

This edition may be sold only in those countries to which it is consigned by Prentice-Hall International. It is not to be re-exported and is not for sale in the U.S.A., Mexico, or Canada.

Acquisitions Editor: Rod Banister
Editorial Assistant: William Becher
VP/Editorial Director: James Boyd
Assistant Editor: Gladys Soto
Marketing Manager: Lori Braumberger
Director of Production: Michael Weinstein
Production Manager: Gail Steier de Acevedo
Production Coordinator: Maureen Wilson
Permissions Coordinator: Monica Stipanov
Manufacturing Buyer: Natacha St. Hill Moore
Senior Manufacturing Manager: Vincent Scelta
Cover Design: Bruce Kenselaar
Cover Photo: George Hunter/Tony Stone Images
Full Service Composition: Progressive Publishing Alternatives



Copyright © 2000, 1997, 1993 by Prentice-Hall, Inc.
Upper Saddle River, New Jersey 07458

All rights reserved. No part of this book may be reproduced, in any form or by any means, without written permission from the Publisher.

0-13-015679-5

Prentice-Hall International (UK) Limited, London
Prentice-Hall of Australia Pty. Limited, Sydney
Prentice-Hall Canada, Inc., Toronto
Prentice-Hall Hispanoamericana, S.A., Mexico
Prentice-Hall of India Private Limited, New Delhi
Prentice-Hall of Japan, Inc., Tokyo
Prentice-Hall (Singapore) Pte Ltd.
Editora Prentice-Hall do Brasil, Ltda., Rio de Janeiro
Prentice-Hall, Upper Saddle River, New Jersey

Printed in the United States of America

10 9 8 7 6 5 4 3 2



Contents

PREFACE xxiii

CHAPTER 1 Introduction 1

- 1.1. Econometrics 1
- 1.2. Econometric Modeling 1
- 1.3. Theoretical and Applied Econometrics 5
- 1.4. Plan of the Book 6
- 1.5. Data and Software 7

CHAPTER 2 Matrix Algebra 9

- 2.1. Introduction 9
- 2.2. Some Terminology 9
- 2.3. Algebraic Manipulation of Matrices 11
 - 2.3.1. *Equality of Matrices* 11
 - 2.3.2. *Transposition* 11
 - 2.3.3. *Matrix Addition* 11
 - 2.3.4. *Matrix Multiplication* 12
 - 2.3.5. *Sums of Values* 14
 - 2.3.6. *A Useful Idempotent Matrix* 16
- 2.4. Geometry of Matrices 17
 - 2.4.1. *Vector Spaces* 18
 - 2.4.2. *Linear Combinations of Vectors and Basis Vectors* 19
 - 2.4.3. *Linear Dependence* 21
 - 2.4.4. *Subspaces* 21
 - 2.4.5. *Rank of a Matrix* 22
 - 2.4.6. *Determinant of a Matrix* 24
 - 2.4.7. *A Least Squares Problem* 27
- 2.5. Solution of a System of Linear Equations 29
 - 2.5.1. *Systems of Linear Equations* 29
 - 2.5.2. *Inverse Matrices* 30
 - 2.5.3. *Nonhomogeneous Systems of Equations* 32
- 2.6. Partitioned Matrices 33
 - 2.6.1. *Addition and Multiplication of Partitioned Matrices* 33
 - 2.6.2. *Determinants of Partitioned Matrices* 34
 - 2.6.3. *Inverses of Partitioned Matrices* 34

