|     | Preface   | xxi  |
|-----|---|------|
|     | Acknowledgments   | xxix |
| I   | INTRODUCTION AND BACKGROUND                                   | 1    |
| 1   | Introduction  | 3    |
| 1.1 | Causal Relationships and Ceteris Paribus Analysis             | 3    |
| 12  | Stochastic Setting and Asymptotic Analysis                    | 4    |
|     | 1.2.1 Data Structures   | 4    |
|     | 1.2.2 Asymptotic Analysis                                     | 7    |
| 13  | Some Examples   | 7    |
| 1.4 | Why Not Fixed Explanatory Variables?                          | 9    |
| 2   | Conditional Expectations and Related Concepts in Econometrics | 13   |
| 21  | Role of Conditional Expectations in Econometrics              | 13   |
| 2.2 | Features of Conditional Expectations                          | 14   |
|     | 2.2.1 Definition and Examples                                 | 14   |
|     | 2.2.2 Partial Effects, Elasticities, and Semielasticities     | 15   |
|     | 2.2.3 Error Form of Models of Conditional Expectations        | 18   |
|     | 2.2.4 Some Properties of Conditional Expectations             | 19   |
|     | 2.2.5 Average Partial Effects                                 | 22   |
| 2.3 | Linear Projections  | 25   |
|     | Problems  |      |
|     | Appendix 2A   | 30   |
|     | 2.A.1 Properties of Conditional Expectations                  | 30   |
|     | 2.A.2 Properties of Conditional Variances and Covariances     | 32   |
|     | 2.A.3 Properties of Linear Projections                        | 34   |
| 3   | Basic Asymptotic Theory                                       | 37   |
| 3.1 | Convergence of Deterministic Sequences                        | 37   |
| 3.2 | Convergence in Probability and Boundedness in Probability     | 38   |
| 3.3 | Convergence in Distribution                                   | 40   |
| 3.4 | Limit Theorems for Random Samples                             | 41   |
| 3.5 | Limiting Behavior of Estimators and Test Statistics           | 42   |
|     | 3.5.1 Asymptotic Properties of Estimators                     | 42   |
|     | 3.5.2 Asymptotic Properties of Test Statistics                | 45   |
|     | Problems  | 47   |

| II  | LINE   | AR MODELS  | 51  |
|-----|--|--|-----|
| 4   | _  | -Equation Linear Model and Ordinary Least Squares            | 53  |
|     | Estima   |  |     |
| 4.1 |  | iew of the Single-Equation Linear Model                      | 53  |
| 4.2 | Asymı  | ptotic Properties of Ordinary Least Squares                  | 55  |
|     | 4.2.1  | Consistency  | 56  |
|     | 4.2.2  | Asymptotic Inference Using Ordinary Least Squares            | 59  |
|     | 4.2.3  | Heteroskedasticity-Robust Inference                          | 60  |
|     |  |  | 62  |
| 4.3 |  | ary Least Squares Solutions to the Omitted Variables Problem | 65  |
|     | 4.3.1  | Ordinary Least Squares Ignoring the Omitted Variables        | 65  |
|     | 4.3.2  | Proxy Variable-Ordinary Least Squares Solution               | 67  |
|     | 4.3.3  | Models with Interactions in Unobservables: Random            |     |
|     |  | Coefficient Models   | 73  |
| 4.4 | -  | rties of Ordinary Least Squares under Measurement Error      | 76  |
|     | 4.4.1  | Measurement Error in the Dependent Variable                  | 76  |
|     | 4.4.2  | Measurement Error in an Explanatory Variable                 | 78  |
|     | Proble   | ems  | 82  |
| 5   | Instru   | mental Variables Estimation of Single-Equation Linear Models | 89  |
| 5.1 | Instrumental Variables and Two-Stage Least Squares |  |     |
|     | 5.1.1  | Motivation for Instrumental Variables Estimation             | 89  |
|     | 5.1.2  | Multiple Instruments: Two-Stage Least Squares                | 96  |
| 5.2 | General Treatment of Two-Stage Least Squares       |  | 98  |
|     | 5.2.1  | Consistency  | 98  |
|     | 5.2.2  | Asymptotic Normality of Two-Stage Least Squares              | 101 |
|     | 5.2.3  | Asymptotic Efficiency of Two-Stage Least Squares             | 103 |
|     | 5.2.4  | Hypothesis Testing with Two-Stage Least Squares              | 104 |
|     | 5.2.5  | Heteroskedasticity-Robust Inference for Two-Stage Least      |     |
|     |  | Squares  | 106 |
|     | 5.2.6  | Potential Pitfalls with Two-Stage Least Squares              | 107 |
| 5.3 |  | lutions to the Omitted Variables and Measurement Error       |     |
|     | Proble   |  | 112 |
|     | 5.3.1  | Leaving the Omitted Factors in the Error Term                | 112 |
|     | 5.3.2  | Solutions Using Indicators of the Unobservables              | 112 |
|     | Proble   | ems  | 115 |

