

Table of Contents

PREFACE	xiv
CHAPTER 1 PRESENTING AND SUMMARIZING DATA	1
1.1 DATA AND VARIABLES	1
1.2 GRAPHICAL PRESENTATION OF DATA	2
<i>Graphical Presentation of Qualitative Data</i>	2
<i>Graphical Presentation of Quantitative Data</i>	2
1.3 NUMERICAL METHODS FOR PRESENTING DATA	5
<i>Symbolic Notation</i>	6
<i>Measures of Central Tendency</i>	7
<i>Measures of Variability</i>	8
<i>Measures of the Shape of a Distribution</i>	9
<i>Measures of Relative Position</i>	10
<i>SAS Example</i>	12
EXERCISES	14
CHAPTER 2 PROBABILITY	15
2.1 RULES ABOUT PROBABILITIES OF SIMPLE EVENTS	15
2.2 COUNTING RULES	16
<i>Multiplicative Rule</i>	17
<i>Permutations</i>	17
<i>Combinations</i>	18
<i>Partition Rule</i>	18
<i>Tree Diagram</i>	18
2.3 COMPOUND EVENTS	19
2.4 BAYES THEOREM	23
EXERCISE	25
CHAPTER 3 RANDOM VARIABLES AND THEIR DISTRIBUTIONS	26
3.1 EXPECTATIONS AND VARIANCES OF RANDOM VARIABLES	26
3.2 PROBABILITY DISTRIBUTIONS FOR DISCRETE RANDOM VARIABLES	28
<i>Expectation and Variance of a Discrete Random Variable</i>	29
<i>Bernoulli Distribution</i>	30
<i>Binomial Distribution</i>	31
<i>Hyper-geometric Distribution</i>	33
<i>Poisson Distribution</i>	33
<i>Multinomial Distribution</i>	33
3.3 PROBABILITY DISTRIBUTIONS FOR CONTINUOUS RANDOM VARIABLES	33
<i>Uniform Distribution</i>	33
<i>Normal Distribution</i>	33
<i>Multivariate Normal Distribution</i>	33
<i>Chi-square Distribution</i>	33

<i>Student t Distribution</i>	48
<i>F Distribution</i>	49
EXERCISES	50
CHAPTER 4 POPULATION AND SAMPLE	52
4.1 FUNCTIONS OF RANDOM VARIABLES AND SAMPLING DISTRIBUTIONS	52
4.2 CENTRAL LIMIT THEOREM.....	53
4.3 STATISTICS WITH DISTRIBUTIONS OTHER THAN NORMAL	53
4.4 DEGREES OF FREEDOM	54
CHAPTER 5 ESTIMATION OF PARAMETERS.....	55
5.1 POINT ESTIMATION	55
5.2 MAXIMUM LIKELIHOOD ESTIMATION	56
5.3 INTERVAL ESTIMATION	57
5.4 ESTIMATION OF PARAMETERS OF A NORMAL POPULATION	59
<i>Maximum Likelihood Estimation</i>	59
<i>Interval Estimation of the Mean</i>	60
<i>Interval Estimation of the Variance</i>	61
EXERCISES	62
CHAPTER 6 HYPOTHESIS TESTING.....	63
6.1 HYPOTHESIS TEST OF A POPULATION MEAN.....	64
<i>P Value</i>	67
<i>A Hypothesis Test can be One- or Two-sided</i>	68
<i>Hypothesis Test of a Population Mean for a Small Sample</i>	69
<i>SAS Example</i>	70
<i>A Simple Check if a Sample Comes from a Normal Distribution using SAS</i>	71
6.2 HYPOTHESIS TEST OF THE DIFFERENCE BETWEEN TWO POPULATION MEANS	72
<i>Large Samples</i>	72
<i>Small Samples and Equal Variances</i>	74
<i>Small Samples and Unequal Variances</i>	75
<i>Dependent Samples</i>	76
<i>Nonparametric Test</i>	77
<i>SAS Examples for Hypotheses Tests of Two Population Means</i>	79
6.3 HYPOTHESIS TEST OF A POPULATION PROPORTION	82
6.4 HYPOTHESIS TEST OF THE DIFFERENCE BETWEEN PROPORTIONS FROM TWO POPULATIONS.....	83
6.5 CHI-SQUARE TEST OF THE DIFFERENCE BETWEEN OBSERVED AND EXPECTED FREQUENCIES	85
<i>SAS Example for Testing the Difference between Observed and Expected Frequencies</i>	86
6.6 HYPOTHESIS TEST OF DIFFERENCES AMONG PROPORTIONS FROM SEVERAL POPULATIONS	87
<i>SAS Example for Testing Differences among Proportions from Several Populations</i>	88