2.6.4. Deviations from Means	34
2.6.5. Kronecker Products	35
2.7. Characteristic Roots and Vectors	36
2.7.1. The Characteristic Equation	36
2.7.2. Characteristic Vectors	37
2.7.3. General Results for Characteristic Roots and Vectors	38
2.7.4. Diagonalization and Spectral Decomposition of a Matrix	38
2.7.5. Rank of a Matrix	39
2.7.6. Condition Number of a Matrix	40
2.7.7. Trace of a Matrix	40
2.7.8. Determinant of a Matrix	41
2.7.9. Powers of a Matrix	42
2.7.10. Idempotent Matrices	43
2.7.11. Factoring a Matrix	44
2.7.12. The Generalized Inverse of a Matrix	45
2.8. Quadratic Forms and Definite Matrices	46
2.8.1. Nonnegative Definite Matrices	47
2.8.2. Idempotent Quadratic Forms	48
2.8.3. Ranking Matrices	48
2.9. Calculus and Matrix Algebra	49
2.9.1. Differentiation and the Taylor Series	49
2.9.2. Optimization	53
2.9.3. Constrained Optimization	55
2.9.4. Transformations	57
Exercises	58

CHAPTER 3 Probability and Distribution Theory 61

3.1. Introduction	61
3.2. Random Variables	61
3.2.1. Probability Distributions	61
3.2.2. Cumulative Distribution Function	62
3.3. Expectations of a Random Variable	63
3.4. Some Specific Probability Distributions	66
3.4.1. The Normal Distribution	66
3.4.2. The Chi-Squared, t , and F Distributions	67
3.4.3. Distributions with Large Degrees of Freedom	68
3.4.4. Size Distributions: The Lognormal Distribution	69
3.4.5. The Gamma and Exponential Distributions	69
3.4.6. The Beta Distribution	70
3.4.7. The Logistic Distribution	70
3.4.8. Discrete Random Variables	70
3.5. The Distribution of a Function of a Random Variable	71
3.6. Joint Distributions	73
3.6.1. Marginal Distributions	73
3.6.2. Expectations in a Joint Distribution	74

3.6.3. Covariance and Correlation	74
3.6.4. Distribution of a Function of Bivariate Random Variables	75
3.7. Conditioning in a Bivariate Distribution	77
3.7.1. Regression: The Conditional Mean	78
3.7.2. Conditional Variance	79
3.7.3. Relationships Among Marginal and Conditional Moments	79
3.7.4. The Analysis of Variance	82
3.8. The Bivariate Normal Distribution	83
3.9. Multivariate Distributions	84
3.9.1. Moments	84
3.9.2. Sets of Linear Functions	85
3.9.3. Nonlinear Functions	86
3.10. The Multivariate Normal Distribution	86
3.10.1. Marginal and Conditional Normal Distributions	87
3.10.2. Linear Functions of a Normal Vector	88
3.10.3. Quadratic Forms in a Standard Normal Vector	88
3.10.4. The F Distribution	90
3.10.5. A Full Rank Quadratic Form	91
3.10.6. Independence of a Linear and a Quadratic Form	91
Exercises	92
CHAPTER 4 Statistical Inference	97
4.1. Introduction	97
4.2. Samples and Sampling Distributions	97
4.2.1. Random Sampling	97
4.2.2. Descriptive Statistics	98
4.2.3. Sampling Distributions	100
4.3. Point Estimation of Parameters	101
4.3.1. Estimation in a Finite Sample	103
4.3.2. Efficient Unbiased Estimation	106
4.4. Large-Sample Distribution Theory	109
4.4.1. Convergence in Probability	110
4.4.2. Convergence in Distribution: Limiting Distributions	113
4.4.3. Asymptotic Distributions	118
4.4.4. Asymptotic Distribution of a Nonlinear Function	120
4.4.5. Asymptotic Expectations	121
4.4.6. Sequences and the Order of a Sequence	122
4.5. Efficient Estimation: Maximum Likelihood	123
4.5.1. Properties of Maximum Likelihood Estimators	126
4.5.2. Estimating the Asymptotic Variance of the Maximum Likelihood Estimator	131
4.6. Two-Step Estimation	133
4.7. Consistent Estimation: The Method of Moments	137
4.7.1. Random Sampling and Estimating the Parameters of Distributions	138

4.7.2. <i>Computing the Variance of a Method of Moments Estimator</i>	141
4.8. Interval Estimation	145
4.9. Hypothesis Testing	147
4.9.1. <i>Testing Procedures</i>	147
4.9.2. <i>Tests Based on Confidence Intervals</i>	149
4.9.3. <i>Three Asymptotically Equivalent Test Procedures</i>	150
4.9.4. <i>An Example of the Test Procedures</i>	157
Exercises	160

