_
1 The Forest before the Trees
1.0 Why Statistics? 1
1.01 Statistics as a Form of Social Control 1
1.02 Objections to Null Hypothesis Significance Testing 2
1.03 Should Significance Tests be Banned? 3
1.04 Math Modeling's the Ultimate Answer 5
1.05 Some Recent Developments in Univariate Statistics 6
1.0.5.1 The MIDS and FEDs criteria as alternatives to power calculation
Table 1.1 Fraction of Population Effect Size That Must Be Statistically
Significant in Order to Achieve a Given Level of Power for Your
Significance Test 9
1.0.5.2 Prior-Information Confidence Intervals (PICIs) 9
1.1 Why Multivariate Statistics? 10
1.1.1 Bonferroni Adjustment: An Alternative to Multivariate Statistics. 13
1.1.2 Why Isn't Bonferroni Adjustment Enough? 14
1.2 A Heuristic Survey of Statistical Techniques 14
Table 1.2 Statistical Techniques 16
1.2.1 Student's <i>t</i> test 17
1.2.2 One-Way Analysis of Variance 18
1.2.3 Hotelling's $T^2$ 21
Example 1.1 Anglo versus Chicano Early Memories 23
1.2.4 One-Way Multivariate Analysis of Variance 24
Example 1.2 Inferring Social Motives from Behavior 25
1.2.5 Higher Order Analysis of Variance 26
1.2.6 Higher Order Manova 27
Example 1.3 Fat, Four-eyed, and Female 28
1.2.7 Pearson r and Bivariate Regression 28
1.2.8 Multiple Correlation and Regression 31
Example 1.4 Chicano Role Models, GPA, and MRA 33
1.2.9 Path Analysis 34
1.2.10 Canonical Correlation 35
Figure 1.1 Multivariate Analyses of Between-Set Relationships 36
Example 1.5 Television Viewing and Fear of Victimization 37
1.2.11 Analysis of Covariance 38
1.2.12 Principal Component Analysis 40
1.2.13 Factor Analysis 42
Example 1.6 Measuring Perceived Deindividuation 44
1.2.14 Structural Equation Modeling 44

xii

1.3 Learning to Use Multivariate Statistics 45 1.3.1 A Taxonomy of Linear Combinatons 45 1.3.1.1 Averages of subsets of the measures 45 1.3.1.2 Profiles 47 1.3.1.3 Contrasts 47 1.3.2 Why the Rest of the Book? 51	
Quiz 1 See How Much You Know after Reading Just One Chapter! 55	
Sample Answers to Quiz 1 56	
2 Multiple Regression: Predicting One Variable	ì,
from Many	
Data Set 1 58	
2.1 The Model 59	
2.2 Choosing Weights 62	
2.2.1 Least Squares Criterion 62	
Table 2.1 Multiple Regression Analyses of Data Set 1 66	
Table 2.2 Data Set 1b: A Presumptuous Data Set    68	
2.2.2 Maximum Correlation Criterion 69	
2.2.3 The Utility of Matrix Algebra 70	
2.2.4 Independence of Irrelevant Parameters 72  2.3 Relating the Sample Equation to the Population Equation 74	
7 7 Kelanno ine Sample Eduction to the Lopalation Education	77
Table 2.3 Summary of Significance Tests for Multiple Regression 2.3.1 R versus S versus x'x as the Basis for MRA 81	• •
Z.J.1 14, Versus By Versus M M as and = mass	
Table 2.4 Alternative who is a second	
<ul><li>2.3.2 Specific Comparisons 84</li><li>2.3.3 Illustrating Significance Tests 86</li></ul>	
Example 2.1 Locus of Control, the CPQ, and Hyperactivity 86	
Computer break 2-1: CPQ vs. LOC, CPT-C, CPT-E 89	
2.3.4 Stepwise Multiple Regression Analysis 95	
Example 2.1 Revisited 96	
2.4 Computer Programs for Multiple Regression 96	
2.4.1 Computer Logic and Organization 97	
2.4.2 Sage Advice on Use of Computer Programs 98	
2.4.3 Computerized Multiple Regression Analysis 100	
2.4.3.1 MATLAB 100	
2.4.3.2 SPSS REGRESSION, Syntax Window 101	
2,4,J.J.J. 31 33 REGRESSIO1 , 1 0 m. c	
Z.4.J.4 DING I ROC RESC MAN I I I I I	
Z.,) Some General Properties of Covariance Manager 1	07
Table 2.5 Measures of Importance in MRA 110	