| 6   | Additi  | ional Single-Equation Topics                                 | 123 |  |
|-----|---|--|-----|--|
| 6.1 | Estimation with Generated Regressors and Instruments              |  |     |  |
|     | 6.1.1   | Ordinary Least Squares with Generated Regressors             | 123 |  |
|     | 6.1.2   | Two-Stage Least Squares with Generated Instruments           | 124 |  |
|     | 6.1.3   | Generated Instruments and Regressors                         | 125 |  |
| 6.2 | Contr   | ol Function Approach to Endogeneity                          | 126 |  |
| 6.3 | Some Specification Tests  |  |     |  |
|     | 6.3.1   | Testing for Endogeneity                                      | 129 |  |
|     | 6.3.2   | Testing Overidentifying Restrictions                         | 134 |  |
|     | 6.3.3   | Testing Functional Form                                      | 137 |  |
|     | 6.3.4   | Testing for Heteroskedasticity                               | 138 |  |
| 6.4 | Corre   | lated Random Coefficient Models                              | 141 |  |
|     | 6.4.1   | When Is the Usual IV Estimator Consistent?                   | 142 |  |
|     | 6.4.2   | Control Function Approach                                    | 145 |  |
| 6.5 | Pooled Cross Sections and Difference-in-Differences Estimation 14 |  |     |  |
|     | 6.5.1   | Pooled Cross Sections over Time                              | 146 |  |
|     | 6.5.2   | Policy Analysis and Difference-in-Differences Estimation     | 147 |  |
|     | Proble  | ems  | 152 |  |
|     | Apper   | ndix 6A  | 157 |  |
| 7   | Estim   | ating Systems of Equations by Ordinary Least Squares and     |     |  |
|     |   | ralized Least Squares  | 161 |  |
| 7.1 | Introd  | luction  | 161 |  |
| 7.2 | Some  | Examples   | 161 |  |
| 7.3 | System Ordinary Least Squares Estimation of a Multivariate Linear |  |     |  |
|     | System 1  |  |     |  |
|     | 7.3.1   | Preliminaries  | 166 |  |
|     | 7.3.2   | Asymptotic Properties of System Ordinary Least Squares       | 167 |  |
|     | 7.3.3   | Testing Multiple Hypotheses                                  | 172 |  |
| 7.4 | Consi   | stency and Asymptotic Normality of Generalized Least Squares | 173 |  |
|     | 7.4.1   | Consistency  | 173 |  |
|     | 7.4.2   | Asymptotic Normality   | 175 |  |
| 7.5 | Feasil  | ble Generalized Least Squares                                | 176 |  |
|     | 7.5.1   | Asymptotic Properties  | 176 |  |
|     | 7.5.2   | Asymptotic Variance of Feasible Generalized Least Squares    |     |  |
|     |   | under a Standard Assumption                                  | 180 |  |

|     | 7.5.3  | Properties of Feasible Generalized Least Squares with       |       |
|-----|--------|---|-------|
|     |        | (Possibly Incorrect) Restrictions on the Unconditional      |       |
|     |        | Variance Matrix   | 182   |
| 7.6 | Testin | g the Use of Feasible Generalized Least Squares             | 183   |
| 7.7 | Seemi  | ngly Unrelated Regressions, Revisited                       | 185   |
|     | 7.7.1  | Comparison between Ordinary Least Squares and Feasible      |       |
|     |        | Generalized Least Squares for Seemingly Unrelated           |       |
|     |        | Regressions Systems   | 185   |
|     | 7.7.2  | Systems with Cross Equation Restrictions                    | 188   |
|     | 7.7.3  | Singular Variance Matrices in Seemingly Unrelated           |       |
|     |        | Regressions Systems   | 189   |
| 7.8 | Linea  | r Panel Data Model, Revisited                               | 191   |
|     | 7.8.1  | Assumptions for Pooled Ordinary Least Squares               | 191   |
|     | 7.8.2  | Dynamic Completeness  | 194   |
|     | 7.8.3  | Note on Time Series Persistence                             | 196   |
|     | 7.8.4  | Robust Asymptotic Variance Matrix                           | 197   |
|     | 7.8.5  | Testing for Serial Correlation and Heteroskedasticity after |       |
|     |        | Pooled Ordinary Least Squares                               | 198   |
|     | 7.8.6  | Feasible Generalized Least Squares Estimation under Strict  | • • • |
|     |        | Exogeneity  | 200   |
|     | Proble | ems   | 202   |
| 8   | Syster | m Estimation by Instrumental Variables                      | 207   |
| 8.1 | Introd | fuction and Examples  | 207   |
| 8.2 | Gener  | ral Linear System of Equations                              | 210   |
| 8.3 | Gener  | ralized Method of Moments Estimation                        | 213   |
|     | 8.3.1  | General Weighting Matrix                                    | 213   |
|     | 8.3.2  | System Two-Stage Least Squares Estimator                    | 216   |
|     | 8.3.3  | Optimal Weighting Matrix                                    | 217   |
|     | 8.3.4  | The Generalized Method of Moments Three-Stage Least         |       |
|     |        | Squares Estimator   | 219   |
| 8.4 | Gene   | ralized Instrumental Variables Estimator                    | 222   |
|     | 8.4.1  | Derivation of the Generalized Instrumental Variables        |       |
|     |        | Estimator and Its Asymptotic Properties                     | 222   |
|     | 8.4.2  | Comparison of Generalized Method of Moment,                 |       |
|     |        | Generalized Instrumental Variables, and the Traditional     |       |
|     |        | Three-Stage Least Squares Estimator                         | 224   |

