

Introductory Econometrics

A MODERN APPROACH

SEVENTH EDITION

Jeffrey M. Wooldridge

Michigan State University

 CENGAGE

Australia • Brazil • Mexico • Singapore • United Kingdom • United States

Brief Contents

Chapter 1	The Nature of Econometrics and Economic Data	1
PART 1: Regression Analysis with Cross-Sectional Data		19
Chapter 2	The Simple Regression Model	20
Chapter 3	Multiple Regression Analysis: Estimation	66
Chapter 4	Multiple Regression Analysis: Inference	117
Chapter 5	Multiple Regression Analysis: OLS Asymptotics	163
Chapter 6	Multiple Regression Analysis: Further Issues	181
Chapter 7	Multiple Regression Analysis with Qualitative Information	220
Chapter 8	Heteroskedasticity	262
Chapter 9	More on Specification and Data Issues	294
PART 2: Regression Analysis with Time Series Data		333
Chapter 10	Basic Regression Analysis with Time Series Data	334
Chapter 11	Further Issues in Using OLS with Time Series Data	366
Chapter 12	Serial Correlation and Heteroskedasticity in Time Series Regressions	394
PART 3: Advanced Topics		425
Chapter 13	Pooling Cross Sections across Time: Simple Panel Data Methods	426
Chapter 14	Advanced Panel Data Methods	462
Chapter 15	Instrumental Variables Estimation and Two-Stage Least Squares	495
Chapter 16	Simultaneous Equations Models	534
Chapter 17	Limited Dependent Variable Models and Sample Selection Corrections	559
Chapter 18	Advanced Time Series Topics	604
Chapter 19	Carrying Out an Empirical Project	642
APPENDICES		
Math Refresher A	Basic Mathematical Tools	666
Math Refresher B	Fundamentals of Probability	684
Math Refresher C	Fundamentals of Mathematical Statistics	714
Advanced Treatment D	Summary of Matrix Algebra	749
Advanced Treatment E	The Linear Regression Model in Matrix Form	760
Answers to Going Further Questions		775
Statistical Tables		784
References		791
Glossary		797
Index		812

Contents

Preface xii
About the Author xxii

CHAPTER 1 The Nature of Econometrics and Economic Data 1

- 1-1 What Is Econometrics? 1
- 1-2 Steps in Empirical Economic Analysis 2
- 1-3 The Structure of Economic Data 5
 - 1-3a Cross-Sectional Data 5
 - 1-3b Time Series Data 7
 - 1-3c Pooled Cross Sections 8
 - 1-3d Panel or Longitudinal Data 9
 - 1-3e A Comment on Data Structures 10
- 1-4 Causality, Ceteris Paribus, and Counterfactual Reasoning 10
 - Summary 14
 - Key Terms 15
 - Problems 15
 - Computer Exercises 15

PART 1

Regression Analysis with Cross-Sectional Data 19

CHAPTER 2 The Simple Regression Model 20

- 2-1 Definition of the Simple Regression Model 20
- 2-2 Deriving the Ordinary Least Squares Estimates 24
 - 2-2a A Note on Terminology 31
- 2-3 Properties of OLS on Any Sample of Data 32
 - 2-3a Fitted Values and Residuals 32
 - 2-3b Algebraic Properties of OLS Statistics 32
 - 2-3c Goodness-of-Fit 35

- 2-4 Units of Measurement and Functional Form 36
 - 2-4a The Effects of Changing Units of Measurement on OLS Statistics 36
 - 2-4b Incorporating Nonlinearities in Simple Regression 37
 - 2-4c The Meaning of "Linear" Regression 40
- 2-5 Expected Values and Variances of the OLS Estimators 40
 - 2-5a Unbiasedness of OLS 40
 - 2-5b Variances of the OLS Estimators 45
 - 2-5c Estimating the Error Variance 48
- 2-6 Regression through the Origin and Regression on a Constant 50
- 2-7 Regression on a Binary Explanatory Variable 51
 - 2-7a Counterfactual Outcomes, Causality, and Policy Analysis 53
- Summary 56
- Key Terms 57
- Problems 58
- Computer Exercises 62

