Introduction to Econometrics

THIRD EDITION

Global Edition

James H. Stock

Harvard University

ł

Mark W. Watson Princeton University



Boston Columbus Indianapolis New York San Francisco Upper Saddle River Amsterdam Cape-Town Dubai London Madrid Milan Munich Paris Montreal Toronto Delhi Mexico City Sao Paulo Sidney Hong Kong Seoul Singapore Taipei

Brief Contents

PART ONE	Introduction and Review
CHAPTER 1	Economic Questions and Data 43
CHAPTER 2	Review of Probability 56
CHAPTER 3	Review of Statistics 106
PART TWO	Fundamentals of Regression Analysis
CHAPTER 4	Linear Regression with One Regressor 149
CHAPTER 5	Regression with a Single Regressor: Hypothesis Tests and Confidence Intervals 186
CHAPTER 6	Linear Regression with Multiple Regressors 221
CHAPTER 7	Hypothesis Tests and Confidence Intervals in Multiple Regression 256
CHAPTER 8	Nonlinear Regression Functions 294
CHAPTER 9	Assessing Studies Based on Multiple Regression 354
PART THREE	Further Topics in Regression Analysis
CHAPTER 10	Regression with Panel Data 389
CHAPTER 11	Regression with a Binary Dependent Variable 423
CHAPTER 12	Instrumental Variables Regression 461
CHAPTER 13	Experiments and Quasi-Experiments 511
PART FOUR	Regression Analysis of Economic Time Series Data
CHAPTER 14	Introduction to Time Series Regression and Forecasting 558
CHAPTER 15	Estimation of Dynamic Causal Effects 625
CHAPTER 16	Additional Topics in Time Series Regression 673
	·
PART FIVE	The Econometric Theory of Regression Analysis
CHAPTER 17	The Theory of Linear Regression with One Regressor 711
CHAPTER 18	The Theory of Multiple Regression 739

Contents

-

Preface 29

PART ONE	Introduction and Review		
CHAPTER 1	Economic Questions and Data	43	
1.1	 Economic Questions We Examine 43 Question #1: Does Reducing Class Size Improve Elementary School Education? 44 Question #2: Is There Racial Discrimination in the Market for Home Loans? 45 Question #3: How Much Do Cigarette Taxes Reduce Smoking? 45 Question #4: What Will the Rate of Inflation Be Next Year? 46 Quantitative Questions, Quantitative Answers 47 		
1.2	Causal Effects and Idealized Experiments 47 Estimation of Causal Effects 48 Forecasting and Causality 49		
1.3	Data: Sources and Types 49 Experimental Versus Observational Data 49 Cross-Sectional Data 50 Time Series Data 51 Panel Data 53		
CHAPTER 2	Review of Probability	56	
2.1	Random Variables and Probability Distributions 57 Probabilities, the Sample Space, and Random Variables 57 Probability Distribution of a Discrete Random Variable 58 Probability Distribution of a Continuous Random Variable 60		
2.2	Expected Values, Mean, and Variance 60 The Expected Value of a Random Variable 60 The Standard Deviation and Variance 63 Mean and Variance of a Linear Function of a Random Variable 64 Other Measures of the Shape of a Distribution 65		

2.3 Two Random Variables 68 Joint and Marginal Distributions 68 Conditional Distributions 69 Independence 73 Covariance and Correlation 73 The Mean and Variance of Sums of Random Variables 74 The Normal, Chi-Squared, Student t, and F 2.4 Distributions 78 The Normal Distribution 78 -The Chi-Squared Distribution 83 The Student *t* Distribution 83 The F Distribution 84 Random Sampling and the Distribution of the Sample 2.5 Average 85 Random Sampling 85 The Sampling Distribution of the Sample Average 86 2.6 Large-Sample Approximations to Sampling Distributions 89 The Law of Large Numbers and Consistency 90 The Central Limit Theorem 92 APPENDIX 2.1 Derivation of Results in Key Concept 2.3 104 **Review of Statistics** 106 CHAPTER 3 3.1 Estimation of the Population Mean 107 **Estimators and Their Properties** 107 Properties of \overline{Y} 109 1 The Importance of Random Sampling 111 3.2 Hypothesis Tests Concerning the Population Mean 112 Null and Alternative Hypotheses 112 The *p*-Value 113 Calculating the *p*-Value When σ_{Y} is Known 114 The Sample Variance, Sample Standard Deviation, and Standard Error 115 Calculating the *p*-Value When σ_V is Unknown 117 The t-Statistic 117 Hypothesis Testing with a Prespecified Significance Level 118 One-Sided Alternatives 120