| 8.5  | Testin | g Using Generalized Method of Moments                         | 226 |
|------|--------|---|-----|
|      | 8.5.1  | Testing Classical Hypotheses                                  | 226 |
|      | 8.5.2  | Testing Overidentification Restrictions                       | 228 |
| 8.6  | More   | Efficient Estimation and Optimal Instruments                  | 229 |
| 8.7  | Summ   | ary Comments on Choosing an Estimator                         | 232 |
|      | Proble | ems   | 233 |
| •    | Simul  | taneous Equations Models                                      | 239 |
| 9.1  | Scope  | of Simultaneous Equations Models                              | 239 |
| 9.2  | Identi | fication in a Linear System                                   | 241 |
|      | 9.2.1  | Exclusion Restrictions and Reduced Forms                      | 241 |
|      | 9.2.2  | General Linear Restrictions and Structural Equations          | 245 |
|      | 9.2.3  | Unidentified, Just Identified, and Overidentified Equations   | 251 |
| 9.3  | Estima | ation after Identification                                    | 252 |
|      | 9.3.1  | Robustness-Efficiency Trade-off                               | 252 |
|      | 9.3.2  | When Are 2SLS and 3SLS Equivalent?                            | 254 |
|      | 9.3.3  | Estimating the Reduced Form Parameters                        | 255 |
| 9.4  | Addit  | ional Topics in Linear Simultaneous Equations Methods         | 256 |
|      | 9.4.1  | Using Cross Equation Restrictions to Achieve Identification   | 256 |
|      | 9.4.2  | Using Covariance Restrictions to Achieve Identification       | 257 |
|      | 9.4.3  | Subtleties Concerning Identification and Efficiency in Linear |     |
|      |        | Systems   | 260 |
| 9.5  | Simul  | taneous Equations Models Nonlinear in Endogenous              |     |
|      | Varial | bles  | 262 |
|      | 9.5.1  | Identification  | 262 |
|      | 9.5.2  | Estimation  | 266 |
|      | 9.5.3  | Control Function Estimation for Triangular Systems            | 268 |
| 9.6  | Differ | ent Instruments for Different Equations                       | 271 |
|      | Proble | ems   | 273 |
| 10   | Basic  | Linear Unobserved Effects Panel Data Models                   | 281 |
| 10.1 | Motiv  | ration: Omitted Variables Problem                             | 281 |
| 10.2 | Assun  | aptions about the Unobserved Effects and Explanatory          |     |
|      | Varial | bles  | 285 |
|      | 10.2.1 | Random or Fixed Effects?                                      | 285 |
|      | 10.2.2 | Strict Exogeneity Assumptions on the Explanatory Variables    | 287 |
|      | 10.2.3 | Some Examples of Unobserved Effects Panel Data Models         | 289 |

