Principles of Econometrics

Fourth Edition

International Student version

R. Carter Hill

Louisiana State University

William E. Griffiths

University of Melbourne

Guay C. Lim

University of Melbourne

WILEY

John Wiley & Sons, Inc.

Contents

Preface v

Chapter 1 An Introduction to Econometrics 1

1.1 Why Study Econometrics? 1
1.2 What Is Econometrics About? 2
1.2.1 Some Examples 3
1.3 The Econometric Model 4
1.4 How Are Data Generated? 5
1.4.1 Experimental Data 5
1.4.2 Nonexperimental Data 6
1.5 Economic Data Types 6
1.5.1 Time-Series Data 7
1.5.2 Cross-Section Data 8
1.5.3 Panel or Longitudinal Data 8
1.6 The Research Process 9
1.7 Writing An Empirical Research Paper 11
1.7.1 Writing a Research Proposal 11
1.7.2 A Format for Writing a Research Report 11
1.8 Sources of Economic Data 13
1.8.1 Links to Economic Data on the Internet 13
1.8.2 Interpreting Economic Data 14
1.8.3 Obtaining the Data 14

Probability Primer 17

Learning Objectives 17
Keywords 18
P.1 Random Variables 18
P.2 Probability Distributions 19
P.3 Joint, Marginal, and Conditional Probabilities 21
P.3.1 Marginal Distributions 22
P.3.2 Conditional Probability 22
P.3.3 Statistical Independence 23
P.4 A Digression: Summation Notation 24
P.5 Properties of Probability Distributions 26
P.5.1 Expected Value of a Random Variable 26
P.5.2 Conditional Expectation 27
P.5.3 Rules for Expected Values 27

P.5.4 Variance of a Random Variable 28
P.5.5 Expected Values of Several Random Variables 30
P.5.6 Covariance Between Two Random Variables 30
P.6 The Normal Distribution 32
P.7 Exercises 34

Chapter 2 The Simple Linear Regression Model 39

Learning Objectives 39
Keywords 40
2.1 An Economic Model 40
2.2 An Econometric Model 43
2.2.1 Introducing the Error Term 46
2.3 Estimating the Regression Parameters 49
2.3.1 The Least Squares Principle 51
2.3.2 Estimates for the Food Expenditure Function 53
2.3.3 Interpreting the Estimates 53
2.3.3a Elasticities 54
2.3.3b Prediction 55
2.3.3c Computer Output 55
2.3.4 Other Economic Models 56
2.4 Assessing the Least Squares Estimators 56
2.4.1 The Estimator b_2 57
2.4.2 The Expected Values of b_1 and b_2 58
2.4.3 Repeated Sampling 59
2.4.4 The Variances and Covariance of b_1 and b_2 60
2.5 The Gauss-Markov Theorem 62
2.6 The Probability Distributions of the Least Squares Estimators 63
2.7 Estimating the Variance of the Error Term 64
2.7.1 Estimating the Variances and Covariance of the Least Squares Estimators 65
2.7.2 Calculations for the Food Expenditure Data 65
2.7.3 Interpreting the Standard Errors 67
2.8 Estimating Nonlinear Relationships 68
2.8.1 Quadratic Functions 69
2.8.2 Using a Quadratic Model 69
2.8.3 A Log-Linear Function 70
2.8.4 Using a Log-Linear Model 71
2.8.5 Choosing a Functional Form 73
2.9 Regression with Indicator Variables 74
2.10 Exercises 75
2.10.1 Problems 75
2.10.2 Computer Exercises 78
Appendix 2A Derivation of the Least Squares Estimates 83
Appendix 2B Deviation from the Mean Form of b_2 84
Appendix 2C b_2 Is a Linear Estimator 85
Appendix 2D Derivation of Theoretical Expression for b_2 85
Appendix 2E Deriving the Variance of b_2 86
Appendix 2F Proof of the Gauss-Markov Theorem 87

Appendix 2G Monte Carlo Simulation 88
2G.1 The Regression Function 88
2G.2 The Random Error 89
2G.3 Theoretically True Values 90
2G.4 Creating a Sample of Data 91
2G.5 Monte Carlo Objectives 92
2G.6 Monte Carlo Results 92