2.7 Anova via MRA 103
Table 2.6 Relationship Between MRA and Anova Effects Model         105
Example 2.2 In-Group/Out-Group Stereotypes 106
<b>Table 2.7</b> Coding of MRA Level-Membership Variables for Study of Stereotypes 113
Example 2.3 Negative Shares and Equity Judgments 106
Table 2.8 Alternative Codings of MRA Predictor Variables, Equity Study 113
Example 2.4 Gender Bias in Faculty Salaries? 116
Table 2.9 Mean Faculty Salary at Hypo. U. as f(College, Gender) 117
Table 2.10 Data for MRA-Based Anova of Gender-Bias Data Set         118
2.8 Alternatives to the Least-Squares Criterion 121
2.9 Path Analysis 122
2.9.1 Path analytic Terminology 123
2.9.2 Preconditions for Path Analysis 124
2.9.3 Estimating and Testing Path coefficients 126
2.9.4 Decomposition of Correlations into Components 128
2.9.5 Overall Test of Goodness of fit 129
2.9.6 Examples 130
Example 2.5 Mother's Effects on Child's IQ 130
Example 2.6 Gender Bias Revisited: More Light on "Suppression" 134
2.9.7 Some Path-Analysis References 136
Demonstration Problem 136
Answers 139
Some Real Data and a Quiz Thereon 143
Table 2.11 Data Set 2: Ratings of Conservatism of Statement         144
Answers 146
<b>Table 2.12</b> Buildup of $R^2$ for Different Orders of Addition of Predictors 146
Figure 2.1 Venn diagram of correlations among Y and four predictors 147
Path Analysis Problem 149
Answers to Path Analysis Problem 150
3 Hotelling's $T^2$ : Tests on One or Two Mean Vectors
3.1 Single-Sample $t$ and $T^2$ 155
3.1 Single-Sample $t$ and $T^2$ 155 <b>Table 3.1</b> Data Set 3: Divisions of Potential Prize, Experiment 3,
Harris & Joyce (1980). 157  Example 3.1 162
3.2 Linearly Related Outcome Variables 165
Example 3.2 166
Table 3.2 Data Set 4: Results of Deutsch Replication 1 167
3.3 Two-Sample t and $T^2$ 170
3.4 Profile Analysis 173
Figure 3.1 Response vectors for groups differing in level and slope 174
right out Weshouse torious for Breaks anyoning in the same and