8

- 3.3 Confidence Intervals for the Population Mean 121
- 3.4 Comparing Means from Different Populations 123
 Hypothesis Tests for the Difference Between Two Means 123
 Confidence Intervals for the Difference Between Two Population Means 125
- 3.5 Differences-of-Means Estimation of Causal Effects Using Experimental Data 125
 The Causal Effect as a Difference of Conditional Expectations 126
 - Estimation of the Causal Effect Using Differences of Means 126
- 3.6 Using the *t*-Statistic When the Sample Size Is Small 128 The *t*-Statistic and the Student *t* Distribution 128 Use of the Student *t* Distribution in Practice 132
- 3.7 Scatterplots, the Sample Covariance, and the Sample Correlation 133
 Scatterplots 133
 Sample Covariance and Correlation 133
 APPENDIX 3.1 The U.S. Current Population Survey 146
 APPENDIX 3.2 Two Proofs That *Υ* Is the Least Squares Estimator of μ_Y 146
 APPENDIX 3.3 A Proof That the Sample Variance Is Consistent 147

PART TWO	Fundamentals of Regression Analysis	
CHAPTER 4	Linear Regression with One Regressor	149
4.1	The Linear Regression Model 149	
4.2	Estimating the Coefficients of the Linear Regression Model The Ordinary Least Squares Estimator 156 OLS Estimates of the Relationship Between Test Scores and the Student-Teacher Ratio 158 Why Use the OLS Estimator? 159	154
4.3	Measures of Fit 161 The R ² 161 The Standard Error of the Regression 162 Application to the Test Score Data 163	

т.т	 The Least Squares Assumptions 164 Assumption #1: The Conditional Distribution of u_i Given X_i Has a Mean of Zero 164 Assumption #2: (X_i, Y_i), i = 1,, n, Are Independently and Identically Distributed 166 Assumption #3: Large Outliers Are Unlikely 167 Use of the Least Squares Assumptions 168
4.5	Sampling Distribution of the OLS Estimators 169 The Sampling Distribution of the OLS Estimators 170
4.6	Conclusion 173
×	 APPENDIX 4.1 The California Test Score Data Set 181 APPENDIX 4.2 Derivation of the OLS Estimators 181 APPENDIX 4.3 Sampling Distribution of the OLS Estimator 182
CHAPTER 5	Regression with a Single Regressor: Hypothesis Tests and Confidence Intervals 186
5.1	Testing Hypotheses About One of the Regression Coefficients 186 Two-Sided Hypotheses Concerning β_1 187
	One-Sided Hypotheses Concerning β_1 190 Testing Hypotheses About the Intercept β_0 192
5.2	One-Sided Hypotheses Concerning β_1 190 Testing Hypotheses About the Intercept β_0 192 Confidence Intervals for a Regression Coefficient 193
5.2 5.3	One-Sided Hypotheses Concerning β_1 190 Testing Hypotheses About the Intercept β_0 192 Confidence Intervals for a Regression Coefficient 193 Regression When X Is a Binary Variable 195 Interpretation of the Regression Coefficients 195
5.2 5.3 5.4	One-Sided Hypotheses Concerning β_1 190 Testing Hypotheses About the Intercept β_0 192 Confidence Intervals for a Regression Coefficient 193 Regression When X Is a Binary Variable 195 Interpretation of the Regression Coefficients 195 Heteroskedasticity and Homoskedasticity 197 What Are Heteroskedasticity and Homoskedasticity? 198 Mathematical Implications of Homoskedasticity 200 What Does This Mean in Practice? 201
5.2 5.3 5.4 5.5	One-Sided Hypotheses Concerning β_1 190 Testing Hypotheses About the Intercept β_0 192 Confidence Intervals for a Regression Coefficient 193 Regression When X Is a Binary Variable 195 Interpretation of the Regression Coefficients 195 Heteroskedasticity and Homoskedasticity 197 What Are Heteroskedasticity and Homoskedasticity 200 What Does This Mean in Practice? 201 The Theoretical Foundations of Ordinary Least Squares 203 Linear Conditionally Unbiased Estimators and the Gauss–Markov