| 10.3 | 144   | ting Unobserved Effects Models by Pooled Ordinary Least | 291 |  |
|------|---|---|-----|--|
| 10.4 | Square  | s<br>m Effects Methods                                  | 291 |  |
| 10.4 | 10.4.1  | Estimation and Inference under the Basic Random Effects | 2)1 |  |
|      | 10.4.1  | Assumptions   | 291 |  |
|      | 10.4.2  | Robust Variance Matrix Estimator                        | 297 |  |
|      |   | General Feasible Generalized Least Squares Analysis     | 298 |  |
|      | 10.4.4  | Testing for the Presence of an Unobserved Effect        | 299 |  |
| 10.5 |   | Effects Methods   | 300 |  |
|      | 10.5.1  | Consistency of the Fixed Effects Estimator              | 300 |  |
|      |   | Asymptotic Inference with Fixed Effects                 | 304 |  |
|      |   | Dummy Variable Regression                               | 307 |  |
|      | 10.5.4  | Serial Correlation and the Robust Variance Matrix       |     |  |
|      |   | Estimator   | 310 |  |
|      | 10.5.5  | Fixed Effects Generalized Least Squares                 | 312 |  |
|      | 10.5.6  | Using Fixed Effects Estimation for Policy Analysis      | 315 |  |
| 10.6 | First D   | differencing Methods                                    | 315 |  |
|      | 10.6.1  | Inference   | 315 |  |
|      | 10.6.2  | Robust Variance Matrix                                  | 318 |  |
|      | 10.6.3  | Testing for Serial Correlation                          | 319 |  |
|      | 10.6.4  | Policy Analysis Using First Differencing                | 320 |  |
| 10.7 | Compa   | arison of Estimators                                    | 321 |  |
|      | 10.7.1  | Fixed Effects versus First Differencing                 | 321 |  |
|      | 10.7.2  | Relationship between the Random Effects and Fixed       |     |  |
|      |   | Effects Estimators                                      | 326 |  |
|      | 10.7.3  | Hausman Test Comparing Random Effects and Fixed         |     |  |
|      |   | Effects Estimators                                      | 328 |  |
|      | Proble  | ms  | 334 |  |
| 11   | More 7  | Topics in Linear Unobserved Effects Models              | 345 |  |
| 11.1 | Genera  | alized Method of Moments Approaches to the Standard     |     |  |
|      | Linear  | Unobserved Effects Model                                | 345 |  |
|      | 11.1.1  | Equivalance between GMM 3SLS and Standard Estimators    | 345 |  |
|      |   | Chamberlain's Approach to Unobserved Effects Models     | 347 |  |
| 11.2 | Rando   | m and Fixed Effects Instrumental Variables Methods      | 349 |  |
| 11.3 | Hausm   | nan and Taylor-Type Models                              | 358 |  |
| 11.4 | First Differencing Instrumental Variables Methods |   |     |  |

| 11.5 | Unobs                              | erved Effects Models with Measurement Error            | 365 |
|------|------------------------------------|--|-----|
| 11.6 | Estima                             | tion under Sequential Exogeneity                       | 368 |
|      | 11.6.1                             | General Framework                                      | 368 |
|      | 11.6.2                             | Models with Lagged Dependent Variables                 | 371 |
| 11.7 | Models                             | s with Individual-Specific Slopes                      | 374 |
|      | 11.7.1                             | Random Trend Model                                     | 375 |
|      | 11.7.2                             | General Models with Individual-Specific Slopes         | 377 |
|      | 11.7.3                             | Robustness of Standard Fixed Effects Methods           | 382 |
|      | 11.7.4                             | Testing for Correlated Random Slopes                   | 384 |
|      | Proble                             | ms   | 387 |
| Ш    | GENE                               | RAL APPROACHES TO NONLINEAR ESTIMATION                 | 395 |
| 12   | M-Esti                             | mation, Nonlinear Regression, and Quantile Regression  | 397 |
| 12.1 | Introd                             | action   | 397 |
| 12.2 | Identif                            | cation, Uniform Convergence, and Consistency           | 401 |
| 12.3 | Asymp                              | totic Normality  | 405 |
| 12.4 | Two-Step M-Estimators              |  |     |
|      | 12.4.1                             | Consistency  | 410 |
|      | 12.4.2                             | Asymptotic Normality                                   | 411 |
| 12.5 | Estimating the Asymptotic Variance |  | 413 |
|      | 12.5.1                             | Estimation without Nuisance Parameters                 | 413 |
|      | 12.5.2                             | Adjustments for Two-Step Estimation                    | 418 |
| 12.6 | Hypoth                             | nesis Testing  | 420 |
|      | 12.6.1                             | Wald Tests   | 420 |
|      | 12.6.2                             | Score (or Lagrange Multiplier) Tests                   | 421 |
|      | 12.6.3                             | Tests Based on the Change in the Objective Function    | 428 |
|      | 12.6.4                             | Behavior of the Statistics under Alternatives          | 430 |
| 12.7 | Optimi                             | zation Methods   | 431 |
|      | 12.7.1                             | Newton-Raphson Method                                  | 432 |
|      | 12.7.2                             | Berndt, Hall, Hall, and Hausman Algorithm              | 433 |
|      | 12.7.3                             | Generalized Gauss-Newton Method                        | 434 |
|      | 12.7.4                             | Concentrating Parameters out of the Objective Function | 435 |
| 12.8 | Simula                             | tion and Resampling Methods                            | 436 |
|      | 12.8.1                             | Monte Carlo Simulation                                 | 436 |
|      | 12.8.2                             | Bootstrapping  | 438 |