xiv

3.5 Discriminant Analysis 182
3.6 Relationship between $T^2$ and MRA 184
3.7 Assumptions Underlying $T^2$ 186
3.7.1 The Assumption of Equal Covariance Matrices 186
3.7.2 Known Covariance Matrix 187
3.7.3 The Assumption of Multivariate Normality 188
3.8 Analyzing Repeated-Measures Designs via T <sup>2</sup> 188
Table 3.3 Repeated-Measures Anova of Data Set 3 189
Example 3.2 Blood Doping 192  Table 3.4 10K Running Time as Affected by an Infusion of One's Own Blood 19
3.9 Single-Symbol Expressions for Simple Cases 196
3.10 Computerized $T^2$ 198
<u>-</u>
3.10.1 Single-Sample and Two-Sample $T^2$ 198 3.10.2 Within-Subjects Anova 199
Demonstration Problems 200
Answers 202
4 Multivariate Analysis of Variance:
· · · · · · · · · · · · · · · · · · ·
<b>Differences Among Several Groups on Several</b>
Measures
4.1 One-Way (Univariate) Analysis of Variance 210
4.1.1 The Overall Test 210
Table 4.1 Summary Table of Anova on Dependent Variable 213
4.1.2 Specific Comparisons 213
Table 4.2 Summary Table for Effects of Instructions on Frequency of DD
Outcomes 215
4.2 One-Way Multivariate Analysis of Variance 218 <b>Table 4.3</b> Critical Values for Contrasts Performed on Linear Combinations of
Variables 222
4.3 Multiple Profile Analysis 224
Example 4.1 Damselfish Territories 227
Table 4.4 Mean Percentage Coverage of Damselfish Territories 227
4.4 Multiple Discriminant Analysis 229
4.5 Greatest Characteristic Roots versus Multiple-Root Tests in Manova 231
4.5.1 "Protected" Univariate Tests 233
4.5.1 "Protected" Univariate Tests 233 4.5.2 Simultaneous Test Procedures and Union Intersection 234
4.5.1 "Protected" Univariate Tests 233 4.5.2 Simultaneous Test Procedures and Union Intersection 234 4.5.3 Invalidity of Partitioned- <i>U</i> Tests of Individual Roots 234
4.5.1 "Protected" Univariate Tests 233 4.5.2 Simultaneous Test Procedures and Union Intersection 234

<ul> <li>4.6 Simple Cases of Manova 240</li> <li>4.7 Higher Order Anova: Interactions 243</li> <li>4.8 Higher Order Manova 245  Example 4.2 Eyeball to Eyeball in a Prisoner's Dilemma 248</li> </ul>
<ul> <li>Table 4.5 Proportion of Mutually Cooperative Choices as f(Contact, Communic'n) 248</li> <li>Table 4.6 Mean Proportion of Total Responses Accounted for by</li> <li>Each Outcome 249</li> </ul>
Table 4.7 Summary Table for Anova on Discriminant Function from One-Way
Manova 251 4.9 Within-Subject Univariate Anova Versus Manova 252
Example 4.3 Stress, Endorphins, and Pain 256
4.10 Computerized Manova 257
4.10.1 Generic Setup for SPSS MANOVA 257
4.10.2 Supplementary Computations 259 4.10.3 Pointing and Clicking to a Manova on SPSS PC 259 4.10.4 Generic Setup for SAS PROC GLM 260
4.10.4 Generic Setup for SAS PROC GLM 260 <b>Demonstration Problems</b> 262
Answers 264
5 Canonical Correlation: Relationships Between Two Sets of Variables
5.1 Formulae for Computing Canonical Rs 268
5.1.1 Heuristic Justification of Canonical Formulae 270
5.1.2. Simple Cases of Canonical Correlations 272
5.1.3. Example of a Canonical Analysis 274 <b>Table 5.1</b> Correlations of Background Variables with Marijuana
Questions 275
Table 5.2 Canonical Analysis of Background Variables versus Marijuana
Questions 276
5.2 Relationships to Other Statistical Techniques 277
5.3 Likelihood-Ratio Tests of Relationships between Sets of Variables 279 5.4 Generalization and Specialization of Canonical Analysis 280
5.4 Generalization and Specialization of Canonical Analysis 280 5.4.1 Testing the Independence of m Sets of Variables 281
Example 5.2 Consistency of Behavior across Different Experimental Games 282
Table 5.3 Correlation Matrix for Game Outcome Variables, Flint (1970) 283
5.4.2 Repeated-Battery Canona 284
5.4.3 Rotation of Canonical Variates 288
Example 5.3 A Canonical Cautionary 290
Figure 5.1 Naturally Occurring versus Canona-based Pairings of Beefy-Breasted Bowery Birds (BBBBs) 291
5.4.4 The Redundancy Coefficient 293
5.4.5 What's Missing from Canonical Analysis? 295