~

• ~

221

` ~

•••

5.6	Using the <i>t</i> -Statistic in Regression When the Sample Size Is Small 206
	The t-Statistic and the Student t Distribution206Use of the Student t Distribution in Practice207
5.7	Conclusion 208
	APPENDIX 5.1 Formulas for OLS Standard Errors 216
·	APPENDIX 5.2 The Gauss–Markov Conditions and a Proof of the Gauss–Markov Theorem 217
CHAPTER 6	Linear Regression with Multiple Regressors 221
6.1	Omitted Variable Bias 221
×	Definition of Omitted Variable Bias 222 A Formula for Omitted Variable Bias 224 Addressing Omitted Variable Bias by Dividing the Data into Groups 226
6.2	The Multiple Regression Model 228 The Population Regression Line 228 The Population Multiple Regression Model 229
6.3	The OLS Estimator in Multiple Regression 231 The OLS Estimator 232 Application to Test Scores and the Student–Teacher Ratio 233
6.4 ,	Measures of Fit in Multiple Regression 235 The Standard Error of the Regression (<i>SER</i>) 235 The <i>R</i> ² 235 The "Adjusted <i>R</i> ² " 236 Application to Test Scores 237
6.5	The Least Squares Assumptions in Multiple Regression 238 Assumption #1: The Conditional Distribution of u_i Given $X_{1i}, X_{2i}, \ldots, X_{ki}$ Has a Mean of Zero 238 Assumption #2: $(X_{1i}, X_{2i}, \ldots, X_{ki}, Y_i)$, $i = 1, \ldots, n$, Are i.i.d. 238 Assumption #3: Large Outliers Are Unlikely 238 Assumption #4: No Perfect Multicollinearity 239
6.6	The Distribution of the OLS Estimators in Multiple Regression 240

-

1	2	Contents

-

6.7	Multicollinearity 241 Examples of Perfect Multicollinearity 242 Imperfect Multicollinearity 244
6.8	Conclusion 245
:	 APPENDIX 6.1 Derivation of Equation (6.1) 253 APPENDIX 6.2 Distribution of the OLS Estimators When There Are Two Regressors and Homoskedastic Errors 254 APPENDIX 6.3 The Frisch–Waugh Theorem 254
CHAPTER 7	Hypothesis Tests and Confidence Intervals in Multiple Regression 256
7.1	Hypothesis Tests and Confidence Intervals for a Single Coefficient 256
	Standard Errors for the OLS Estimators 256 Hypothesis Tests for a Single Coefficient 257 Confidence Intervals for a Single Coefficient 258 Application to Test Scores and the Student–Teacher Ratio 259
7.2	Tests of Joint Hypotheses261Testing Hypotheses on Two or More Coefficients261The F-Statistic263Application to Test Scores and the Student–Teacher Ratio265The Homoskedasticity-Only F-Statistic266
7.3	Testing Single Restrictions Involving Multiple //
7.4	Confidence Sets for Multiple Coefficients 270
7.5	Model Specification for Multiple Regression271Omitted Variable Bias in Multiple Regression272The Role of Control Variables in Multiple Regression272Model Specification in Theory and in Practice275Interpreting the R^2 and the Adjusted R^2 in Practice276
7.6	Analysis of the Test Score Data Set 277
7.7	Conclusion 282

` -

	APPENDIX 7.1 The Bonferroni Test of a Joint Hypothesis 290 APPENDIX 7.2 Conditional Mean Independence 292	
CHAPTER 8	Nonlinear Regression Functions	294
8.1	A General Strategy for Modeling Nonlinear Regression Functions' 296 Test Scores and District Income 296 The Effect on Y of a Change in-X in Nonlinear Specifications 299 A General Approach to Modeling Nonlinearities Using Multiple Regression 304	
8.2	Nonlinear Functions of a Single Independent Variable 304 Polynomials 305 Logarithms 307 Polynomial and Logarithmic Models of Test Scores and District Income 315	
8.3	Interactions Between Independent Variables 316 Interactions Between Two Binary Variables 317 Interactions Between a Continuous and a Binary Variable 320 Interactions Between Two Continuous Variables 324	
8.4	Nonlinear Effects on Test Scores of the Student-Teacher Ratio 328 Discussion of Regression Results 331 Summary of Findings 335	
`8.5	 Conclusion 336 APPENDIX 8.1 Regression Functions That Are Nonlinear in the Parameters 348 APPENDIX 8.2 Slopes and Elasticities for Nonlinear Regression Functions 351 	
CHAPTER 9	Assessing Studies Based on Multiple Regression	354
0.1	Internal and External Validity 254	