Chapter 3 Interval Estimation and Hypothesis Testing 94

Learning Objectives 94
Keywords 94
3.1 Interval Estimation 95
3.1.1 The t-Distribution 95
3.1.2 Obtaining Interval Estimates 97
3.1.3 An Illustration 98
3.1.4 The Repeated Sampling Context 99
3.2 Hypothesis Tests 100
3.2.1 The Null Hypothesis 101
3.2.2 The Alternative Hypothesis 101
3.2.3 The Test Statistic 101
3.2.4 The Rejection Region 101
3.2.5 A Conclusion 102
3.3 Rejection Regions for Specific Alternatives 102
3.3.1 One-Tail Tests with Alternative "Greater Than" (>) 102
3.3.2 One-Tail Tests with Alternative "Less Than" (<) 103
3.3.3 Two-Tail Tests with Alternative "Not Equal To" ($\neq$) 104
3.4 Examples of Hypothesis Tests 105
3.4.1 Right-Tail Tests 105
3.4.1a One-Tail Test of Significance 105
3.4.1b One-Tail Test of an Economic Hypothesis 106
3.4.2 Left-Tail Tests 107
3.4.3 Two-Tail Tests 108
3.4.3a Two-Tail Test of an Economic Hypothesis 108
3.4.3b Two-Tail Test of Significance 109
3.5 The p-Value 110
3.5.1 p-Value for a Right-Tail Test 111
3.5.2 p-Value for a Left-Tail Test 112
3.5.3 p-Value for a Two-Tail Test 112
3.5.4 p-Value for a Two-Tail Test of Significance 113
3.6 Linear Combinations of Parameters 114
3.6.1 Estimating Expected Food Expenditure 115
3.6.2 An Interval Estimate of Expected Food Expenditure 115
3.6.3 Testing a Linear Combination of Parameters 116
3.6.4 Testing Expected Food Expenditure 117
3.7 Exercises 118
3.7.1 Problems 118
3.7.2 Computer Exercises 120
Appendix 3A Derivation of the t-Distribution 125
Appendix 3B Distribution of the t-Statistic under H_1 126

Appendix 3C Monte Carlo Simulation 127
3C.1 Repeated Sampling Properties of Interval Estimators 127
3C.2 Repeated Sampling Properties of Hypothesis Tests 128
3C.3 Choosing The Number Of Monte Carlo Samples 129

Chapter 4 Prediction, Goodness-of-Fit, and Modeling Issues 130

Learning Objectives 130
Keywords 131
4.1 Least Squares Prediction 131
4.1.1 Prediction in the Food Expenditure Model 134
4.2 Measuring Goodness-of-Fit 135
4.2.1 Correlation Analysis 137
4.2.2 Correlation Analysis and R^2 137
4.2.3 The Food Expenditure Example 138
4.2.4 Reporting the Results 138
4.3 Modeling Issues 139
4.3.1 The Effects of Scaling the Data 139
4.3.2 Choosing a Functional Form 140
4.3.3 A Linear-Log Food Expenditure Model 143
4.3.4 Using Diagnostic Residual Plots 145
4.3.4a Heteroskedastic Residual Pattern 146
4.3.4b Detecting Model Specification Errors 147
4.3.5 Are the Regression Errors Normally Distributed? 147
4.4 Polynomial Models 149
4.4.1 Quadratic and Cubic Equations 149
4.4.2 An Empirical Example 149
4.5 Log-Linear Models 151
4.5.1 A Growth Model 152
4.5.2 A Wage Equation 153
4.5.3 Prediction in the Log-Linear Model 153
4.5.4 A Generalized R^2 Measure 154
4.5.5 Prediction Intervals in the Log-Linear Model 155
4.6 Log-Log Models 156
4.6.1 A Log-Log Poultry Demand Equation 156
4.7 Exercises 157
4.7.1 Problems 157
4.7.2 Computer Exercises 159
Appendix 4A Development of a Prediction Interval 163
Appendix 4B The Sum of Squares Decomposition 164
Appendix 4C The Log-Normal Distribution 165

