Contents

Preface v

1 Introduction 1

2 Linear Models 3
- 2.1 Regression Models in Econometrics . . . 3
- 2.2 Econometric Models . . . 6
- 2.3 The Reduced Form . . . 10
- 2.4 The Multivariate Regression Model . . . 12
- 2.5 The Classical Multivariate Linear Regression Model . . . 15
- 2.6 The Generalized Linear Regression Model . . . 16

3 The Linear Regression Model 19
- 3.1 The Linear Model . . . 19
- 3.2 The Principle of Ordinary Least Squares (OLS) . . . 20
- 3.3 Geometric Properties of OLS . . . 21
- 3.4 Best Linear Unbiased Estimation . . . 23
  - 3.4.1 Basic Theorems . . . 23
  - 3.4.2 Linear Estimators . . . 28
  - 3.4.3 Mean Dispersion Error . . . 29
- 3.5 Estimation (Prediction) of the Error Term e and σ^2 . . . 31
- 3.6 Classical Regression under Normal Errors . . . 32
- 3.7 Testing Linear Hypotheses . . . 34
- 3.8 Analysis of Variance and Goodness of Fit . . . 41

3.8.1 Bivariate Regression 41
3.8.2 Multiple Regression 46
3.8.3 A Complex Example 50
3.8.4 Graphical Presentation 54
3.9 The Canonical Form 60
3.10 Methods for Dealing with Multicollinearity 61
3.10.1 Principal Components Regression 62
3.10.2 Ridge Estimation 63
3.10.3 Shrinkage Estimates 67
3.10.4 Partial Least Squares 67
3.11 Projection Pursuit Regression 71
3.12 Total Least Squares 72
3.13 Minimax Estimation 75
3.13.1 Inequality Restrictions 75
3.13.2 The Minimax Principle 78
3.14 Censored Regression 83
3.14.1 Introduction 83
3.14.2 LAD Estimators and Asymptotic Normality 84
3.14.3 Tests of Linear Hypotheses 85

4 The Generalized Linear Regression Model 89
4.1 Optimal Linear Estimation of β 89
4.2 The Aitken Estimator 96
4.3 Misspecification of the Dispersion Matrix 98
4.4 Heteroscedasticity and Autoregression 101

5 Exact and Stochastic Linear Restrictions 111
5.1 Use of Prior Information 111
5.2 The Restricted Least-Squares Estimator 112
5.3 Stepwise Inclusion of Exact Linear Restrictions 115
5.4 Biased Linear Restrictions and MDE Comparison with the OLSE 120
5.5 MDE Matrix Comparisons of Two Biased Estimators 123
5.6 MDE Matrix Comparison of Two Linear Biased Estimators 129
5.7 MDE Comparison of Two (Biased) Restricted Estimators . 130
5.7.1 Special Case: Stepwise Biased Restrictions 134
5.8 Stochastic Linear Restrictions 138
5.8.1 Mixed Estimator 138
5.8.2 Assumptions about the Dispersion Matrix 140
5.8.3 Biased Stochastic Restrictions 143
5.9 Weakened Linear Restrictions 147
5.9.1 Weakly (R, r)-Unbiasedness 147
5.9.2 Optimal Weakly (R, r)-Unbiased Estimators 148
5.9.3 Feasible Estimators—Optimal Substitution of β in $\hat{\beta}_1(\beta, A)$ 152

5.9.4 RLSE Instead of the Mixed Estimator 153

6 Prediction Problems in the Generalized Regression Model 155
6.1 Introduction 155
6.2 Some Simple Linear Models 155
6.3 The Prediction Model 158
6.4 Optimal Heterogeneous Prediction 159
6.5 Optimal Homogeneous Prediction 161
6.6 MDE Matrix Comparisons between Optimal and Classical Predictors 165
6.6.1 Comparison of Classical and Optimal Prediction with Respect to the y_*-Superiority 167
6.6.2 Comparison of Classical and Optimal Predictors with Respect to the $X_*\beta$-Superiority 170
6.7 Prediction Regions 172

7 Sensitivity Analysis 177
7.1 Introduction 177
7.2 Prediction Matrix 177
7.3 The Effect of a Single Observation on the Estimation of Parameters 183
7.3.1 Measures Based on Residuals 184
7.3.2 Algebraic Consequences of Omitting an Observation 185
7.3.3 Detection of Outliers 186
7.4 Diagnostic Plots for Testing the Model Assumptions 191
7.5 Measures Based on the Confidence Ellipsoid 192
7.6 Partial Regression Plots 199

8 Analysis of Incomplete Data Sets 203
8.1 Statistical Analysis with Missing Data 203
8.2 Missing Data in the Response 209
8.2.1 Least-Squares Analysis for Complete Data 209
8.2.2 Least-Squares Analysis for Filled-up Data 210
8.2.3 Analysis of Covariance—Bartlett's Method 211
8.3 Missing Values in the X-Matrix 212
8.3.1 Missing Values and Loss in Efficiency 214
8.3.2 Standard Methods for Incomplete X-Matrices 216
8.4 Maximum Likelihood Estimates of Missing Values 219
8.5 Weighted Mixed Regression 221
8.5.1 Minimizing the MDEP 223
8.5.2 The Two-Stage WMRE 226

9 Robust Regression 229
9.1 Introduction 229
9.2 Least Absolute Deviation Estimators—Univariate Case . . . 230

9.3 M-Estimates: Univariate Case 234
9.4 Asymptotic Distributions of LAD Estimators 237
9.4.1 Univariate Case 237
9.4.2 Multivariate Case 238
9.5 General M-Estimates 240
9.6 Test of Significance 243

10 Models for Binary Response Variables **247**
10.1 Generalized Linear Models 247
10.2 Contingency Tables 249
10.2.1 Introduction 249
10.2.2 Ways of Comparing Proportions 250
10.2.3 Sampling in Two-Way Contingency Tables 253
10.2.4 Likelihood Function and Maximum Likelihood Estimates 254
10.2.5 Testing the Goodness of Fit 256
10.3 GLM for Binary Response 259
10.3.1 Logit Models 259
10.3.2 Loglinear Models 259
10.3.3 Logistic Regression 260
10.3.4 Testing the Model 263
10.3.5 Distribution Functions as Link Function 263
10.4 Logit Models for Categorical Data 264
10.5 Goodness of Fit—Likelihood-Ratio Test 265
10.6 Loglinear Models for Categorical Variables 267
10.6.1 Two-Way Contingency Tables 267
10.6.2 Three-Way Contingency Tables 270
10.7 The Special Case of Binary Response 274
10.8 Coding of Categorical Explanatory Variables 276
10.8.1 Dummy and Effect Coding 276
10.8.2 Coding of Response Models 279
10.8.3 Coding of Models for the Hazard Rate 281

A Matrix Algebra **285**
A.1 Introduction 285
A.2 Trace of a Matrix 287
A.3 Determinant of a Matrix 288
A.4 Inverse of a Matrix 290
A.5 Orthogonal Matrices 291
A.6 Rank of a Matrix 292
A.7 Range and Null Space 292
A.8 Eigenvalues and Eigenvectors 293
A.9 Decomposition of Matrices 295
A.10 Definite Matrices and Quadratic Forms 298
A.11 Idempotent Matrices 304

A.12 Generalized Inverse 305
A.13 Projectors 314
A.14 Functions of Normally Distributed Variables 315
A.15 Differentiation of Scalar Functions of Matrices 318
A.16 Miscellaneous Results, Stochastic Convergence 321

B Tables **325**

References **329**

Index **345**