CHAPTER 3 Multiple Regression Analysis: Estimation 66

- 3-1 Motivation for Multiple Regression 67
 - 3-1a The Model with Two Independent Variables 67
 - 3-1b The Model with k Independent Variables 69
- 3-2 Mechanics and Interpretation of Ordinary Least Squares 70
 - 3-2a Obtaining the OLS Estimates 70
 - 3-2b Interpreting the OLS Regression Equation 71
 - 3-2c On the Meaning of "Holding Other Factors Fixed" in Multiple Regression 73
 - 3-2d Changing More Than One Independent Variable Simultaneously 74

3-2e	<i>OLS Fitted Values and Residuals</i>	74
3-2f	<i>A "Partialling Out" Interpretation of Multiple Regression</i>	75
3-2g	<i>Comparison of Simple and Multiple Regression Estimates</i>	75
3-2h	<i>Goodness-of-Fit</i>	76
3-2i	<i>Regression through the Origin</i>	79
3-3	The Expected Value of the OLS Estimators	79
3-3a	<i>Including Irrelevant Variables in a Regression Model</i>	83
3-3b	<i>Omitted Variable Bias: The Simple Case</i>	84
3-3c	<i>Omitted Variable Bias: More General Cases</i>	87
3-4	The Variance of the OLS Estimators	87
3-4a	<i>The Components of the OLS Variances: Multicollinearity</i>	89
3-4b	<i>Variances in Misspecified Models</i>	92
3-4c	<i>Estimating σ^2: Standard Errors of the OLS Estimators</i>	93
3-5	Efficiency of OLS: The Gauss-Markov Theorem	95
3-6	Some Comments on the Language of Multiple Regression Analysis	96
3-7	Several Scenarios for Applying Multiple Regression	97
3-7a	<i>Prediction</i>	98
3-7b	<i>Efficient Markets</i>	98
3-7c	<i>Measuring the Tradeoff between Two Variables</i>	99
3-7d	<i>Testing for Ceteris Paribus Group Differences</i>	99
3-7e	<i>Potential Outcomes, Treatment Effects, and Policy Analysis</i>	100
	Summary	102
	Key Terms	104
	Problems	104
	Computer Exercises	109

CHAPTER 4 Multiple Regression Analysis: Inference 117

4-1	Sampling Distributions of the OLS Estimators	117
4-2	Testing Hypotheses about a Single Population Parameter: The <i>t</i> Test	120
4-2a	<i>Testing against One-Sided Alternatives</i>	122
4-2b	<i>Two-Sided Alternatives</i>	126
4-2c	<i>Testing Other Hypotheses about β_j</i>	128
4-2d	<i>Computing p-Values for <i>t</i> Tests</i>	130

4-2e	<i>A Reminder on the Language of Classical Hypothesis Testing</i>	132
4-2f	<i>Economic, or Practical, versus Statistical Significance</i>	132
4-3	Confidence Intervals	134
4-4	Testing Hypotheses about a Single Linear Combination of the Parameters	136
4-5	Testing Multiple Linear Restrictions: The <i>F</i> Test	139
4-5a	<i>Testing Exclusion Restrictions</i>	139
4-5b	<i>Relationship between <i>F</i> and <i>t</i> Statistics</i>	144
4-5c	<i>The R-Squared Form of the <i>F</i> Statistic</i>	145
4-5d	<i>Computing p-Values for <i>F</i> Tests</i>	146
4-5e	<i>The <i>F</i> Statistic for Overall Significance of a Regression</i>	147
4-5f	<i>Testing General Linear Restrictions</i>	148
4-6	Reporting Regression Results	149
4-7	Revisiting Causal Effects and Policy Analysis	151
	Summary	152
	Key Terms	154
	Problems	154
	Computer Exercises	159

CHAPTER 5 Multiple Regression Analysis: OLS Asymptotics 163

5-1	Consistency	164
5-1a	<i>Deriving the Inconsistency in OLS</i>	167
5-2	Asymptotic Normality and Large Sample Inference	168
5-2a	<i>Other Large Sample Tests: The Lagrange Multiplier Statistic</i>	172
5-3	Asymptotic Efficiency of OLS	175
	Summary	176
	Key Terms	176
	Problems	176
	Computer Exercises	178