Chapter 5 The Multiple Regression Model 167

Learning Objectives 167
Keywords 168
5.1 Introduction 168
5.1.1 The Economic Model 168
5.1.2 The Econometric Model 170
5.1.2a The General Model 172
5.1.2b The Assumptions of the Model 172

5.2 Estimating the Parameters of the Multiple Regression Model 174
5.2.1 Least Squares Estimation Procedure 174
5.2.2 Least Squares Estimates Using Hamburger Chain Data 175
5.2.3 Estimation of the Error Variance σ^2 176
5.3 Sampling Properties of the Least Squares Estimator 177
5.3.1 The Variances and Covariances of the Least Squares Estimators 178
5.3.2 The Distribution of the Least Squares Estimators 180
5.4 Interval Estimation 182
5.4.1 Interval Estimation for a Single Coefficient 182
5.4.2 Interval Estimation for a Linear Combination of Coefficients 183
5.5 Hypothesis Testing 184
5.5.1 Testing the Significance of a Single Coefficient 185
5.5.2 One-Tail Hypothesis Testing for a Single Coefficient 187
5.5.2a Testing for Elastic Demand 187
5.5.2b Testing Advertising Effectiveness 188
5.5.3 Hypothesis Testing for a Linear Combination of Coefficients 188
5.6 Polynomial Equations 189
5.6.1 Cost and Product Curves 190
5.6.2 Extending the Model for Burger Barn Sales 192
5.6.3 The Optimal Level of Advertising: Inference for a Nonlinear Combination of Coefficients 193
5.7 Interaction Variables 195
5.7.1 Log-Linear Models 197
5.8 Measuring Goodness-of-Fit 198
5.9 Exercises 199
5.9.1 Problems 199
5.9.2 Computer Exercises 203
Appendix 5A Derivation of Least Squares Estimators 210
Appendix 5B Large Sample Analysis 211
5B.1 Consistency 211
5B.2 Asymptotic Normality 213
5B.3 Monte Carlo Simulation 213
5B.4 The Delta Method 215
5B.4.1 Nonlinear Functions of a Single Parameter 215
5B.4.2 The Delta Method Illustrated 216
5B.4.3 Monte Carlo Simulation of the Delta Method 217
5B.5 The Delta Method Extended 217
5B.5.1 The Delta Method Illustrated: Continued 218
5B.5.2 Monte Carlo Simulation of the Extended Delta Method 219

Chapter 6 Further Inference in the Multiple Regression Model 221
Learning Objectives 221
Keywords 222
6.1 Testing Joint Hypotheses 222
6.1.1 Testing the Effect of Advertising: The *F*-Test 223
6.1.2 Testing the Significance of the Model 225
6.1.3 The Relationship Between *t*- and *F*-Tests 227

6.1.4 More General F-Tests 228
6.1.4a A One-Tail Test 230
6.1.5 Using Computer Software 230
6.2 The Use of Nonsample Information 231
6.3 Model Specification 233
6.3.1 Omitted Variables 234
6.3.2 Irrelevant Variables 235
6.3.3 Choosing the Model 236
6.3.4 Model Selection Criteria 237
6.3.4a The Adjusted Coefficient of Determination 237
6.3.4b Information Criteria 238
6.3.4c An Example 238
6.3.5 RESET 238
6.4 Poor Data, Collinearity, and Insignificance 240
6.4.1 The Consequences of Collinearity 240
6.4.2 An Example 241
6.4.3 Identifying and Mitigating Collinearity 242
6.5 Prediction 243
6.5.1 An Example 244
6.6 Exercises 246
6.6.1 Problems 246
6.6.2 Computer Exercises 248
Appendix 6A Chi-Square and F-tests: More Details 254
Appendix 6B Omitted-Variable Bias: A Proof 256