| 12.9  | Multivariate Nonlinear Regression Methods                     | 442 |
|-------|---|-----|
|       | 12.9.1 Multivariate Nonlinear Least Squares                   | 442 |
|       | 12.9.2 Weighted Multivariate Nonlinear Least Squares          | 444 |
| 12.10 | Quantile Estimation   | 449 |
|       | 12.10.1 Quantiles, the Estimation Problem, and Consistency    | 449 |
|       | 12.10.2 Asymptotic Inference                                  | 454 |
|       | 12.10.3 Quantile Regression for Panel Data                    | 459 |
|       | Problems  | 462 |
| 13    | Maximum Likelihood Methods                                    | 469 |
| 13.1  | Introduction  | 469 |
| 13.2  | Preliminaries and Examples                                    | 470 |
| 13.3  | General Framework for Conditional Maximum Likelihood          |     |
|       | Estimation  | 473 |
| 13.4  | Consistency of Conditional Maximum Likelihood Estimation      | 475 |
| 13.5  | Asymptotic Normality and Asymptotic Variance Estimation       | 476 |
|       | 13.5.1 Asymptotic Normality                                   | 476 |
|       | 13.5.2 Estimating the Asymptotic Variance                     | 479 |
| 13.6  | Hypothesis Testing  | 481 |
| 13.7  | Specification Testing   | 482 |
| 13.8  | Partial (or Pooled) Likelihood Methods for Panel Data         |     |
|       | 13.8.1 Setup for Panel Data                                   | 486 |
|       | 13.8.2 Asymptotic Inference                                   | 490 |
|       | 13.8.3 Inference with Dynamically Complete Models             | 492 |
| 13.9  | Panel Data Models with Unobserved Effects                     | 494 |
|       | 13.9.1 Models with Strictly Exogenous Explanatory Variables   | 494 |
|       | 13.9.2 Models with Lagged Dependent Variables                 | 497 |
| 13.10 | Two-Step Estimators Involving Maximum Likelihood              | 499 |
|       | 13.10.1 Second-Step Estimator Is Maximum Likelihood Estimator | 499 |
|       | 13.10.2 Surprising Efficiency Result When the First-Step      |     |
|       | Estimator Is Conditional Maximum Likelihood Estimator         | 500 |
| 13.11 | Quasi-Maximum Likelihood Estimation                           | 502 |
|       | 13.11.1 General Misspecification                              | 502 |
|       | 13.11.2 Model Selection Tests                                 | 505 |
|       | 13.11.3 Quasi-Maximum Likelihood Estimation in the Linear     |     |
|       | Exponential Family  | 509 |

|      | Problem              |  | 514<br>517 |
|------|----------------------|--|------------|
|      | Append               |  | 522        |
| 14   | General              | ized Method of Moments and Minimum Distance Estimation   | 525        |
| 14.1 | Asympt               | otic Properties of Generalized Method of Moments         | 525        |
| 14.2 |                      | ion under Orthogonality Conditions                       | 530        |
| 14.3 | Systems              | s of Nonlinear Equations                                 | 532        |
| 14.4 | Efficient Estimation |  |            |
|      | 14.4.1               | General Efficiency Framework                             | 538        |
|      | 14.4.2               | Efficiency of Maximum Likelihood Estimator               | 540        |
|      | 14.4.3               | Efficient Choice of Instruments under Conditional Moment |            |
|      |                      | Restrictions   | 542        |
| 14.5 | Classica             | al Minimum Distance Estimation                           | 545        |
| 14.6 | Panel I              | Data Applications  | 547        |
|      | 14.6.1               | Nonlinear Dynamic Models                                 | 547        |
|      | 14.6.2               | Minimum Distance Approach to the Unobserved Effects      |            |
|      |                      | Model  | 549        |
|      | 14.6.3               | Models with Time-Varying Coefficients on the Unobserved  |            |
|      |                      | Effects  | 551        |
|      | Probler              | ms   | 555        |
|      | Append               | lix 14A  | 558        |
| IV   | NONL                 | INEAR MODELS AND RELATED TOPICS                          | 559        |
| 15   | Binary               | Response Models  | 561        |
| 15.1 | Introdu              | action   | 561        |
| 15.2 | Linear               | Probability Model for Binary Response                    | 562        |
| 15.3 | Index N              | Models for Binary Response: Probit and Logit             | 565        |
| 15.4 | Maxim                | um Likelihood Estimation of Binary Response Index        |            |
|      | Models               | 3  | 567        |
| 15.5 | Testing              | in Binary Response Index Models                          | 569        |
|      | 15.5.1               | Testing Multiple Exclusion Restrictions                  | 570        |
|      | 15.5.2               | Testing Nonlinear Hypotheses about $\beta$               | 571        |
|      | 1553                 | Tests against More General Alternatives                  | 571        |