9.1 Internal and External Validity 354 Threats to Internal Validity - 355 Threats to External Validity 356

`~

Contents

13

~

9.2	Threats to Internal Validity of Multiple Regression Analysis 358	
	Omitted Variable Bias 358 Misspecification of the Functional Form of the Regression Function 360 Measurement Error and Errors-in-Variables Bias 361	
:	Missing Data and Sample Selection 364 Simultaneous Causality 366 Sources of Inconsistency of OLS Standard Errors 368	
9.3	Internal and External Validity When the Regression Is Used for Forecasting 369 Using Regression Models for Forecasting 369 Assessing the Validity of Regression Models for Forecasting 371	
9.4	Example: Test Scores and Class Size 371 External Validity 371 Internal Validity 378 Discussion and Implications 380	
9.5	Conclusion 381	
	APPENDIX 9.1 The Massachusetts Elementary School	
	Testing Data 387	
PART THREE	Testing Data 387 Further Topics in Regression Analysis	
PART THREE CHAPTER 10	Testing Data 387 Further Topics in Regression Analysis Regression with Panel Data 3	89
PART THREE CHAPTER 10 10.1	Testing Data 387 Further Topics in Regression Analysis Regression with Panel Data Panel Data 390 Example: Traffic Deaths and Alcohol Taxes 391	89
PART THREE CHAPTER 10 10.1 10.2	Testing Data 387 Further Topics in Regression Analysis Regression with Panel Data 3 Panel Data 390 3 Example: Traffic Deaths and Alcohol Taxes 391 Panel Data with Two Time Periods: "Before and After" Comparisons 393	89
PART THREE CHAPTER 10 10.1 10.2 10.3	Testing Data 387 Further Topics in Regression Analysis Regression with Panel Data 3 Panel Data 390 390 Example: Traffic Deaths and Alcohol Taxes 391 391 Panel Data with Two Time Periods: "Before and After" Comparisons 393 Fixed Effects Regression 396 396 The Fixed Effects Regression Model 396 396 Estimation and Inference 398 400	89

•

۰.

- 10.5 The Fixed Effects Regression Assumptions and Standard Errors for Fixed Effects Regression 404
 The Fixed Effects Regression Assumptions 404
 Standard Errors for Fixed Effects Regression 406
- 10.6 Drunk Driving Laws and Traffic Deaths 407
- 10.7 Conclusion 411 APPENDIX 10.1 The State Traffic Fatality Data Set 418 APPENDIX 10.2 Standard Errors for Fixed Effects Regression 418

CHAPTER 11 Regression with a Binary Dependent Variable 423

- Binary Dependent Variables and the Linear Probability Model 424
 Binary Dependent Variables 424
 The Linear Probability Model 426
- Probit and Logit Regression 429
 Probit Regression 429
 Logit Regression 434
 Comparing the Linear Probability, Probit, and Logit Models 436
- 11.3 Estimation and Inference in the Logit and Probit Models 436
 Nonlinear Least Squares Estimation 437
 Maximum Likelihood Estimation 438
 Measures of Fit 439
- 11.4 Application to the Boston HMDA Data 440
- 11.5 Conclusion 447 APPENDIX 11.1 The Boston HMDA Data Set 455 APPENDIX 11.2 Maximum Likelihood Estimation 455 APPENDIX 11.3 Other Limited Dependent Variable Models 458

CHAPTER 12 Instrumental Variables Regression

- 461
- 12.1 The IV Estimator with a Single Regressor and a Single Instrument 462
 The IV Model and Assumptions 462
 The Two Stage Least Squares Estimator 463