CHAPTER 6 Multiple Regression Analysis: Further Issues 181

6-1	Effects of Data Scaling on OLS Statistics	181
6-1a	<i>Beta Coefficients</i>	184
6-2	More on Functional Form	186
6-2a	<i>More on Using Logarithmic Functional Forms</i>	186

6-2b *Models with Quadratics* 188
 6-2c *Models with Interaction Terms* 192
 6-2d *Computing Average Partial Effects* 194

6-3 More on Goodness-of-Fit and Selection of Regressors 195
 6-3a *Adjusted R-Squared* 196
 6-3b *Using Adjusted R-Squared to Choose between Nonnested Models* 197
 6-3c *Controlling for Too Many Factors in Regression Analysis* 199
 6-3d *Adding Regressors to Reduce the Error Variance* 200

6-4 Prediction and Residual Analysis 201
 6-4a *Confidence Intervals for Predictions* 201
 6-4b *Residual Analysis* 205
 6-4c *Predicting y When $\log(y)$ Is the Dependent Variable* 205
 6-4d *Predicting y When the Dependent Variable Is $\log(y)$* 207

Summary 209
 Key Terms 211
 Problems 211
 Computer Exercises 214

CHAPTER 7 Multiple Regression Analysis with Qualitative Information 220

7-1 Describing Qualitative Information 221

7-2 A Single Dummy Independent Variable 222
 7-2a *Interpreting Coefficients on Dummy Explanatory Variables When the Dependent Variable Is $\log(y)$* 226

7-3 Using Dummy Variables for Multiple Categories 228
 7-3a *Incorporating Ordinal Information by Using Dummy Variables* 230

7-4 Interactions Involving Dummy Variables 232
 7-4a *Interactions among Dummy Variables* 232
 7-4b *Allowing for Different Slopes* 233
 7-4c *Testing for Differences in Regression Functions across Groups* 237

7-5 A Binary Dependent Variable: The Linear Probability Model 239

7-6 More on Policy Analysis and Program Evaluation 244
 7-6a *Program Evaluation and Unrestricted Regression Adjustment* 245

7-7 Interpreting Regression Results with Discrete Dependent Variables 249

Summary 250
 Key Terms 251
 Problems 251
 Computer Exercises 256

CHAPTER 8 Heteroskedasticity 262

8-1 Consequences of Heteroskedasticity for OLS 262

8-2 Heteroskedasticity-Robust Inference after OLS Estimation 263
 8-2a *Computing Heteroskedasticity-Robust LM Tests* 267

8-3 Testing for Heteroskedasticity 269
 8-3a *The White Test for Heteroskedasticity* 271

8-4 Weighted Least Squares Estimation 273
 8-4a *The Heteroskedasticity Is Known up to a Multiplicative Constant* 273
 8-4b *The Heteroskedasticity Function Must Be Estimated: Feasible GLS* 278
 8-4c *What If the Assumed Heteroskedasticity Function Is Wrong?* 281
 8-4d *Prediction and Prediction Intervals with Heteroskedasticity* 283

8-5 The Linear Probability Model Revisited 284

Summary 286
 Key Terms 287
 Problems 287
 Computer Exercises 290

CHAPTER 9 More on Specification and Data Issues 294

9-1 Functional Form Misspecification 295
 9-1a *RESET as a General Test for Functional Form Misspecification* 297
 9-1b *Tests against Nonnested Alternatives* 298

9-2 Using Proxy Variables for Unobserved Explanatory Variables 299
 9-2a *Using Lagged Dependent Variables as Proxy Variables* 303
 9-2b *A Different Slant on Multiple Regression* 304
 9-2c *Potential Outcomes and Proxy Variables* 305

9-3 Models with Random Slopes 306

9-4 Properties of OLS under Measurement Error 308
 9-4a *Measurement Error in the Dependent Variable* 308

- 9-4b *Measurement Error in an Explanatory Variable* 310
- 9-5 Missing Data, Nonrandom Samples, and Outlying Observations 313
 - 9-5a *Missing Data* 313
 - 9-5b *Nonrandom Samples* 315
 - 9-5c *Outliers and Influential Observations* 317
- 9-6 Least Absolute Deviations Estimation 321
 - Summary 323
 - Key Terms 324
 - Problems 324
 - Computer Exercises 328

