The question of cost. 2.13 The fundamental principle of sample design. 2.14 Scope of this book. Reference.

#### CHAPTER 3 BASIC METHODS OF SAMPLE SELECTION 33

3.1 Simple random sampling. 3.2 Estimation in simple random sampling. 3.3 Estimation of sampling error in wtr (without-replacement) sampling. 3.4 Sampling with replacement. 3.5 A general procedure. 3.6 A better estimator in wr sampling. 3.7 Estimation of proportions. 3.8 Systematic sampling. 3.9 Estimation in systematic sampling. 3.10 An alternative expression for the variance. 3.11 Estimation of variance in systematic sampling. 3.12 Sampling with unequal probabilities. 3.13 An alternative sampling procedure. 3.14 Estimation in wr pps sampling. 3.15 Comparison with sampling with equal probabilities. 3.16 Sampling without replacement with unequal probabilities. 3.17 A more general selection procedure. 3.18 Another type of selection procedure. 3.19 Estimation procedures. 3.20 Estimation of variance. 3.21 Two useful relations. 3.22 An alternative expression for the variance. 3.23 Comparison of wtr and wr schemes. 3.24 Another procedure of estimation in wtr sampling. 3.25 Estimation of variance. References.

## CHAPTER 4 STRATIFICATION 61

**4.1** Introduction. **4.2** Estimation in stratified sampling. **4.3** Allocation of sample to strata. **4.4** Allocation in simple random sampling. **4.4.1** X-proportional allocation. **4.4.2** Estimation of proportions. **4.5** Allocation in unequal-probability sampling. **4.6** Formation of strata. **4.6.1** Proportional allocation. **4.6.2** Equal allocation. **4.6.3** Optimum allocation. **4.6.4** Strata of equal aggregate size. **4.7** The number of strata. **4.8** Some practical situations. **4.8.1** The method of collapsed strata. **4.8.2** Estimation of gain due to stratification. **4.8.3** Dependent selection. **4.8.4** Estimating several parametric functions. **4.9** The stratum of nonrespondents. **4.10** Latin Square stratification. References.

# CHAPTER 5 FURTHER USE OF SUPPLEMENTARY INFORMATION 85

5.1 Introduction.
5.2 Ratio estimation.
5.3 Bias of the ratio estimate.
5.4 An approximate expression for bias.
5.5 Mean square error.
5.6 Bounds on the MSE.
5.7 Comparison with simple average.
5.8 Sample estimate of MSE.
5.9 Unbiased ratio estimation.
5.10 The variance of the unbiased ratio estimator.
5.11 Relative precision of the unbiased ratio estimator.
5.12 Unbiased ratio-type estimators.
5.13 Difference estimation.
5.14 Regression estimation.
5.15 Use of multiauxiliary information.
5.16 The case of two x-variates.
5.17 Multivariate ratio estimation.
5.18 Ratio estimation in stratified sampling.

## CHAPTER 6 SAMPLING AND SUBSAMPLING OF CLUSTERS 107

6.1 Introduction. 6.2 Single-stage cluster sampling. 6.2.1 Estimation of proportions. 6.2.2 Estimation of efficiency of cluster sampling. 6.2.3 Other

estimators in cluster sampling. **6.3** Multistage sampling. **6.3.1** Calculation of variance. **6.3.2** Estimation of variance. **6.4** Selection of psu's with unequal probabilities. **6.5** Selection of psu's with replacement. **6.5.1** Selection with replacement (scheme C). **6.6** Comparison of schemes A and B. **6.6.1** Comparison based on the sample. **6.7** Stratified multistage sampling. **6.8** Estimation of Ratios. **6.8.1** Sampling without replacement. **6.8.2** Sampling with replacement. **6.8.3** Extension to stratified sampling. **6.9** Choice of sampling and subsampling fractions. **6.9.1** Choice of optimum probabilities. **6.10** Some useful multistage designs. **6.10.1** Randomized systematic sampling of psu's. **6.10.2** One psu per stratum. **6.10.3** One psu per randomized substratum. **6.10.4** Psu's selected with pps of remainder. References.

#### CHAPTER 7 DOUBLE-SAMPLING PROCEDURES AND REPETITIVE SURVEYS 139

7.1 Introduction. 7.2 Double sampling for difference estimation. 7.2.1 Independent samples. 7.3 Double sampling for pps estimation. 7.3.1 The case of independent samples. 7.4 Double sampling with pps selection. 7.4.1 Independent samples. 7.5 Double sampling for unbiased ratio estimation. 7.6 Double sampling for biased ratio estimation. 7.6.1 Comparison with the difference estimator. 7.7 Double sampling for regression estimation. 7.8 Double sampling for stratification. 7.9 Repetitive surveys. 7.9.1 Sampling over two occasions. 7.9.2 Minimum variance current estimates. 7.9.3 Estimation of change. 7.9.4 Estimation of sum on two occasions. 7.10 Regression estimation in repetitive surveys. 7.11 Sampling on more than two occasions. 7.12 A useful procedure. References.

## CHAPTER 8 NONSAMPLING ERRORS 165

8.1 Introduction. 8.2 Response errors. 8.3 Response bias. 8.4 The analysis of data. 8.5 The optimum number of interviewers. 8.6 Estimation of variance components. 8.7 Some restricted models. 8.8 Uncorrelated response errors. 8.9 Estimation of response bias. 8.10 Extension to other sampling designs. 8.11 Response and sampling variance. 8.11.1 Application to estimating proportions. 8.11.2 Estimation of simple response variance. 8.12 The problem of nonresponse. 8.12.1 Practical procedures. 8.13 Some examples of sources of error. References.

### CHAPTER 9 OTHER DEVELOPMENTS 189

9.1 Introduction. 9.2 Variance estimation. 9.2.1 Variance estimation in stratified sampling. 9.2.2 The number of degrees of freedom. 9.2.3 The method of random groups. 9.2.4 Variance estimation in wtr sampling. 9.2.5 Variance estimation in randomized pps systematic sampling. 9.3 Estimation for subpopulations. 9.3.1 Subpopulation analysis for other designs. 9.4 The best linear estimator. 9.5 The method of overlapping maps. 9.5.1 Changing selection probabilities. 9.6 Two-way stratification with small samples. 9.7 Systematic sampling. 9.7.1 Data exhibiting periodicity. 9.7.2 Populations showing trend. 9.7.3 Autocorrelated populations. 9.8 Controlled selection. 9.9 A general rule for variance estimation in multistage sampling. 9.10 Sampling from imperfect frames. 9.11 Sampling inspection. 9.11.1 Double-sampling plans. References.

# **EXERCISES 225**

REFERENCES TO EXERCISES WITH REMARKS 263

APPENDIX 1 REPORT ON AN ACTUAL SAMPLE SURVEY 271

APPENDIX 2 PRINCIPAL NOTATION USED 282

APPENDIX 3 RANDOM NUMBERS 284

INDEX 287