	Why Does IV Regression Work? 464 The Sampling Distribution of the TSLS Estimator 468 Application to the Demand for Cigarettes 470
12.2	The General IV Regression Model 472 TSLS in the General IV Model 474 Instrument Relevance and Exogeneity in the General IV Model 475 The IV Regression Assumptions and Sampling Distribution of the TSLS Estimator 476 Inference Using the TSLS Estimator 477 Application to the Demand for Cigarettes 478
12.3	Checking Instrument Validity 479 Assumption #1: Instrument Relevance 480 Assumption #2: Instrument Exogeneity 482
12.4	Application to the Demand for Cigarettes 485
12.5	Where Do Valid Instruments Come From? 490 Three Examples 491
12.6	Conclusion 495
·····	 APPENDIX 12.1 The Cigarette Consumption Panel Data Set 502 APPENDIX 12.2 Derivation of the Formula for the TSLS Estimator in Equation (12.4) 503 APPENDIX 12.3 Large-Sample Distribution of the TSLS Estimator 503 APPENDIX 12.4 Large-Sample Distribution of the TSLS Estimator When the Instrument Is Not Valid 505 APPENDIX 12.5 Instrumental Variables Analysis with Weak Instruments 506 APPENDIX 12.6 TSLS with Control Variables 509
CHAPTER 13	Experiments and Quasi-Experiments 511
13.1	Potential Outcomes, Causal Effects, and Idealized Experiments 512 Potential Outcomes and the Average Causal Effect 512 Econometric Methods for Analyzing Experimental
	Data 514

~

`_

.

~-

13.2	Threats to Validity of Experiments515Threats to Internal Validity515Threats to External Validity519
13.3 ;	Experimental Estimates of the Effect of Class Size Reductions520Experimental Design520Analysis of the STAR Data522Comparison of the Observational and Experimental Estimates of Class Size Effects527
13.4	Quasi-Experiments 529 Examples 530 The Differences-in-Differences Estimator 532 Instrumental Variables Estimators 536 Regression Discontinuity Estimators 536
13.5	Potential Problems withQuasi-Experiments538Threats to Internal Validity538Threats to External Validity540
13.6	Experimental and Quasi-Experimental Estimates in Heterogeneous Populations 540 OLS with Heterogeneous Causal Effects 541 IV Regression with Heterogeneous Causal Effects 542
13.7	Conclusion 545
X	 APPENDIX 13.1 The Project STAR Data Set 554 APPENDIX 13.2 IV Estimation When the Causal Effect Varies Across Individuals 555 APPENDIX 13.3 The Potential Outcomes Framework for Analyzing Data from Experiments 556
PART FOUR	Regression Analysis of Economic Time Series Data
CHAPTER 14	Introduction to Time Series Regression and Forecasting 558
14.1	Using Regression Models for Forecasting 559
14.2	Introduction to Time Series Data and Serial Correlation 560 The Rates of Inflation and Unemployment in the United States 560

Lags, First Differences, Logarithms, and Growth Rates 562 Autocorrelation 565 Other Examples of Economic Time Series 566 Autoregressions 568 14.3 The First Order Autoregressive Model 568 The pth Order Autoregressive Model 571 Time Series Regression with Additional Predictors and the ĵ. 14.4 Autoregressive Distributed Lag Model 574 Forecasting Changes in the Inflation Rate Using Past Unemployment Rates 574 Stationarity 577 Time Series Regression with Multiple Predictors 578 Forecast Uncertainty and Forecast Intervals 581 ` 14.5 Lag Length Selection Using Information Criteria 584 Determining the Order of an Autoregression 584 Lag Length Selection in Time Series Regression with Multiple Predictors 587 14.6 Nonstationarity I: Trends 588 What Is a Trend? 588 Problems Caused by Stochastic Trends 591 Detecting Stochastic Trends: Testing for a Unit AR Root 593 Avoiding the Problems Caused by Stochastic Trends 597 Nonstationarity II: Breaks 14.7 598 What Is a Break? 598 Testing for Breaks 599 Pseudo Out-of-Sample Forecasting 603 Avoiding the Problems Caused by Breaks 609 14.8 Conclusion 610 APPENDIX 14.1 Time Series Data Used in Chapter 14 619 APPENDIX 14.2 Stationarity in the AR(1) Model 620 APPENDIX 14.3 Lag Operator Notation 621 APPENDIX 14.4 ARMA Models 622 APPENDIX 14.5 Consistency of the BIC Lag Length Estimator 623 **Estimation of Dynamic Causal Effects** 625 CHAPTER 15