Chapter 7 Using Indicator Variables 258

Learning Objectives 258
Keywords 258
7.1 Indicator Variables 259
7.1.1 Intercept Indicator Variables 260
7.1.1a Choosing the Reference Group 261
7.1.2 Slope-Indicator Variables 261
7.1.3 An Example: The University Effect on House Prices 263
7.2 Applying Indicator Variables 264
7.2.1 Interactions Between Qualitative Factors 265
7.2.2 Qualitative Factors with Several Categories 266
7.2.3 Testing the Equivalence of Two Regressions 268
7.2.4 Controlling for Time 270
7.2.4a Seasonal Indicators 270
7.2.4b Year Indicators 271
7.2.4c Regime Effects 271
7.3 Log-Linear Models 271
7.3.1 A Rough Calculation 272
7.3.2 An Exact Calculation 272
7.4 The Linear Probability Model 273
7.4.1 A Marketing Example 274
7.5 Treatment Effects 275
7.5.1 The Difference Estimator 276
7.5.2 Analysis of the Difference Estimator 277

7.5.3 Application of Difference Estimation: Project STAR 278
7.5.4 The Difference Estimator with Additional Controls 279
7.5.4a School Fixed Effects 280
7.5.4b Linear Probability Model Check of Random Assignment 281
7.5.5 The Differences-in-Differences Estimator 282
7.5.6 Estimating the Effect of a Minimum Wage Change 284
7.5.7 Using Panel Data 286
7.6 Exercises 287
7.6.1 Problems 287
7.6.2 Computer Exercises 290
Appendix 7A Details of Log-Linear Model Interpretation 296
Appendix 7B Derivation of the Differences-in-Differences Estimator 297

Chapter 8 Heteroskedasticity 298

Learning Objectives 298
Keywords 298
8.1 The Nature of Heteroskedasticity 299
8.1.1 Consequences for the Least Squares Estimator 302
8.2 Detecting Heteroskedasticity 303
8.2.1 Residual Plots 303
8.2.2 Lagrange Multiplier Tests 303
8.2.2a The White Test 306
8.2.2b Testing the Food Expenditure Example 306
8.2.3 The Goldfeld-Quandt Test 307
8.2.3a The Food Expenditure Example 308
8.3 Heteroskedasticity-Consistent Standard Errors 309
8.4 Generalized Least Squares: Known Form of Variance 311
8.4.1 Variance Proportional to x 311
8.4.1a Transforming the Model 311
8.4.1b Weighted Least Squares 312
8.4.1c Food Expenditure Estimates 313
8.4.2 Grouped Data 313
8.5 Generalized Least Squares: Unknown Form of Variance 315
8.5.1 Using Robust Standard Errors 318
8.6 Heteroskedasticity in the Linear Probability Model 319
8.6.1 The Marketing Example Revisited 320
8.7 Exercises 321
8.7.1 Problems 321
8.7.2 Computer Exercises 325
Appendix 8A Properties of the Least Squares Estimator 331
Appendix 8B Lagrange Multiplier Tests for Heteroskedasticity 332

Chapter 9 Regression with Time-Series Data: Stationary Variables 335

Learning Objectives 335
Keywords 336
9.1 Introduction 336
9.1.1 Dynamic Nature of Relationships 337
9.1.2 Least Squares Assumptions 339
9.1.2a Stationarity 339

9.1.3 Alternative Paths Through the Chapter 339
9.2 Finite Distributed Lags 341
9.2.1 Assumptions 343
9.2.2 An Example: Okun's Law 343
9.3 Serial Correlation 347
9.3.1 Serial Correlation in Output Growth 347
9.3.1a Computing Autocorrelations 348
9.3.1b The Correlogram 349
9.3.2 Serially Correlated Errors 350
9.3.2a A Phillips Curve 351
9.4 Other Tests for Serially Correlated Errors 353
9.4.1 A Lagrange Multiplier Test 353
9.4.1a Testing Correlation at Longer Lags 355
9.4.2 The Durbin-Watson Test 355
9.5 Estimation with Serially Correlated Errors 356
9.5.1 Least Squares Estimation 357
9.5.2 Estimating an AR(1) Error Model 358
9.5.2a Properties of an AR(1) Error 359
9.5.2b Nonlinear Least Squares Estimation 361
9.5.2c Generalized Least Squares Estimation 362
9.5.3 Estimating a More General Model 362
9.5.4 Summary of Section 9.5 and Looking Ahead 364
9.6 Autoregressive Distributed Lag Models 365
9.6.1 The Phillips Curve 367
9.6.2 Okun's Law 369
9.6.3 Autoregressive Models 370
9.7 Forecasting 372
9.7.1 Forecasting with an AR Model 372
9.7.2 Forecasting with an ARDL Model 374
9.7.3 Exponential Smoothing 375
9.8 Multiplier Analysis 378
9.9 Exercises 382
9.9.1 Problems 382
9.9.2 Computer Exercises 386
Appendix 9A The Durbin-Watson Test 392
9A.1 The Durbin-Watson Bounds Test 394
Appendix 9B Properties of an AR(1) Error 396
Appendix 9C Generalized Least Squares Estimation 397