| 15.6 | Repor                       | ting the Results for Probit and Logit                    | 573 |
|------|-----------------------------|--|-----|
| 15.7 | Specifi                     | cation Issues in Binary Response Models                  | 582 |
|      | 15.7.1                      | Neglected Heterogeneity                                  | 582 |
|      | 15.7.2                      | Continuous Endogenous Explanatory Variables              | 583 |
|      | 15.7.3                      |  | 594 |
|      | 15.7.4                      | Heteroskedasticity and Nonnormality in the Latent        |     |
|      |                             | Variable Model   | 599 |
|      | 15.7.5                      | Estimation under Weaker Assumptions                      | 604 |
| 15.8 | Binary                      | Response Models for Panel Data                           | 608 |
|      | 15.8.1                      | Pooled Probit and Logit                                  | 609 |
|      | 15.8.2                      | Unobserved Effects Probit Models under Strict Exogeneity | 610 |
|      | 15.8.3                      | Unobserved Effects Logit Models under Strict Exogeneity  | 619 |
|      | 15.8.4                      | Dynamic Unobserved Effects Models                        | 625 |
|      | 15.8.5                      | Probit Models with Heterogeneity and Endogenous          |     |
|      |                             | Explanatory Variables                                    | 630 |
|      | 15.8.6                      | Semiparametric Approaches                                | 632 |
|      | Proble                      | ms   | 635 |
| 16   | Multin                      | omial and Ordered Response Models                        | 643 |
| 16.1 | Introdu                     | action   | 643 |
| 16.2 | Multinomial Response Models |  |     |
|      | 16.2.1                      | Multinomial Logit  | 643 |
|      | 16.2.2                      | Probabilistic Choice Models                              | 646 |
|      | 16.2.3                      | Endogenous Explanatory Variables                         | 651 |
|      |                             | Panel Data Methods                                       | 653 |
| 16.3 | Ordere                      | d Response Models  | 655 |
|      | 16.3.1                      | Ordered Logit and Ordered Probit                         | 655 |
|      | 16.3.2                      | Specification Issues in Ordered Models                   | 658 |
|      | 16.3.3                      | Endogenous Explanatory Variables                         | 660 |
|      | 16.3.4                      | Panel Data Methods                                       | 662 |
|      | Problems                    |  | 663 |
| 17   | Corner                      | Solution Responses                                       | 667 |
| 17.1 | Motiva                      | tion and Examples  | 667 |
| 17.2 | Useful                      | Expressions for Type I Tobit                             | 671 |

| 17.3 | Estima             | tion and Inference with the Type I Tobit Model         | 676 |  |
|------|--------------------|--|-----|--|
| 17.4 | Report             | ing the Results  | 677 |  |
| 17.5 | Specific           | cation Issues in Tobit Models                          | 680 |  |
|      | 17.5.1             | Neglected Heterogeneity                                | 680 |  |
|      | 17.5.2             | Endogenous Explanatory Models                          | 681 |  |
|      | 17.5.3             | Heteroskedasticity and Nonnormality in the Latent      |     |  |
|      |                    | Variable Model   | 685 |  |
|      | 17.5.4             | Estimating Parameters with Weaker Assumptions          | 687 |  |
| 17.6 | Two-Pa             | art Models and Type II Tobit for Corner Solutions      | 690 |  |
|      | 17.6.1             | Truncated Normal Hurdle Model                          | 692 |  |
|      | 17.6.2             | Lognormal Hurdle Model and Exponential Conditional     |     |  |
|      |                    | Mean   | 694 |  |
|      | 17.6.3             | Exponential Type II Tobit Model                        | 697 |  |
| 17.7 | Two-L              | imit Tobit Model                                       | 703 |  |
| 17.8 | Panel Data Methods |  |     |  |
|      | 17.8.1             | Pooled Methods   | 705 |  |
|      | 17.8.2             | Unobserved Effects Models under Strict Exogeneity      | 707 |  |
|      | 17.8.3             | Dynamic Unobserved Effects Tobit Models                | 713 |  |
|      | Proble             | ms   | 715 |  |
| 18   | Count,             | Fractional, and Other Nonnegative Responses            | 723 |  |
| 18.1 | Introdu            | uction   | 723 |  |
| 18.2 | Poisson            | n Regression   | 724 |  |
|      | 18.2.1             | Assumptions Used for Poisson Regression and Quantities |     |  |
|      |                    | of Interest  | 724 |  |
|      | 18.2.2             | Consistency of the Poisson QMLE                        | 727 |  |
|      | 18.2.3             | Asymptotic Normality of the Poisson QMLE               | 728 |  |
|      | 18.2.4             | Hypothesis Testing                                     | 732 |  |
|      | 18.2.5             | 1.5  | 734 |  |
| 18.3 | Other              | Count Data Regression Models                           | 736 |  |
|      | 18.3.1             |  | 736 |  |
|      | 18.3.2             |  | 739 |  |
| 18.4 |                    | na (Exponential) Regression Model                      | 740 |  |
| 18.5 |                    | Endogeneity with an Exponential Regression Function    |     |  |
| 18.6 | -                  | onal Responses   | 748 |  |