CHAPTER 5 Computation and Optimization 164

5.1. Introduction	164
5.2. Digital Computing	165
5.3. Data Input and Generation	166
5.3.1. <i>Data Input</i>	166
5.3.2. <i>Generating Pseudo-Random Numbers</i>	167
5.3.3. <i>Monte Carlo Studies</i>	171
5.3.4. <i>Bootstrapping</i>	173
5.4. Computation in Econometrics	174
5.4.1. <i>Summation and Multiplication</i>	174
5.4.2. <i>Computing Integrals</i>	176
5.4.3. <i>Computing Derivatives</i>	185
5.5 Optimization	186
5.5.1. <i>Algorithms</i>	188
5.5.2. <i>Gradient Methods</i>	189
5.5.3. <i>Aspects of Maximum Likelihood Estimation</i>	193
5.5.4. <i>Optimization with Constraints</i>	197
5.5.5. <i>Some Practical Considerations</i>	199
5.6. Examples	200
Exercises	208

CHAPTER 6 The Classical Multiple Linear Regression Model: Specification and Estimation 210

6.1. Introduction	210
6.2. The Linear Model	210
6.3. Assumptions of the Classical Linear Regression Model	213
6.3.1. <i>Linearity of the Regression Model</i>	213
6.3.2. <i>Full Rank</i>	218
6.3.3. <i>Regression</i>	219
6.3.4. <i>Spherical Disturbances</i>	220
6.3.5. <i>Nonstochastic Regressors</i>	221
6.3.6. <i>Normality</i>	222
6.3.7. <i>Summary</i>	223
6.4. Least Squares Regression	223
6.4.1. <i>The Least Squares Coefficient Vector</i>	224

6.4.2. Algebraic Aspects of the Least Squares Solution	230
6.4.3. Partitioned Regression and Partial Regression	231
6.4.4. Partial Regression and Partial Correlation Coefficients	233
6.5. Goodness of Fit and the Analysis of Variance	236
6.6. Statistical Properties of the Least Squares Estimator in Finite Samples	242
6.6.1. Nonstochastic Regressors	242
6.6.2. Stochastic Regressors	245
6.6.3. Normality and the Distribution of \mathbf{b}	246
6.6.4. Estimating σ^2 and the Variance of \mathbf{b}	247
6.6.5. Testing a Hypothesis About a Coefficient	248
6.6.6. Confidence Intervals for Parameters	250
6.6.7. Testing the Significance of the Regression	253
6.6.8. Test Statistics with Stochastic \mathbf{X} and Normal ϵ	255
6.7. The Multicollinearity Problem	255
6.8. Missing Observations	259
6.9. Regression Diagnostics and Influential Data Points	263
Exercises	264

CHAPTER 7 Inference and Prediction 271

7.1. Introduction	271
7.2. Testing Restrictions	271
7.2.1. Two Approaches to Testing Hypotheses	272
7.2.2. Testing a Set of Linear Restrictions	272
7.2.3. Testing One Linear Restriction	273
7.2.4. Testing J Linear Restrictions	274
7.2.5. A Test Based on a Confidence Region	276
7.2.6. Nonnormal Disturbances	278
7.3. The Restricted Least Squares Estimator	281
7.4. A Test Based on Loss of Fit	282
7.5. Examples and Some General Procedures	283
7.6. Tests of Structural Change	287
7.6.1. Different Parameter Vectors	288
7.6.2. Different Constant Terms	289
7.6.3. Change in a Subset of Coefficients	290
7.6.4. Insufficient Observations	291
7.7. Tests of Structural Change with Unequal Variances	292
7.8. Alternative Tests of Model Stability	293
7.9. Testing Nonlinear Restrictions	297
7.10. Choosing Between Nonnested Models	300
7.10.1. An Encompassing Model	301
7.10.2. The J Test	302