Chapter 10 Random Regressors and Moment-Based Estimation 400

Learning Objectives 400
Keywords 401
10.1 Linear Regression with Random x's 401
10.1.1 The Small Sample Properties of the Least Squares Estimator 402
10.1.2 Large Sample Properties of the Least Squares Estimator 403
10.1.3 Why Least Squares Estimation Fails 404
10.2 Cases in Which x and e Are Correlated 405
10.2.1 Measurement Error 405

10.2.2 Simultaneous Equations Bias 406
10.2.3 Omitted Variables 407
10.2.4 Least Squares Estimation of a Wage Equation 407
10.3 Estimators Based on the Method of Moments 408
10.3.1 Method of Moments Estimation of a Population Mean and Variance 408
10.3.2 Method of Moments Estimation in the Simple Linear Regression Model 409
10.3.3 Instrumental Variables Estimation in the Simple Linear Regression Model 410
10.3.3a The Importance of Using Strong Instruments 411
10.3.4 Instrumental Variables Estimation in the Multiple Regression Model 411
10.3.4a Using Surplus Instruments in Simple Regression 412
10.3.4b Surplus Moment Conditions 413
10.3.5 Assessing Instrument Strength Using the First Stage Model 414
10.3.5a One Instrumental Variable 414
10.3.5b More Than One Instrumental Variable 414
10.3.6 Instrumental Variables Estimation of the Wage Equation 415
10.3.7 Partial Correlation 416
10.3.8 Instrumental Variables Estimation in a General Model 417
10.3.8a Assessing Instrument Strength in a General Model 418
10.3.8b Hypothesis Testing with Instrumental Variables Estimates 419
10.3.8c Goodness-of-Fit with Instrumental Variables Estimates 419
10.4 Specification Tests 419
10.4.1 The Hausman Test for Endogeneity 420
10.4.2 Testing Instrument Validity 421
10.4.3 Specification Tests for the Wage Equation 422
10.5 Exercises 423
10.5.1 Problems 423
10.5.2 Computer Exercises 424
Appendix 10A Conditional and Iterated Expectations 428
10.A.1 Conditional Expectations 429
10.A.2 Iterated Expectations 429
10.A.3 Regression Model Applications 430
Appendix 10B The Inconsistency of the Least Squares Estimator 430
Appendix 10C The Consistency of the *IV* Estimator 431
Appendix 10D The Logic of the Hausman Test 432
Appendix 10E Testing for Weak Instruments 434
10E.1 A Test for Weak Identification 435
10E.2 Examples of Testing for Weak Identification 437
10E.3 Testing for Weak Identification: Conclusions 439
Appendix 10F Monte Carlo Simulation 440
10F.1 Illustrations Using Simulated Data 440
10F.1.1 The Hausman Test 441
10F.1.2 Test for Weak Instruments 442
10F.1.3 Testing the Validity of Surplus Instruments 442
10F.2 The Repeated Sampling Properties of *IV/2SLS* 442