xvi Contents

|      | 18.6.1   | Exogenous Explanatory Variables                    | 748 |
|------|--|--|-----|
|      | 18.6.2   | Endogenous Explanatory Variables                   | 753 |
| 18.7 | Panel Data Methods   |  |     |
|      | 18.7.1   | Pooled QMLE  | 756 |
|      | 18.7.2   | Specifying Models of Conditional Expectations with |     |
|      |  | Unobserved Effects                                 | 758 |
|      | 18.7.3   | Random Effects Methods                             | 759 |
|      | 18.7.4   | Fixed Effects Poisson Estimation                   | 762 |
|      | 18.7.5   | Relaxing the Strict Exogeneity Assumption          | 764 |
|      | 18.7.6   | Fractional Response Models for Panel Data          | 766 |
|      | Problem  | ms   | 769 |
| 19   | Censor   | ed Data, Sample Selection, and Attrition           | 777 |
| 19.1 | Introdu  | action   | 777 |
| 19.2 | Data C   | Censoring  | 778 |
|      | 19.2.1   | Binary Censoring                                   | 780 |
|      |  | Interval Coding                                    | 783 |
|      | 19.2.3   | Censoring from Above and Below                     | 785 |
| 19.3 | Overvi   | ew of Sample Selection                             | 790 |
| 19.4 | When 6   | Can Sample Selection Be Ignored?                   | 792 |
|      | 19.4.1   | Linear Models: Estimation by OLS and 2SLS          | 792 |
|      | 19.4.2   | Nonlinear Models                                   | 798 |
| 19.5 | Selection on the Basis of the Response Variable: Truncated |  |     |
|      | Regress  | sion   | 799 |
| 19.6 | Inciden  | ntal Truncation: A Probit Selection Equation       | 802 |
|      | 19.6.1   | Exogenous Explanatory Variables                    | 802 |
|      | 19.6.2   | Endogenous Explanatory Variables                   | 809 |
|      | 19.6.3   | Binary Response Model with Sample Selection        | 813 |
|      | 19.6.4   | An Exponential Response Function                   | 814 |
| 19.7 | Inciden  | ntal Truncation: A Tobit Selection Equation        | 815 |
|      | 19.7.1   | Exogenous Explanatory Variables                    | 815 |
|      | 19.7.2   | Endogenous Explanatory Variables                   | 817 |
|      | 19.7.3   | Estimating Structural Tobit Equations with Sample  |     |
|      |  | Selection  | 819 |
| 19.8 | Inverse  | Probability Weighting for Missing Data             | 821 |