xvi

5.5 Computerized Canonical Correlation 297 5.5 1 Matrix-Manipulation Systems 297
5.5.1 Matrix-Manipulation Systems 297 5.5.1.1 MATLAB 297
5.5.1.1 MATLAB 297 5.5.1.2 SAS PROC MATRIX and SPSS Matrix/End Matrix 299
5.5.2 SAS PROC CANCORR 301
5.5.3. Canona via SPSS MANOVA 304
5.5.4 SPSS Canona From Correlation Matrix: Be Careful 305
Demonstration Problems and Some Real Data Employing Canonical
Correlation 307
Answers 309
Alisweis 509
<b>6</b> Principal Component Analysis:
Relationships Within a Single Set of Variables
6.1 Definition of Principal Components 319
6.1.1 Terminology and Notation in PCA and FA 320
6.1.2 Scalar Formulae for Simple Cases of PCA 322
6.1.3 Computerized PCA 325
6.1.4 Additional Unique Properties (AUPs) of PCs 326
6.2 Interpretation of Principal Components 327
Example 6.1 Known generating variables 332
6.3 Uses of Principal Components 333
6.3.1 Uncorrelated Contributions 333
6.3.2 Computational Convenience 334
6.3.3 Principal Component Analysis as a Means of Handling Linear
Dependence 335
6.3.4 Examples of PCA 338
Example 6.2 Components of the WISC-R 338
Example 6.3 Attitudes toward cheating 343
Table 6.1 PCA on Questions 12-23 of Cheating Questionnaire         344
Example 6.4 Fat, four-eyed, and female again 344
Table 6.2 Manova Test of Obesity Main Effect    345
Table 6.3 PCA-Based Manova of Obesity Main Effect 347
6.3.5 Quantifying Goodness of Interpretation of Components 348
6.4 Significance Tests for Principal Components 351
6.4.1 Sampling Properties of Covariance-Based PCs 353
6.4.2 Sampling Properties of Correlation-Based PCs 354
6.5 Rotation of Principal Components 356
Example 6.1 revisited 356
6.5.1 Basic Formulae for Rotation 358
Figure 6.1 Factor structures, example 6.1 358
Figure 6.2 Rotation, general case 358
6.5.2 Objective Criteria for Rotation 360

Contents
<ul> <li>Table 6.4 Quadrant within which 4φ Must Fall as Function of Signs of Numerator and Denominator of Expression (6.9)</li> <li>6.5.3 Examples of Rotated PCs</li> </ul>
Table 6.5 Intermediate Calculations for Quartimax and Varimax Rotation         365
<b>Table 6.6</b> Varimax Rotation of $PC_1$ - $PC_4$ , Cheating Questionnaire 367
Table 6.7 Varimax Rotation of All Twelve PCs, Cheating Questionnaire         368
Table 6.8 Large Loadings for Cheating Questionnaire         369
6.5.4 Individual Scores on Rotated <i>PC</i> s 369
Example 6.5 A factor fable 373
Figure 6.3 Architectural dimensions of houses 373
Figure 6.4 Schematic representation of 27 houses 374
Table 6.9 Scores on Observed and Derived Variables for 27 Houses         375
Figure 6.5 Same 27 houses sorted on basis of loadings-based interpretation of Factor 1 377
6.5.5 Uncorrelated-Components Versus Orthogonal-Profiles Rotation 379
<b>Demonstration Problems</b> 381
Answers 383
Figure 6.6 Rotation of factor structure for problem 1 386
7 Factor Analysis: The Search for Structure
7.1 The Model 394
7.1 The Model 334 7.2 Communalities 397
7.2.1 Theoretical Solution 398
7.2.2 Empirical Approximations 400
7.2.3 Iterative Procedure 401
7.2.4 Is the Squared Multiple Correlation the True Communality? 401
7.3 Factor Analysis Procedures Requiring Communality Estimates 404
7.3.1 Principal Factor Analysis 404
7.3.2 Triangular (Choleski) Decomposition 405
7.3.3 Centroid Analysis 406
7.4 Methods Requiring Estimate of Number of Factors 406
7.5 Other Approaches to Factor Analysis 409 7.6 Factor Loadings versus Factor Scores 410
7.0 I actor Loadings voices I actor be also
7.6.1 Factor Score Indeterminacy 411 7.6.2 Relative Validities of Loadings-Derived versus Scoring-Coefficient-Derived
Factor Interpretations 412
Factor Interpretations 412 <b>Table 7.1</b> Mean Validity, Univocality, and Orthogonality of Regression and
Loading Estimates for Three Levels of Complexity 413
7.6.3 Regression-Based Interpretation of Factors is Still a Hard Sell 414
7.0.5 Regression-Based Interpretation of Analysis versus Factor Analysis 416
7.7.1 Similarity of Factor Scoring Coefficients 410
Table 7.2 Comparison of Factor Structures for PCA versus Two PFAs of
Same Data 417
Same Data 11.