PART 2

Regression Analysis with Time Series Data 333

CHAPTER 10 Basic Regression Analysis with Time Series Data 334

- 10-1 The Nature of Time Series Data 334
- 10-2 Examples of Time Series Regression Models 335
 - 10-2a *Static Models* 336
 - 10-2b *Finite Distributed Lag Models* 336
 - 10-2c *A Convention about the Time Index* 338
- 10-3 Finite Sample Properties of OLS under Classical Assumptions 339
 - 10-3a *Unbiasedness of OLS* 339
 - 10-3b *The Variances of the OLS Estimators and the Gauss-Markov Theorem* 342
 - 10-3c *Inference under the Classical Linear Model Assumptions* 344
- 10-4 Functional Form, Dummy Variables, and Index Numbers 345
- 10-5 Trends and Seasonality 351
 - 10-5a *Characterizing Trending Time Series* 351
 - 10-5b *Using Trending Variables in Regression Analysis* 354
 - 10-5c *A Detrending Interpretation of Regressions with a Time Trend* 356
 - 10-5d *Computing R-Squared When the Dependent Variable Is Trending* 357
 - 10-5e *Seasonality* 358
- Summary 360
- Key Terms 361

- Problems 361
- Computer Exercises 363

CHAPTER 11 Further Issues in Using OLS with Time Series Data 366

- 11-1 Stationary and Weakly Dependent Time Series 367
 - 11-1a *Stationary and Nonstationary Time Series* 367
 - 11-1b *Weakly Dependent Time Series* 368
- 11-2 Asymptotic Properties of OLS 370
- 11-3 Using Highly Persistent Time Series in Regression Analysis 376
 - 11-3a *Highly Persistent Time Series* 376
 - 11-3b *Transformations on Highly Persistent Time Series* 380
 - 11-3c *Deciding Whether a Time Series Is I(1)* 381
- 11-4 Dynamically Complete Models and the Absence of Serial Correlation 382
- 11-5 The Homoskedasticity Assumption for Time Series Models 385
 - Summary 386
 - Key Terms 387
 - Problems 387
 - Computer Exercises 390

CHAPTER 12 Serial Correlation and Heteroskedasticity in Time Series Regressions 394

- 12-1 Properties of OLS with Serially Correlated Errors 395
 - 12-1a *Unbiasedness and Consistency* 395
 - 12-1b *Efficiency and Inference* 395
 - 12-1c *Goodness-of-Fit* 396
 - 12-1d *Serial Correlation in the Presence of Lagged Dependent Variables* 396
- 12-2 Serial Correlation–Robust Inference after OLS 398
- 12-3 Testing for Serial Correlation 401
 - 12-3a *A t Test for AR(1) Serial Correlation with Strictly Exogenous Regressors* 402
 - 12-3b *The Durbin-Watson Test under Classical Assumptions* 403
 - 12-3c *Testing for AR(1) Serial Correlation without Strictly Exogenous Regressors* 404
 - 12-3d *Testing for Higher-Order Serial Correlation* 406

- 12-4** Correcting for Serial Correlation with Strictly Exogenous Regressors 407
- 12-4a *Obtaining the Best Linear Unbiased Estimator in the AR(1) Model* 408
- 12-4b *Feasible GLS Estimation with AR(1) Errors* 409
- 12-4c *Comparing OLS and FGLS* 411
- 12-4d *Correcting for Higher-Order Serial Correlation* 413
- 12-4e *What if the Serial Correlation Model Is Wrong?* 413
- 12-5** Differencing and Serial Correlation 414
- 12-6** Heteroskedasticity in Time Series Regressions 415
- 12-6a *Heteroskedasticity-Robust Statistics* 416
- 12-6b *Testing for Heteroskedasticity* 416
- 12-6c *Autoregressive Conditional Heteroskedasticity* 417
- 12-6d *Heteroskedasticity and Serial Correlation in Regression Models* 418
- Summary 419
- Key Terms 420
- Problems 420
- Computer Exercises 421