6.7	HYPOTHESIS TEST OF POPULATION VARIANCE.....	90
6.8	HYPOTHESIS TEST OF THE DIFFERENCE OF TWO POPULATION VARIANCES.....	90
6.9	HYPOTHESIS TESTS USING CONFIDENCE INTERVALS.....	91
6.10	STATISTICAL AND PRACTICAL SIGNIFICANCE.....	92
6.11	TYPES OF ERRORS IN INFERENCES AND POWER OF TEST	92
	<i>SAS Examples for the Power of Test</i>	99
6.12	SAMPLE SIZE	104
	<i>SAS Examples for Sample Size</i>	105
6.13	EQUIVALENCE TESTS.....	109
	EXERCISES	113
CHAPTER 7 SIMPLE LINEAR REGRESSION		114
7.1	THE SIMPLE REGRESSION MODEL.....	114
7.2	ESTIMATION OF THE REGRESSION PARAMETERS – LEAST SQUARES ESTIMATION	118
7.3	RESIDUALS AND THEIR PROPERTIES.....	121
7.4	MAXIMUM LIKELIHOOD ESTIMATION	123
7.5	EXPECTATIONS AND VARIANCES OF THE PARAMETER ESTIMATORS	124
7.6	STUDENT <i>t</i> TEST IN TESTING HYPOTHESES ABOUT THE PARAMETERS	124
7.7	CONFIDENCE INTERVALS OF THE PARAMETERS	126
7.8	MEAN AND PREDICTION CONFIDENCE INTERVALS OF THE RESPONSE VARIABLE	127
7.9	PARTITIONING TOTAL VARIABILITY	129
	<i>Relationships among Sums of Squares</i>	131
	<i>Theoretical Distribution of Sum of Squares</i>	132
7.10	TEST OF HYPOTHESES – <i>F</i> TEST	132
7.11	LIKELIHOOD RATIO TEST	135
7.12	COEFFICIENT OF DETERMINATION	137
	<i>Shortcut Calculation of Sums of Squares and the Coefficient of Determination</i>	137
7.13	MATRIX APPROACH TO SIMPLE LINEAR REGRESSION	138
	<i>The Simple Regression Model</i>	138
	<i>Estimation of Parameters</i>	139
	<i>Maximum Likelihood Estimation</i>	142
7.14	SAS EXAMPLE FOR SIMPLE LINEAR REGRESSION	143
7.15	POWER OF TESTS.....	145
	<i>SAS Examples for Calculating the Power of Test</i>	146
	EXERCISES	149
CHAPTER 8 CORRELATION.....		150
8.1	ESTIMATION OF THE COEFFICIENT OF CORRELATION AND TESTS OF HYPOTHESES	151
	<i>SAS Example for Correlation</i>	154
8.2	PARTIAL CORRELATION	154
	<i>SAS Example for Partial Correlation</i>	156

8.3 RANK CORRELATION	158
<i>SAS Example for Rank Correlation</i>	158
EXERCISES	159
 CHAPTER 9 MULTIPLE LINEAR REGRESSION	160
9.1 TWO INDEPENDENT VARIABLES	161
<i>Estimation of Parameters</i>	162
<i>Student t test in Testing Hypotheses</i>	165
<i>Partitioning Total Variability and Tests of Hypotheses</i>	166
9.2 PARTIAL AND SEQUENTIAL SUMS OF SQUARES	168
9.3 TESTING MODEL FIT USING A LIKELIHOOD RATIO TEST	172
9.4 SAS EXAMPLE FOR MULTIPLE REGRESSION	174
9.5 POWER OF MULTIPLE REGRESSION	176
<i>SAS Example for Calculating Power</i>	177
9.6 PROBLEMS WITH REGRESSION	178
<i>Analysis of Residuals</i>	179
<i>Extreme Observations</i>	180
<i>Multicollinearity</i>	183
<i>SAS Example for Detecting Problems with Regression</i>	184
9.7 RIDGE REGRESSION	190
<i>SAS Example for Ridge Regression</i>	191
9.8 ROBUST REGRESSION	193
<i>SAS Example for Robust Regression</i>	194
<i>SAS Example for Comparing Methods for Detecting Extreme Observations</i>	196
9.9 CHOOSING THE BEST MODEL	202
<i>SAS Example for Model Selection</i>	203
 CHAPTER 10 CURVILINEAR REGRESSION	206
10.1 POLYNOMIAL REGRESSION	206
<i>SAS Example for Quadratic Regression</i>	210
10.2 NONLINEAR REGRESSION	211
<i>SAS Example for Nonlinear Regression</i>	213
10.3 SEGMENTED REGRESSION	215
<i>Segmented Linear Regression</i>	216
<i>SAS Example for Segmented Linear Regression</i>	217
<i>Segmented Cubic Regression – Cubic Splines</i>	221
<i>SAS Example for Cubic Spline Regression</i>	222
<i>Using Segmented Regression to Estimate a Plateau</i>	224
<i>SAS Example for Segmented Regression with Plateau</i>	226
 CHAPTER 11 FIXED EFFECTS ONE-WAY ANALYSIS OF VARIANCE	231
11.1 THE FIXED EFFECTS ONE-WAY MODEL	233
11.2 PARTITIONING TOTAL VARIABILITY	235
11.3 HYPOTHESIS TEST – F TEST	237
11.4 ESTIMATION OF GROUP MEANS	241
11.5 MAXIMUM LIKELIHOOD ESTIMATION	241