7.10.3. *The Cox Test* 303
 7.10.4 *Model Selection* 306
 7.11. Prediction 307
 7.11.1. *A Convenient Method of Computing the Forecasts* 308
 7.11.2. *Measuring the Accuracy of Forecasts* 310
 Exercises 312

CHAPTER 8 Functional Form, Nonlinearity, and Specification 316

8.1. Introduction 316
 8.2. Dummy Variables 316
 8.2.1. *Comparing Two Means* 316
 8.2.2. *Binary Variables in Regression* 318
 8.2.3. *Several Categories* 319
 8.2.4. *Several Groupings* 319
 8.2.5. *Threshold Effects* 321
 8.2.6. *Interactions and Spline Regression* 322
 8.3. Nonlinearity in the Variables 325
 8.3.1. *Functional Forms* 325
 8.3.2. *Identifying Nonlinearity* 327
 8.3.3. *Intrinsic Linearity and Identification* 330
 8.4. Specification Analysis 332
 8.4.1. *Selection of Variables* 332
 8.4.2. *Omission of Relevant Variables* 334
 8.4.3. *Inclusion of Irrelevant Variables* 337
 8.5. Biased Estimators and Pretest Estimators 338
 8.5.1. *The Mean-Squared-Error Test* 338
 8.5.2. *Pretest Estimators* 341
 8.5.3. *Inequality Restrictions* 344
 Exercises 345

CHAPTER 9 Large-Sample Results and Alternative Estimators for the Classical Regression Model 350

9.1. Introduction 350
 9.2. The Finite Sample Properties of Least Squares 351
 9.3. Asymptotic Properties of the Least Squares Estimator 352
 9.3.1. *Consistency of the Least Squares Estimator of β* 352
 9.3.2. *Asymptotic Normality of the Least Squares Estimator* 354
 9.3.3. *Consistency of s^2 and the Estimator of $\text{Asy. Var}[\mathbf{b}]$* 356
 9.3.4. *Asymptotic Distribution of a Function of \mathbf{b} : The Delta Method* 357
 9.3.5. *Asymptotic Behavior of the Standard Test Statistics* 360
 9.4. Stochastic Regressors 362
 9.4.1. *Independent Observations* 362

9.4.2. Heterogeneity in the Distributions of \mathbf{x}_i	366
9.4.3. Dependent Observations	368
9.5. Instrumental Variable Estimation and Measurement Error	370
9.5.1. The Instrumental Variable Estimator	371
9.5.2. Measurement Error	375
9.5.3. Proxy Variables	380
9.5.4. Hausman's Specification Test and an Application to Instrumental Variable Estimation	383
9.6. Normally Distributed Disturbances	387
9.6.1. Asymptotic Efficiency: Maximum Likelihood Estimation	387
9.6.2. Stochastic Regressors	390
9.6.3. Wald, Lagrange Multiplier, and Likelihood Ratio Test Statistics	390
9.6.4. Wald, LR, and LM Statistics for Linear Restrictions in the Linear Model	392
9.7. Nonnormal Disturbances	393
9.7.1. The Stochastic Frontier Model	394
9.7.2. Detecting Departures from Normality	397
9.8. Alternative Estimation Methods	399
9.8.1. Least Absolute Deviations Estimation	399
9.8.2. Bayesian Estimation	402
Exercises	412

CHAPTER 10 Nonlinear Regression Models 416

10.1. Introduction	416
10.2. Nonlinear Regression Models	416
10.2.1. The Linearized Regression	417
10.2.2. The Nonlinear Least Squares Estimator	419
10.2.3. Computing the Nonlinear Least Squares Estimator	421
10.3. Alternative Estimators for Nonlinear Regression Models	424
10.3.1. Maximum Likelihood and Nonlinear Least Squares Estimation	424
10.3.2. Nonlinear Instrumental Variables Estimation	430
10.3.3. Two-Step Nonlinear Least Squares Estimation	432
10.4. Hypothesis Testing and Parametric Restrictions	438
10.4.1. Significance Tests for Restrictions: F and Wald Statistics	438
10.4.2. Tests Based on the Likelihood: LR and LM Statistics	439
10.4.3. A Specification Test for Nonlinear Regressions: The P_E Test	441
10.5. The Box–Cox Transformation	444
10.5.1. Transforming the Independent Variables	445
10.5.2. Transforming the Model	446
10.5.3. A Test for (Log-) Linearity	448
10.5.4. Lagrange Multiplier Tests for the Box–Cox Model	449
Exercises	453