PART 3

Advanced Topics 425

CHAPTER 13 Pooling Cross Sections across Time: Simple Panel Data Methods 426

- 13-1** Pooling Independent Cross Sections across Time 427
- 13-1a *The Chow Test for Structural Change across Time* 431
- 13-2** Policy Analysis with Pooled Cross Sections 431
- 13-2a *Adding an Additional Control Group* 436
- 13-2b *A General Framework for Policy Analysis with Pooled Cross Sections* 437
- 13-3** Two-Period Panel Data Analysis 439
- 13-3a *Organizing Panel Data* 444
- 13-4** Policy Analysis with Two-Period Panel Data 444
- 13-5** Differencing with More Than Two Time Periods 447
- 13-5a *Potential Pitfalls in First Differencing Panel Data* 451

- Summary 451
- Key Terms 452
- Problems 452
- Computer Exercises 453

CHAPTER 14 Advanced Panel Data Methods 462

- 14-1** Fixed Effects Estimation 463
- 14-1a *The Dummy Variable Regression* 466
- 14-1b *Fixed Effects or First Differencing?* 467
- 14-1c *Fixed Effects with Unbalanced Panels* 468
- 14-2** Random Effects Models 469
- 14-2a *Random Effects or Pooled OLS?* 473
- 14-2b *Random Effects or Fixed Effects?* 473
- 14-3** The Correlated Random Effects Approach 474
- 14-3a *Unbalanced Panels* 476
- 14-4** General Policy Analysis with Panel Data 477
- 14-4a *Advanced Considerations with Policy Analysis* 478
- 14-5** Applying Panel Data Methods to Other Data Structures 480
- Summary 483
- Key Terms 484
- Problems 484
- Computer Exercises 486

CHAPTER 15 Instrumental Variables Estimation and Two-Stage Least Squares 495

- 15-1** Motivation: Omitted Variables in a Simple Regression Model 496
- 15-1a *Statistical Inference with the IV Estimator* 500
- 15-1b *Properties of IV with a Poor Instrumental Variable* 503
- 15-1c *Computing R-Squared after IV Estimation* 505
- 15-2** IV Estimation of the Multiple Regression Model 505
- 15-3** Two-Stage Least Squares 509
- 15-3a *A Single Endogenous Explanatory Variable* 509
- 15-3b *Multicollinearity and 2SLS* 511
- 15-3c *Detecting Weak Instruments* 512
- 15-3d *Multiple Endogenous Explanatory Variables* 513
- 15-3e *Testing Multiple Hypotheses after 2SLS Estimation* 513