11.6 LIKELIHOOD RATIO TEST	242
11.7 MULTIPLE COMPARISONS AMONG GROUP MEANS	244
<i>Least Significance Difference (LSD)</i>	244
<i>Tukey Test</i>	245
<i>Contrasts</i>	246
<i>Orthogonal contrasts</i>	248
<i>Scheffe Test</i>	250
11.8 TEST OF HOMOGENEITY OF VARIANCE.....	251
11.9 SAS EXAMPLE FOR THE FIXED EFFECTS ONE-WAY MODEL	252
11.10 POWER OF THE FIXED EFFECTS ONE-WAY MODEL	254
<i>SAS Example for Calculating Power</i>	257
11.11 MATRIX APPROACH TO THE FIXED EFFECTS ONE-WAY MODEL.....	258
<i>Linear Model</i>	258
<i>Estimating Parameters</i>	259
<i>Maximum Likelihood Estimation</i>	264
<i>Regression Model for the One-way Analysis of Variance</i>	264
11.12 NONPARAMETRIC TESTS	267
<i>SAS Example for Nonparametric Tests</i>	269
EXERCISES	271
 CHAPTER 12 RANDOM EFFECTS ONE-WAY ANALYSIS OF VARIANCE	272
12.1 THE RANDOM EFFECTS ONE-WAY MODEL	273
12.2 HYPOTHESIS TEST	274
12.3 PREDICTION OF GROUP MEANS	275
12.4 VARIANCE COMPONENT ESTIMATION.....	275
12.5 INTRACLASS CORRELATION.....	277
12.6 MAXIMUM LIKELIHOOD ESTIMATION	278
12.7 RESTRICTED MAXIMUM LIKELIHOOD ESTIMATION	280
12.8 SAS EXAMPLE FOR THE RANDOM EFFECTS ONE-WAY MODEL	282
12.9 MATRIX APPROACH TO THE ONE-WAY ANALYSIS OF VARIANCE MODEL	284
<i>Linear Model</i>	284
<i>Prediction of Random Effects</i>	285
<i>Maximum Likelihood Estimation</i>	287
<i>Restricted Maximum Likelihood Estimation</i>	288
EXERCISE	289
 CHAPTER 13 MIXED MODELS	290
13.1 PREDICTION OF RANDOM EFFECTS	291
13.2 MAXIMUM LIKELIHOOD ESTIMATION	292
13.3 RESTRICTED MAXIMUM LIKELIHOOD ESTIMATION	293
 CHAPTER 14 CONCEPTS OF EXPERIMENTAL DESIGN.....	295
14.1 EXPERIMENTAL UNITS AND REPLICATIONS	296
14.2 EXPERIMENTAL ERROR.....	297
14.3 PRECISION OF EXPERIMENTAL DESIGN.....	298
14.4 CONTROLLING EXPERIMENTAL ERROR	300
14.5 UNBALANCED AND MISSING DATA.....	301

14.6 REQUIRED NUMBER OF REPLICATIONS.....	302
<i>SAS Example for the Number of Replications.....</i>	304
CHAPTER 15 BLOCKING	306
15.1 RANDOMIZED COMPLETE BLOCK DESIGN	306
<i>Partitioning Total Variability</i>	308
<i>Hypotheses Test – F test.....</i>	309
<i>SAS Example for Block Design</i>	313
15.2 RANDOMIZED BLOCK DESIGN – TWO OR MORE UNITS PER TREATMENT AND BLOCK	314
<i>Partitioning Total Variability and Test of Hypotheses</i>	315
<i>SAS Example for Two or More Experimental Units per Block × Treatment.....</i>	321
15.3 POWER OF TEST.....	324
<i>SAS Example for Calculating Power</i>	325
15.4 MISSING DATA IN RANDOMIZED BLOCK DESIGNS.....	326
15.5 A NONPARAMETRIC TEST.....	333
<i>SAS Examples for Nonparametric Test.....</i>	334
EXERCISE	335
CHAPTER 16 CHANGE-OVER DESIGNS	336
16.1 SIMPLE CHANGE-OVER DESIGN.....	336
16.2 CHANGE-OVER DESIGNS WITH THE EFFECTS OF PERIODS	339
<i>SAS Example for Change-over Designs with the Effects of Periods.....</i>	341
16.3 LATIN SQUARE	343
<i>SAS Example for Latin Square.....</i>	347
16.4 CHANGE-OVER DESIGN SET AS SEVERAL LATIN SQUARES.....	349
<i>SAS Example for Several Latin Squares</i>	351
EXERCISE	355
CHAPTER 17 FACTORIAL EXPERIMENTS	356
17.1 THE TWO FACTOR FACTORIAL EXPERIMENT	356
<i>SAS Example for Factorial Experiment</i>	363
EXERCISE	364
CHAPTER 18 HIERARCHICAL OR NESTED DESIGN.....	365
18.1 HIERARCHICAL DESIGN WITH TWO FACTORS.....	365
<i>SAS Example for Hierarchical Design.....</i>	370
CHAPTER 19 MORE ABOUT BLOCKING.....	373
19.1 BLOCKING WITH PENS, CORRALS AND PADDOCKS	373
<i>SAS Example for Designs with Pens and Paddocks.....</i>	377
19.2 DOUBLE BLOCKING.....	379