Contents xvii

| 19.9 | Sample   | Selection and Attrition in Linear Panel Data Models   | 827        |  |
|------|--|---|------------|--|
|      | 19.9.1   | Fixed and Random Effects Estimation with Unbalanced   |            |  |
|      |  | Panels  | 828        |  |
|      | 19.9.2   | Testing and Correcting for Sample Selection Bias      | 832        |  |
|      | 19.9.3   | Attrition   | 837        |  |
|      | Probler  | ns  | 845        |  |
| 20   | Stratifi   | ed Sampling and Cluster Sampling                      | 853        |  |
| 20.1 | Introdu  | action  | 853        |  |
| 20.2 | Stratific  | ed Sampling   | 854        |  |
|      | 20.2.1   | Standard Stratified Sampling and Variable Probability |            |  |
|      |  | Sampling  | 854        |  |
|      | 20.2.2   | Weighted Estimators to Account for Stratification     | 856        |  |
|      | 20.2.3   | Stratification Based on Exogenous Variables           | 861        |  |
| 20.3 | Cluster  | Cluster Sampling                                      |            |  |
|      | 20.3.1   | Inference with a Large Number of Clusters and Small   |            |  |
|      |  | Cluster Sizes   | 864        |  |
|      | 20.3.2   | Cluster Samples with Unit-Specific Panel Data         | 876        |  |
|      | 20.3.3   | Should We Apply Cluster-Robust Inference with Large   |            |  |
|      |  | Group Sizes?  | 883        |  |
|      | 20.3.4   | Inference When the Number of Clusters Is Small        | 884<br>894 |  |
| 20.4 | -  | Complex Survey Sampling                               |            |  |
|      | Problem  | ms  | 899        |  |
| 21   | Estima   | ting Average Treatment Effects                        | 903        |  |
| 21.1 | Introd   | action  | 903        |  |
| 21.2 | A Cou  | Counterfactual Setting and the Self-Selection Problem |            |  |
| 21.3 | Methods Assuming Ignorability (or Unconfoundedness) of |   |            |  |
|      | Treatment  |   |            |  |
|      | 21.3.1   | Identification  | 911        |  |
|      | 21.3.2   | Regression Adjustment                                 | 915        |  |
|      | 21.3.3   | Propensity Score Methods                              | 920        |  |
|      | 21.3.4   | Combining Regression Adjustment and Propensity Score  |            |  |
|      |  | Weighting   | 930        |  |
|      | 21.3.5   | Matching Methods                                      | 934        |  |

| 21.4 | Instrumental Variables Methods                               |   | 937  |
|------|--|---|------|
|      | 21.4.1   | Estimating the Average Treatment Effect Using IV          | 937  |
|      | 21.4.2   | Correction and Control Function Approaches                | 945  |
|      | 21.4.3   | Estimating the Local Average Treatment Effect by IV       | 951  |
| 21.5 | Regression Discontinuity Designs                             |   |      |
|      | 21.5.1   | The Sharp Regression Discontinuity Design                 | 954  |
|      | 21.5.2   | The Fuzzy Regression Discontinuity Design                 | 957  |
|      | 21.5.3   | Unconfoundedness versus the Fuzzy Regression              |      |
|      |  | Discontinuity   | 959  |
| 21.6 | Furthe   | Further Issues  |      |
|      | 21.6.1   | Special Considerations for Responses with Discreteness or |      |
|      |  | Limited Range   | 960  |
|      | 21.6.2   | Multivalued Treatments                                    | 961  |
|      | 21.6.3   | Multiple Treatments                                       | 964  |
|      | 21.6.4   | Panel Data  | 968  |
|      | Problems   |   | 975  |
| 22   | Duratio  | ion Analysis  |      |
| 22.1 | Introdu  | uction  |      |
| 22.2 | Hazaro   | 1 Functions   | 984  |
|      | 22.2.1   | Hazard Functions without Covariates                       | 984  |
|      | 22.2.2   | Hazard Functions Conditional on Time-Invariant            |      |
|      |  | Covariates  | 988  |
|      | 22.2.3   | Hazard Functions Conditional on Time-Varying              |      |
|      |  | Covariates  | 989  |
| 22.3 | Analysis of Single-Spell Data with Time-Invariant Covariates |   | 991  |
|      | 22.3.1   | Flow Sampling   | 992  |
|      | 22.3.2   | Maximum Likelihood Estimation with Censored Flow          |      |
|      |  | Data  | 993  |
|      | 22.3.3   | Stock Sampling  | 1000 |
|      | 22.3.4   | Unobserved Heterogeneity                                  | 1003 |
| 22.4 | Analysis of Grouped Duration Data                            |   | 1010 |
|      | 22.4.1   | Time-Invariant Covariates                                 | 1011 |
|      | 22.4.2   | Time-Varying Covariates                                   | 1015 |
|      | 22.4.3   | Unobserved Heterogeneity                                  | 1017 |

| v | 1 | • |
|---|---|---|

| 22.5 | Furthe     | r Issues   | 1018 |
|------|------------|--|------|
|      | 22.5.1     | Cox's Partial Likelihood Method for the Proportional |      |
|      |            | Hazard Model   | 1018 |
|      | 22.5.2     | Multiple-Spell Data                                  | 1018 |
|      | 22.5.3     | Competing Risks Models                               | 1019 |
|      | Problems   |  | 1019 |
|      | References |  |      |
|      | Index      |  | 1045 |