15-4	IV Solutions to Errors-in-Variables Problems	514	17-2	The Tobit Model for Corner Solution Responses	571
15-5	Testing for Endogeneity and Testing Overidentifying Restrictions	515	17-2a	<i>Interpreting the Tobit Estimates</i>	572
	15-5a <i>Testing for Endogeneity</i>	515	17-2b	<i>Specification Issues in Tobit Models</i>	578
	15-5b <i>Testing Overidentification Restrictions</i>	516	17-3	The Poisson Regression Model	578
15-6	2SLS with Heteroskedasticity	518	17-4	Censored and Truncated Regression Models	582
15-7	Applying 2SLS to Time Series Equations	519	17-4a	<i>Censored Regression Models</i>	583
15-8	Applying 2SLS to Pooled Cross Sections and Panel Data	521	17-4b	<i>Truncated Regression Models</i>	586
	Summary	522	17-5	Sample Selection Corrections	588
	Key Terms	523	17-5a	<i>When Is OLS on the Selected Sample Consistent?</i>	588
	Problems	523	17-5b	<i>Incidental Truncation</i>	589
	Computer Exercises	526		Summary	593
				Key Terms	593
				Problems	594
				Computer Exercises	596
<hr/>					
CHAPTER 16 Simultaneous Equations Models 534					
<hr/>					
16-1	The Nature of Simultaneous Equations Models	535	CHAPTER 18 Advanced Time Series Topics 604		
16-2	Simultaneity Bias in OLS	538	<hr/>		
16-3	Identifying and Estimating a Structural Equation	539	18-1	Infinite Distributed Lag Models	605
	16-3a <i>Identification in a Two-Equation System</i>	540	18-1a	<i>The Geometric (or Koyck) Distributed Lag Model</i>	607
	16-3b <i>Estimation by 2SLS</i>	543	18-1b	<i>Rational Distributed Lag Models</i>	608
16-4	Systems with More Than Two Equations	545	18-2	Testing for Unit Roots	610
	16-4a <i>Identification in Systems with Three or More Equations</i>	545	18-3	Spurious Regression	614
	16-4b <i>Estimation</i>	546	18-4	Cointegration and Error Correction Models	616
16-5	Simultaneous Equations Models with Time Series	546	18-4a	<i>Cointegration</i>	616
16-6	Simultaneous Equations Models with Panel Data	549	18-4b	<i>Error Correction Models</i>	620
	Summary	551	18-5	Forecasting	622
	Key Terms	552	18-5a	<i>Types of Regression Models Used for Forecasting</i>	623
	Problems	552	18-5b	<i>One-Step-Ahead Forecasting</i>	624
	Computer Exercises	555	18-5c	<i>Comparing One-Step-Ahead Forecasts</i>	627
			18-5d	<i>Multiple-Step-Ahead Forecasts</i>	628
			18-5e	<i>Forecasting Trending, Seasonal, and Integrated Processes</i>	631
<hr/>					
CHAPTER 17 Limited Dependent Variable Models and Sample Selection Corrections 559					
<hr/>					
17-1	Logit and Probit Models for Binary Response	560		Summary	635
	17-1a <i>Specifying Logit and Probit Models</i>	560		Key Terms	636
	17-1b <i>Maximum Likelihood Estimation of Logit and Probit Models</i>	563		Problems	636
	17-1c <i>Testing Multiple Hypotheses</i>	564		Computer Exercises	638
	17-1d <i>Interpreting the Logit and Probit Estimates</i>	565	<hr/>		
			CHAPTER 19 Carrying Out an Empirical Project 642		
			<hr/>		
			19-1	Posing a Question	642
			19-2	Literature Review	644

19-3 Data Collection 645
 19-3a *Deciding on the Appropriate Data Set* 645
 19-3b *Entering and Storing Your Data* 646
 19-3c *Inspecting, Cleaning, and Summarizing Your Data* 647

19-4 Econometric Analysis 648

19-5 Writing an Empirical Paper 651
 19-5a *Introduction* 651
 19-5b *Conceptual (or Theoretical) Framework* 652
 19-5c *Econometric Models and Estimation Methods* 652
 19-5d *The Data* 654
 19-5e *Results* 655
 19-5f *Conclusions* 656
 19-5g *Style Hints* 656

Summary 658
 Key Terms 658
 Sample Empirical Projects 658
 List of Journals 664
 Data Sources 665

MATH REFRESHER A Basic Mathematical Tools 666

A-1 The Summation Operator and Descriptive Statistics 666

A-2 Properties of Linear Functions 668

A-3 Proportions and Percentages 671

A-4 Some Special Functions and Their Properties 672
 A-4a *Quadratic Functions* 672
 A-4b *The Natural Logarithm* 674
 A-4c *The Exponential Function* 677

A-5 Differential Calculus 678
 Summary 680
 Key Terms 681
 Problems 681

MATH REFRESHER B Fundamentals of Probability 684

B-1 Random Variables and Their Probability Distributions 684
 B-1a *Discrete Random Variables* 685
 B-1b *Continuous Random Variables* 687

B-2 Joint Distributions, Conditional Distributions, and Independence 688
 B-2a *Joint Distributions and Independence* 688
 B-2b *Conditional Distributions* 690

B-3 Features of Probability Distributions 691
 B-3a *A Measure of Central Tendency: The Expected Value* 691
 B-3b *Properties of Expected Values* 692
 B-3c *Another Measure of Central Tendency: The Median* 694
 B-3d *Measures of Variability: Variance and Standard Deviation* 695
 B-3e *Variance* 695
 B-3f *Standard Deviation* 696
 B-3g *Standardizing a Random Variable* 696
 B-3h *Skewness and Kurtosis* 697