CHAPTER 20 SPLIT-PLOT DESIGN	382
20.1 SPLIT-PLOT DESIGN – MAIN PLOTS IN RANDOMIZED BLOCKS	382
<i>SAS Example: Main Plots in Randomized Blocks</i>	386
20.2 SPLIT-PLOT DESIGN – MAIN PLOTS IN A COMPLETELY RANDOMIZED DESIGN	388
<i>SAS Example: Main Plots in a Completely Randomized Design</i>	391
EXERCISE	393
CHAPTER 21 ANALYSIS OF COVARIANCE	394
21.1 COMPLETELY RANDOMIZED DESIGN WITH A COVARIATE	394
<i>SAS Example for a Completely Randomized Design with a Covariate</i>	396
21.2 TESTING THE DIFFERENCE BETWEEN REGRESSION SLOPES	398
<i>SAS Example for Testing the Difference between Regression Slopes</i>	402
CHAPTER 22 REPEATED MEASURES	405
22.1 HOMOGENEOUS VARIANCES AND COVARIANCES AMONG REPEATED MEASURES	405
<i>SAS Example for Homogeneous Variances and Covariances</i>	408
22.2 HETEROGENEOUS VARIANCES AND COVARIANCES AMONG REPEATED MEASURES	413
<i>SAS Examples for Heterogeneous Variances and Covariances</i>	414
22.3 RANDOM COEFFICIENT REGRESSION.....	420
<i>SAS Examples for Random Coefficient Regression</i>	421
22.4 ACCOUNTING FOR BASELINE MEASUREMENTS.....	427
22.5 MISSING DATA IN REPEATED MEASURES ANALYSIS	429
CHAPTER 23 ANALYSIS OF NUMERICAL TREATMENT LEVELS	432
23.1 LACK OF FIT	432
<i>SAS Example for Lack of Fit</i>	435
23.2 POLYNOMIAL ORTHOGONAL CONTRASTS	437
<i>SAS Example for Polynomial Contrasts</i>	439
CHAPTER 24 DISCRETE DEPENDENT VARIABLES	441
24.1 LOGIT MODELS, LOGISTIC REGRESSION	442
<i>Testing Hypotheses</i>	444
<i>SAS Examples for Logistic Models</i>	448
24.2 DIAGNOSTICS TEST – ROC CURVE.....	454
<i>SAS Example for Diagnostic Tests</i>	463
24.3 PROBIT MODEL	467
<i>SAS Example for a Probit Model</i>	469
24.4 LOG-LINEAR MODELS	472
<i>SAS Example for a Log-linear Model</i>	475
SOLUTIONS OF EXERCISES	478

APPENDIX A: VECTORS AND MATRICES	480
TYPES AND PROPERTIES OF MATRICES.....	480
MATRIX AND VECTOR OPERATIONS	481
APPENDIX B: STATISTICAL TABLES.....	484
AREA UNDER THE STANDARD NORMAL CURVE, $Z > Z_\alpha$	484
CRITICAL VALUES OF STUDENT T DISTRIBUTIONS, $T > T_\alpha$	485
CRITICAL VALUES OF CHI-SQUARE DISTRIBUTIONS, $\chi^2 > \chi^2_\alpha$	487
CRITICAL VALUES OF F DISTRIBUTIONS, $F > F_\alpha$, $\alpha = 0.05$	489
CRITICAL VALUE OF F DISTRIBUTIONS, $F > F_\alpha$, $\alpha = 0.01$	491
CRITICAL VALUES OF THE STUDENTIZED RANGE, $Q(A, V)$	493
BIBLIOGRAPHY	494
SUBJECT INDEX.....	498