CHAPTER 11 Nonspherical Disturbances, Generalized Regression, and GMM Estimation 455

11.1. Introduction	455
11.2. Consequences for Least Squares Estimation	456
11.2.1. Finite-Sample Properties of Ordinary Least Squares	457
11.2.2. Asymptotic Properties of Least Squares	458
11.2.3. Asymptotic Properties of Nonlinear Least Squares	460
11.2.4. Asymptotic Properties of the Instrumental Variables Estimator	460
11.2.5. Robust Estimation of Asymptotic Covariance Matrices	462
11.3. Efficient Estimation	465
11.3.1. Generalized Least Squares (GLS)	465
11.3.2. Maximum Likelihood Estimation When Ω Is Known	467
11.4. Estimation When Ω Is Unknown	469
11.4.1. Feasible Generalized Least Squares	469
11.4.2. Maximum Likelihood Estimation When Ω Is Unknown	470
11.5. The Generalized Method of Moments (GMM) Estimator	474
11.5.1. Methods of Moments Estimators	475
11.5.2. Generalizing the Method of Moments	476
11.5.3. Computation of q and Using Nonoptimal Weighting Matrices	481
11.5.4. Testing the Validity of the Moment Restrictions	482
11.5.5. GMM Estimation of Econometric Models	483
11.5.6. Pseudo-Maximum Likelihood Estimation and Robust Asymptotic Covariance Matrices	488
11.6. Testing Hypotheses in the GMM Framework	491
11.6.1. GMM Counterparts to the Wald, LM, and LR Tests	491
11.6.2. Conditional Moment Tests	493
Exercises	496

CHAPTER 12 Heteroscedasticity 499

12.1. Introduction	499
12.2. Ordinary Least Squares Estimation	501
12.2.1. Inefficiency of Least Squares	502
12.2.2. The Estimated Covariance Matrix of \mathbf{b}	503
12.2.3. Estimating the Appropriate Covariance Matrix for Ordinary Least Squares	506
12.3. Testing for Heteroscedasticity	507
12.3.1. White's General Test	508
12.3.2. The Goldfeld–Quandt Test	509
12.3.3. The Breusch–Pagan/Godfrey Test	509
12.3.4. Testing for Groupwise Heteroscedasticity	511
12.4. Generalized Least Squares When Ω Is Known	512
12.5. Estimation When Ω Contains Unknown Parameters	514
12.5.1. Two-Step Estimation	514

12.5.2. <i>Maximum Likelihood Estimation</i>	516
12.5.3. <i>Likelihood Based Tests for Heteroscedasticity</i>	520
12.6. General Conclusions	521
Exercises	522
CHAPTER 13 Autocorrelated Disturbances	525
13.1. Introduction	525
13.2. The Analysis of Time-Series Data	528
13.3. Disturbance Processes	530
13.3.1. <i>Characteristics of Disturbance Processes</i>	530
13.3.2. <i>AR(1) Disturbances</i>	531
13.4. Least Squares Estimation	533
13.4.1. <i>OLS Estimation with Lagged Dependent Variables</i>	534
13.4.2. <i>Efficiency of Least Squares</i>	535
13.4.3. <i>Estimating the Variance of the Least Squares Estimator</i>	537
13.5. Testing for Autocorrelation	538
13.5.1. <i>The Durbin–Watson Test</i>	538
13.5.2. <i>Other Testing Procedures</i>	540
13.5.3. <i>Testing in the Presence of Lagged Dependent Variables</i>	542
13.6. Efficient Estimation When Ω Is Known	543
13.6.1. <i>Generalized Least Squares</i>	543
13.6.2. <i>Maximum Likelihood Estimation</i>	545
13.7. Estimation When Ω Is Unknown	546
13.7.1. <i>AR(1) Disturbances</i>	546
13.7.2. <i>AR(2) Disturbances</i>	550
13.7.3. <i>Estimation with a Lagged Dependent Variable</i>	550
13.8. Common Factors	552
13.9. Forecasting in the Presence of Autocorrelation	553
Exercises	555
CHAPTER 14 Models for Panel Data	557
14.1. Introduction	557
14.2. Panel Data Models	557
14.3. Fixed Effects	560
14.3.1. <i>Testing the Significance of the Group Effects</i>	562
14.3.2. <i>The Within and Between Groups Estimators</i>	562
14.3.3. <i>Fixed Time and Group Effects</i>	564
14.3.4. <i>Unbalanced Panels and Fixed Effects</i>	566
14.4. Random Effects	567
14.4.1. <i>Generalized Least Squares</i>	568
14.4.2. <i>Feasible Generalized Least Squares When Ω Is Unknown</i>	570
14.4.3. <i>Testing for Random Effects</i>	572