Chapter 11 Simultaneous Equations Models **446**

Learning Objectives 446
Keywords 446
11.1 A Supply and Demand Model 447
11.2 The Reduced-Form Equations 449
11.3 The Failure of Least Squares Estimation 450
11.4 The Identification Problem 450
11.5 Two-Stage Least Squares Estimation 452
11.5.1 The General Two-Stage Least Squares Estimation Procedure 453
11.5.2 The Properties of the Two-Stage Least Squares Estimator 454
11.6 An Example of Two-Stage Least Squares Estimation 454
11.6.1 Identification 455
11.6.2 The Reduced-Form Equations 455
11.6.3 The Structural Equations 456
11.7 Supply and Demand at the Fulton Fish Market 457
11.7.1 Identification 458
11.7.2 The Reduced-Form Equations 458
11.7.3 Two-Stage Least Squares Estimation of Fish Demand 460
11.8 Exercises 461
11.8.1 Problems 461
11.8.2 Computer Exercises 462
Appendix 11A An Algebraic Explanation of the Failure of Least Squares 466
Appendix 11B *2SLS* Alternatives 467
11.B.1 The *k*-Class of Estimators 467
11.B.2 The *LIML* Estimator 468
11.B.2.1 Fuller's Modified *LIML* 469
11.B.2.2 Advantages of *LIML* 469
11.B.2.3 Stock-Yogo Weak *IV* Tests for *LIML* 470
11B.2.3a Testing for Weak Instruments with *LIML* 471
11B.2.3b Testing for Weak Instruments with Fuller Modified *LIML* 472
11.B.3 Monte Carlo Simulation Results 473

Chapter 12 Regression with Time-Series Data: Nonstationary Variables **474**

Learning Objectives 474
Keywords 474
12.1 Stationary and Nonstationary Variables 475
12.1.1 The First-Order Autoregressive Model 477
12.1.2 Random Walk Models 480
12.2 Spurious Regressions 482
12.3 Unit Root Tests for Stationarity 484
12.3.1 Dickey–Fuller Test 1 (No Constant and No Trend) 484
12.3.2 Dickey–Fuller Test 2 (With Constant but No Trend) 484
12.3.3 Dickey–Fuller Test 3 (With Constant and With Trend) 485
12.3.4 The Dickey–Fuller Critical Values 485

12.3.5 The Dickey Fuller Testing Procedures 486
12.3.6 The Dickey–Fuller Tests: An Example 487
12.3.7 Order of Integration 487
12.4 Cointegration 488
12.4.1 An Example of a Cointegration Test 489
12.4.2 The Error Correction Model 490
12.5 Regression When There Is No Cointegration 492
12.5.1 First Difference Stationary 492
12.5.2 Trend Stationary 493
12.5.3 Summary 494
12.6 Exercises 494
12.6.1 Problems 494
12.6.2 Computer Exercises 496

Chapter 13 Vector Error Correction and Vector Autoregressive Models 498

Learning Objectives 498
Keywords 498
13.1 VEC and VAR Models 499
13.2 Estimating a Vector Error Correction Model 501
13.2.1 Example 501
13.3 Estimating a VAR Model 503
13.4 Impulse Responses and Variance Decompositions 505
13.4.1 Impulse Response Functions 505
13.4.1a The Univariate Case 505
13.4.1b The Bivariate Case 505
13.4.2 Forecast Error Variance Decompositions 507
13.4.2a Univariate Analysis 508
13.4.2b Bivariate Analysis 508
13.4.2c The General Case 509
13.5 Exercises 510
13.5.1 Problems 510
13.5.2 Computer Exercises 511
Appendix 13A The Identification Problem 516

Chapter 14 Time-Varying Volatility and ARCH Models 517

Learning Objectives 517
Keywords 517
14.1 The ARCH Model 518
14.2 Time-Varying Volatility 520
14.3 Testing, Estimating, and Forecasting 523
14.3.1 Testing for ARCH Effects 523
14.3.2 Estimating ARCH Models 524
14.3.3 Forecasting Volatility 525
14.4 Extensions 525
14.4.1 The GARCH Model—Generalized ARCH 526
14.4.2 Allowing for an Asymmetric Effect 526
14.4.3 GARCH-In-Mean and Time-Varying Risk Premium 528