xviii	Contents
Table 7.3 Comparison of Kaiser-Normalized Factor Structure Table 7.4 Comparison of Factor-Score Coefficients 41 7.7.2 Bias in Estimates of Factor Loadings 420 7.8 Computerized Exploratory Factor Analysis 421  Example 7.1 WISC-R Revisited 423	_
7.9 Confirmatory Factor Analysis 433	
7.9.1 SAS PROC CALIS	
Example 7.1 Revisited: Model Comparisons Galore	134
8 The Forest Revisited	
8.1 Scales of Measurement and Multivariate Statistics 444	
Table 8.1 Representative Critical Values for Measures of	
8.2 Effects of Violations of Distributional Assumptions in Multiv Analysis 450	ariate
	ariate
Analysis 450 8.3 Nonlinear Relationships in Multivariate Statistics 453 8.4 The Multivariate General Linear Hypothesis 456	
Analysis 450 8.3 Nonlinear Relationships in Multivariate Statistics 453	

464 8.5.1 General Approach and Examples

Example 8.2 Path Analysis of Scarr (1985) via SEM

Example 8.3 All Three Colleges in the Faculty Salary Example

Example 8.4 Increment to Canonical R<sup>2</sup> via CALIS LinEqs?

8.5.2 SEM Is Not a General Model for Multivariate Statistics 473

Example 8.5 Higher-Order Confirmatory Factor Analysis via SEM: WISC-R One

More Time 473

8.5.3 Other User-Friendly SEM Programs 478

8.6 Where to Go from Here

8.7 Summing Up 480

### Digression 1

### Finding Maxima and Minima of Polynomials

Dl .1 Derivatives and Slopes

D1.2 Optimization Subject to Constraints

## **Digression 2**

#### **Matrix Algebra**

D2.1 Basic Notation 487

D2.2 Linear Combinations of Matrices 489

D2.3 Multiplication of Matrices

ed
4
•

Derivation 3.1 $T^2$ and Associated Discriminant Function 546	
Single-Sample $T^2$ 546	
Two-Sample $T^2$ 548	
Derivation 3.2 Relationship between T <sup>2</sup> and MRA 549	<b>5.40</b>
Two-Sample t Versus Pearson r With Group-Membership Variables	549
Single-Sample t Test versus "Raw-Score" $r_{xy}$ 550	
T <sup>2</sup> Versus MRA 551	

Derivation 4.1 Maximizing  $F(\mathbf{a})$  in Manova 552

Derivation 5.1 Canonical Correlation and Canonical Variates 534	
Derivation 5.2 Canonical Correlation as "Mutual Regression Analysis"	556
	557

Derivation 6.1 Principal Components 560
Derivation 6.2 PC Coefficients Define Both Components in Terms of Xs and Xs in Terms of PCs 562
Derivation 6.3 What Does Rotation of Loadings Do to Coefficients? 564

Derivation 7.1 Near Equivalence of PCA and Equal-Communalities PFA 566

#### References 567 Index 584