14.4.4.	<i>Hausman's Test for Fixed or Random Effects</i>	576
14.4.5.	<i>Unbalanced Panels and Random Effects</i>	577
14.5.	Heteroscedasticity and Robust Covariance Estimation	578
14.5.1.	<i>Robust Estimation of the Fixed Effects Model</i>	579
14.5.2.	<i>Heteroscedasticity in the Random Effects Model</i>	580
14.6.	Autocorrelation	581
14.7.	Dynamic Models	582
14.8.	Conclusions	584
	Exercises	584

CHAPTER 15^f Systems of Regression Equations 590

15.1.	Introduction	590
15.2.	Covariance Structures for Time-Series Cross-Sectional Data	592
15.2.1.	<i>Cross-Sectional Heteroscedasticity</i>	594
15.2.2.	<i>Cross-Sectional Correlation</i>	599
15.2.3.	<i>Autocorrelation</i>	603
15.2.4.	<i>Summary</i>	607
15.3.	A Random Coefficients Model	608
15.4.	The Seemingly Unrelated Regressions Model	614
15.4.1.	<i>Generalized Least Squares</i>	615
15.4.2.	<i>Seemingly Unrelated Regressions with Identical Regressors</i>	616
15.4.3.	<i>Feasible Generalized Least Squares</i>	617
15.4.4.	<i>Maximum Likelihood Estimation</i>	622
15.4.5.	<i>Maximum Likelihood Estimation of the Seemingly Unrelated Regressions Model with a Block of Zeros in the Coefficient Matrix</i>	632
15.4.6.	<i>Autocorrelation</i>	634
15.5.	Systems of Demand Equations: Singular Systems	636
15.6.	Flexible Functional Forms: The Translog Cost Function	640
15.7.	Nonlinear Systems and GMM Estimation	644
15.7.1.	<i>GLS Estimation</i>	644
15.7.2.	<i>Maximum Likelihood Estimation</i>	646
15.7.3.	<i>GMM Estimation</i>	647
	Exercises	648

CHAPTER 16 Simultaneous-Equations Models 652

16.1.	Introduction	652
16.2.	Fundamental Issues in Simultaneous-Equations Models	653
16.2.1.	<i>Illustrative Systems of Equations</i>	653
16.2.2.	<i>Endogeneity and Causality</i>	656
16.2.3.	<i>A General Notation for Linear Simultaneous Equations Models</i>	658
16.2.4.	<i>Nonlinear Systems of Equations</i>	662
16.3.	The Problem of Identification	663