14.5 Exercises 529
14.5.1 Problems 529
14.5.2 Computer Exercises 530

Chapter 15 Panel Data Models 537

Learning Objectives 537
Keywords 538
15.1 A Microeconomic Panel 539
15.2 Pooled Model 540
15.2.1 Cluster-Robust Standard Errors 541
15.2.2 Pooled Least Squares Estimates of Wage Equation 542
15.3 The Fixed Effects Model 543
15.3.1 The Least Squares Dummy Variable Estimator for Small N 544
15.3.2 The Fixed Effects Estimator 547
15.3.2a Fixed Effects Estimates of Wage Equation for $N = 10$ 548
15.3.3 Fixed Effects Estimates of Wage Equation from Complete Panel 549
15.4 The Random Effects Model 551
15.4.1 Error Term Assumptions 552
15.4.2 Testing for Random Effects 553
15.4.3 Estimation of the Random Effects Model 555
15.4.4 Random Effects Estimation of the Wage Equation 555
15.5 Comparing Fixed and Random Effects Estimators 557
15.5.1 Endogeneity in the Random Effects Model 557
15.5.2 The Fixed Effects Estimator in a Random Effects Model 558
15.5.3 A Hausman Test 558
15.6 The Hausman-Taylor Estimator 560
15.7 Sets of Regression Equations 561
15.7.1 Grunfeld's Investment Data 562
15.7.2 Estimation: Equal Coefficients, Equal Error Variances 564
15.7.3 Estimation: Different Coefficients, Equal Error Variances 564
15.7.4 Estimation: Different Coefficients, Different Error Variances 565
15.7.5 Seemingly Unrelated Regressions 566
15.7.5a Separate or Joint Estimation? 568
15.7.5b Testing Cross-Equation Hypotheses 569
15.8 Exercises 570
15.8.1 Problems 570
15.8.2 Computer Exercises 572
Appendix 15A Cluster-Robust Standard Errors: Some Details 581
Appendix 15B Estimation of Error Components 583

Chapter 16 Qualitative and Limited Dependent Variable Models 585

Learning Objectives 585
Keywords 585
16.1 Models with Binary Dependent Variables 586
16.1.1 The Linear Probability Model 587
16.1.2 The Probit Model 589
16.1.3 Interpretation of the Probit Model 590

16.1.4 Maximum Likelihood Estimation of the Probit Model 591
16.1.5 A Transportation Example 592
16.1.6 Further Post-estimation Analysis 593
16.2 The Logit Model for Binary Choice 595
16.2.1 An Empirical Example from Marketing 595
16.2.2 Wald Hypothesis Tests 597
16.2.3 Likelihood Ratio Hypothesis Tests 598
16.3 Multinomial Logit 599
16.3.1 Multinomial Logit Choice Probabilities 599
16.3.2 Maximum Likelihood Estimation 600
16.3.3 Post-estimation Analysis 601
16.3.4 An Example 602
16.4 Conditional Logit 604
16.4.1 Conditional Logit Choice Probabilities 604
16.4.2 Post-estimation Analysis 605
16.4.3 An Example 606
16.5 Ordered Choice Models 607
16.5.1 Ordinal Probit Choice Probabilities 607
16.5.2 Estimation and Interpretation 609
16.5.3 An Example 610
16.6 Models for Count Data 611
16.6.1 Maximum Likelihood Estimation 611
16.6.2 Interpretation in the Poisson Regression Model 612
16.6.3 An Example 613
16.7 Limited Dependent Variables 614
16.7.1 Censored Data 614
16.7.2 A Monte Carlo Experiment 615
16.7.3 Maximum Likelihood Estimation 617
16.7.4 Tobit Model Interpretation 619
16.7.5 An Example 620
16.7.6 Sample Selection 620
16.7.6a The Econometric Model 621
16.7.6b Heckit Example: Wages of Married Women 622
16.8 Exercises 624
Appendix 16A Probit Marginal Effects: Details 631
16.A.1 Standard Error of Marginal Effect at a Given Point 631
16.A.2 Standard Error of Average Marginal Effect 632

Appendix A Mathematical Tools 634

Learning Objectives 634
Keywords 634
A.1 Some Basics 635
A.1.1 Numbers 635
A.1.2 Exponents 635
A.1.3 Scientific Notation 635
A.1.4 Logarithms and the Number *e* 636
A.1.5 Decimals and Percentages 637
A.1.6 Logarithms and Percentages 638