B-4 Features of Joint and Conditional Distributions 697
 B-4a *Measures of Association: Covariance and Correlation* 697
 B-4b *Covariance* 697
 B-4c *Correlation Coefficient* 698
 B-4d *Variance of Sums of Random Variables* 699
 B-4e *Conditional Expectation* 700
 B-4f *Properties of Conditional Expectation* 702
 B-4g *Conditional Variance* 704

B-5 The Normal and Related Distributions 704
 B-5a *The Normal Distribution* 704
 B-5b *The Standard Normal Distribution* 705
 B-5c *Additional Properties of the Normal Distribution* 707
 B-5d *The Chi-Square Distribution* 708
 B-5e *The t Distribution* 708
 B-5f *The F Distribution* 709

Summary 711
 Key Terms 711
 Problems 711

MATH REFRESHER C Fundamentals of Mathematical Statistics 714

C-1 Populations, Parameters, and Random Sampling 714
 C-1a *Sampling* 714

C-2 Finite Sample Properties of Estimators 715
 C-2a *Estimators and Estimates* 715
 C-2b *Unbiasedness* 716

C-2c <i>The Sampling Variance of Estimators</i>	718	D-2e <i>Partitioned Matrix Multiplication</i>	752
C-2d <i>Efficiency</i>	719	D-2f <i>Trace</i>	753
C-3 Asymptotic or Large Sample Properties of Estimators	721	D-2g <i>Inverse</i>	753
C-3a <i>Consistency</i>	721	D-3 Linear Independence and Rank of a Matrix	754
C-3b <i>Asymptotic Normality</i>	723	D-4 Quadratic Forms and Positive Definite Matrices	754
C-4 General Approaches to Parameter Estimation	724	D-5 Idempotent Matrices	755
C-4a <i>Method of Moments</i>	725	D-6 Differentiation of Linear and Quadratic Forms	755
C-4b <i>Maximum Likelihood</i>	725	D-7 Moments and Distributions of Random Vectors	756
C-4c <i>Least Squares</i>	726	D-7a <i>Expected Value</i>	756
C-5 Interval Estimation and Confidence Intervals	727	D-7b <i>Variance-Covariance Matrix</i>	756
C-5a <i>The Nature of Interval Estimation</i>	727	D-7c <i>Multivariate Normal Distribution</i>	756
C-5b <i>Confidence Intervals for the Mean from a Normally Distributed Population</i>	729	D-7d <i>Chi-Square Distribution</i>	757
C-5c <i>A Simple Rule of Thumb for a 95% Confidence Interval</i>	731	D-7e <i>t Distribution</i>	757
C-5d <i>Asymptotic Confidence Intervals for Nonnormal Populations</i>	732	D-7f <i>F Distribution</i>	757
C-6 Hypothesis Testing	733	Summary	757
C-6a <i>Fundamentals of Hypothesis Testing</i>	733	Key Terms	757
C-6b <i>Testing Hypotheses about the Mean in a Normal Population</i>	735	Problems	758
C-6c <i>Asymptotic Tests for Nonnormal Populations</i>	738		
C-6d <i>Computing and Using p-Values</i>	738		
C-6e <i>The Relationship between Confidence Intervals and Hypothesis Testing</i>	741		
C-6f <i>Practical versus Statistical Significance</i>	742		
C-7 Remarks on Notation	743		
Summary	743		
Key Terms	744		
Problems	744		

ADVANCED TREATMENT D Summary of Matrix Algebra 749

D-1 Basic Definitions	749
D-2 Matrix Operations	750
D-2a <i>Matrix Addition</i>	750
D-2b <i>Scalar Multiplication</i>	750
D-2c <i>Matrix Multiplication</i>	751
D-2d <i>Transpose</i>	752

ADVANCED TREATMENT E The Linear Regression Model in Matrix Form 760

E-1 The Model and Ordinary Least Squares Estimation	760
E-1a <i>The Frisch-Waugh Theorem</i>	762
E-2 Finite Sample Properties of OLS	763
E-3 Statistical Inference	767
E-4 Some Asymptotic Analysis	769
E-4a <i>Wald Statistics for Testing Multiple Hypotheses</i>	771
Summary	771
Key Terms	771
Problems	772
Answers to Going Further Questions	775
Statistical Tables	784
References	791
Glossary	797
Index	812