16.3.1. <i>The Rank and Order Conditions for Identification</i>	667
16.3.2. <i>Identification Through Nonsample Information</i>	672
16.4. <i>Methods of Estimation</i>	676
16.5. <i>Single Equation: Limited Information Methods</i>	677
16.5.1. <i>Ordinary Least Squares</i>	677
16.5.2. <i>Estimation by Instrumental Variables and GMM</i>	680
16.6. <i>System Methods of Estimation</i>	690
16.6.1. <i>Three-Stage Least Squares</i>	692
16.6.2. <i>Full-Information Maximum Likelihood</i>	693
16.6.3. <i>GMM Estimation</i>	696
16.7. <i>Comparison of Methods</i>	698
16.8. <i>Specification Tests</i>	700
16.9. <i>Properties of Dynamic Models</i>	702
16.9.1. <i>Dynamic Models and Their Multipliers</i>	702
16.9.2. <i>Stability</i>	706
16.9.3. <i>Adjustment to Equilibrium</i>	707
Exercises	710

CHAPTER 17 Regressions with Lagged Variables 712

17.1. <i>Introduction</i>	712
17.2. <i>Distributed Lag Models</i>	713
17.2.1. <i>Lagged Effects in a Regression Model</i>	713
17.2.2. <i>The Lag and Difference Operators</i>	716
17.2.3. <i>Unrestricted Finite Distributed Lag Models</i>	717
17.2.4. <i>Polynomial Distributed Lag Models</i>	718
17.2.5. <i>The Geometric Lag Model: A Lagged Dependent Variable</i>	720
17.3. <i>Autoregressive Distributed Lag Models</i>	724
17.3.1. <i>Estimation of the ARDL Model</i>	725
17.3.2. <i>Computation of the Lag Weights in the ARDL Model</i>	726
17.3.3. <i>Stability of a Dynamic Equation</i>	728
17.3.4. <i>Forecasting</i>	730
17.4. <i>Some Methodological Issues in the Analysis of Dynamic Models</i>	733
17.4.1. <i>An Error Correction Model</i>	733
17.4.2. <i>Autocorrelation</i>	735
17.4.3. <i>Specification Analysis</i>	736
17.4.4. <i>Common Factor Restrictions</i>	737
17.5. <i>Vector Autoregressions</i>	740
17.5.1. <i>Testing for Granger Causality</i>	742
17.5.2. <i>Impulse Response Functions</i>	744
17.5.3. <i>Structural VARs</i>	745
17.5.4. <i>VARs in Microeconomics</i>	746
Exercises	747

CHAPTER 18	Time-Series Models	748
18.1.	Introduction	748
18.2.	Stationary Stochastic Processes	749
18.2.1.	Autoregressive Moving-Average Processes	750
18.2.2.	Stationarity and Invertibility	752
18.2.3.	Autocorrelations of a Stationary Stochastic Process	754
18.2.4.	Partial Autocorrelations of a Stationary Stochastic Process	757
18.2.5.	Modeling Univariate Time Series	759
18.2.6.	Estimation of the Parameters of a Univariate Time Series	761
18.2.7.	Nonlinear Least Squares Estimation of ARMA and ARMAX Models	764
18.2.8.	The Frequency Domain	769
18.3.	Nonstationary Processes and Unit Roots	776
18.3.1.	Integrated Processes and Differencing	776
18.3.2.	Random Walks, Trends, and Spurious Regressions	778
18.3.3.	Tests for Unit Roots in Economic Data	781
18.3.4.	Long Memory Models	785
18.3.5.	Seasonality	788
18.4.	Cointegration	789
18.4.1.	Common Trends	792
18.4.2.	Error Correction and VAR Representations	793
18.4.3.	Testing for Cointegration	794
18.4.4.	Estimating Cointegration Relationships	796
18.5.	Autoregressive Conditional Heteroscedasticity	796
18.5.1.	The ARCH(1) Model	797
18.5.2.	ARCH(Q), Generalized ARCH, and the ARCH-in-Mean Models	800
18.5.3.	Maximum Likelihood Estimation of the GARCH Model	802
18.5.4.	Pseudo-Maximum Likelihood Estimation	807
18.5.5.	Testing for GARCH Effects	808
Exercise		810
CHAPTER 19	Models with Discrete Dependent Variables	811
19.1.	Introduction	811
19.2.	Discrete Choice Models	811
19.3.	Models for Binary Choice	812
19.3.1.	The Regression Approach	813
19.3.2.	Index Function and Random Utility Models	818
19.4.	Estimation and Inference in Binary Choice Models	820
19.4.1.	Robust Covariance Matrix Estimation	823
19.4.2.	Marginal Effects	824
19.4.3.	Hypothesis Tests	825
19.4.4.	Specification Tests in Binary Choice Models	827
19.4.5.	Measuring Goodness of Fit	831
19.4.6.	Analysis of Proportions Data	834

19.5. Recent Developments in Binary Choice Modeling	837
19.5.1. <i>Random and Fixed Effects Models for Panel Data</i>	837
19.5.2. <i>Semiparametric Analysis</i>	841
19.5.3. <i>The Maximum Score Estimator (MSCORE)</i>	842
19.5.4. <i>A Kernel Estimator for a Nonparametric Regression Function</i>	844
19.5.5. <i>Semiparametric Estimation</i>	846
19.6. Bivariate and Multivariate Probit Models	849
19.6.1. <i>Maximum Likelihood Estimation</i>	849
19.6.2. <i>Extensions</i>	856
19.7. Logit Models for Multiple Choices	857
19.7.1. <i>The Multinomial Logit Model</i>	859
19.7.2. <i>The Conditional Logit Model</i>	862
19.7.3. <i>The Independence of Irrelevant Alternatives</i>	864
19.7.4. <i>Nested Logit Models</i>	865
19.7.5. <i>Multinomial Models Based on the Normal Distribution</i>	871
19.8. Ordered Data	875
19.9. Models for Count Data	880
19.9.1. <i>Measuring Goodness of Fit</i>	882
19.9.2. <i>A Specification Test for Functional Form</i>	884
19.9.3. <i>Testing for Overdispersion</i>	884
19.9.4. <i>Heterogeneity and the Negative Binomial Regression Model</i>	886
19.9.5. <i>Poisson Models for Panel Data</i>	887
19.9.6. <i>Hurdle and Zero-Altered Poisson Models</i>	889
19.9.7. <i>A Count Model for Time-Series Data</i>	892
Exercises	893

CHAPTER 20 Limited Dependent Variable and Duration Models 896

20.1. Introduction	896
20.2. Truncation	897
20.2.1. <i>Truncated Distributions</i>	897
20.2.2. <i>Moments of Truncated Distributions</i>	898
20.2.3. <i>The Truncated Regression Model</i>	901
20.3. Censored Data	905
20.3.1. <i>The Censored Normal Distribution</i>	906
20.3.2. <i>The Censored Regression Model: Tobit Analysis</i>	908
20.3.3. <i>Estimation</i>	911
20.3.4. <i>Some Issues in Specification</i>	912
20.3.5. <i>Censoring and Truncation in Models for Counts</i>	919
20.4. Selection: Incidental Truncation	926
20.4.1. <i>Incidental Truncation in a Bivariate Distribution</i>	927
20.4.2. <i>Regression in a Model of Selection</i>	927
20.4.3. <i>Estimation</i>	930
20.4.4. <i>Treatment Effects</i>	933

20.4.5. <i>The Normality Assumption</i>	934
20.4.6. <i>Selection in Qualitative Response Models</i>	935
20.5. Models for Duration Data	937
20.5.1. <i>Duration Data</i>	937
20.5.2. <i>A Regression-like Approach: Parametric Models of Duration</i>	938
20.5.3. <i>Other Approaches</i>	948
Exercises	950
APPENDIX A. Data Sets Used in Applications	953
APPENDIX B. Statistical Tables	957
B1. Cumulative Normal Distribution	957
B2. Percentiles of the Student's t Distribution	958
B3. Percentiles of the Chi-Squared Distribution	959
B4. 95th Percentiles of the F Distribution	960
B5. 99th Percentiles of the F Distribution	961
B6. Durbin–Watson Statistic: 5 Percent Significance Points of d_L and d_U	962
REFERENCES	963
AUTHOR INDEX	989
SUBJECT INDEX	995