15.1 An Initial Taste of the Orange Juice Data 626

673

15.2 Dynamic Causal Effects 629 Causal Effects and Time Series Data 629 Two Types of Exogeneity 632 Estimation of Dynamic Causal Effects with Exogenous 15.3 Regressors 634 The Distributed Lag Model Assumptions 634 Autocorrelated u_n, Standard Errors, and Inference 635 Dynamic Multipliers and Cumulative Dynamic Multipliers 636 Heteroskedasticity- and Autocorrelation-Consistent Standard 15.4 Errors 637 Distribution of the OLS Estimator with Autocorrelated Frrors 638 HAC Standard Errors 640 15.5 Estimation of Dynamic Causal Effects with Strictly Exogenous Regressors 642 The Distributed Lag Model with AR(1) Errors 643 OLS Estimation of the ADL Model 646 GLS Estimation 647 The Distributed Lag Model with Additional Lags and AR(p) Errors 649 Orange Juice Prices and Cold Weather 652 15.6 15.7 Is Exogeneity Plausible? Some Examples 660 U.S. Income and Australian Exports 660 Oil Prices and Inflation 661 Monetary Policy and Inflation 662 The Phillips Curve 662 15.8 Conclusion 663 APPENDIX 15.1 The Orange Juice Data Set 669 APPENDIX 15.2 The ADL Model and Generalized Least Squares in Lag Operator Notation 670 CHAPTER 16 Additional Topics in Time Series Regression 16.1 Vector Autoregressions 673

The VAR Model 674 A VAR Model of the Rates of Inflation and Unemployment 677

16.2	Multiperiod Forecasts 678 Iterated Multiperiod Forecasts 678 Direct Multiperiod Forecasts 680 Which Method Should You Use? 683
16.3	Orders of Integration and the DF-GLS Unit Root Test 684 Other Models of Trends and Orders of Integration 684 The DF-GLS Test for a Unit Root 686 Why Do Unit Root Tests Have Nonnormal Distributions? 689
16.4	Cointegration 691 Cointegration and Error Correction 691 How Can You Tell Whether Two Variables Are Cointegrated? 693 Estimation of Cointegrating Coefficients 696 Extension to Multiple Cointegrated Variables 697 · Application to Interest Rates 698
16.5	Volatility Clustering and Autoregressive Conditional Heteroskedasticity 701 Volatility Clustering 701 Autoregressive Conditional Heteroskedasticity 702 Application to Stock Price Volatility 704
16.6	Conclusion 704 APPENDIX 16.1 U.S. Financial Data Used in Chapter 16 710
PART FIVE	The Econometric Theory of Regression Analysis
CHAPTER 17	The Theory of Linear Regression with One Regressor
17.1	The Extended Least Squares Assumptions and the OLS Estimator 712 The Extended Least Squares Assumptions 712 The OLS Estimator 714
17.2	Fundamentals of Asymptotic Distribution Theory714Convergence in Probability and the Law of Large Numbers715The Central Limit Theorem and Convergence in Distribution717

.

711

••

	Slutsky's Theorem and the Continuous Mapping Theorem 718 Application to the <i>t</i> -Statistic Based on the Sample Mean 719
17.3	Asymptotic Distribution of the OLS Estimator and <i>t</i> -Statistic 720
:	Consistency and Asymptotic Normality of the OLS Estimators 720 Consistency of Heteroskedasticity-Robust Standard Errors 720 Asymptotic Normality of the Heteroskedasticity-Robust <i>t</i> -Statistic 722
17.4	Exact Sampling Distributions When the Errors Are Normally Distributed 722
	Distribution of $\hat{\beta}_1$ with Normal Errors 722 Distribution of the Homoskedasticity-Only <i>t</i> -Statistic 724
17.5	 Weighted Least Squares 725 WLS with Known Heteroskedasticity 725 WLS with Heteroskedasticity of Known Functional Form 726 Heteroskedasticity-Robust Standard Errors or WLS? 729 APPENDIX 17.1 The Normal and Related Distributions and Moments of Continuous Random Variables 734 APPENDIX 17.2 Two Inequalities 737
CHAPTER 18	The Theory of Multiple Regression
CHAPTER 18 18.1	The Theory of Multiple Regression The Linear Multiple Regression Model and OLS Estimator in Matrix Form 740
CHAPTER 18 18.1	The Theory of Multiple Regression The Linear Multiple Regression Model and OLS Estimator in Matrix Form 740 The Multiple Regression Model in Matrix Notation 740 The Extended Least Squares Assumptions 742 The OLS Estimator 743
CHAPTER 18 18.1 , 18.2	The Theory of Multiple Regression The Linear Multiple Regression Model and OLS Estimator in Matrix Form 740 The Multiple Regression Model in Matrix Notation 740 The Extended Least Squares Assumptions 742 The OLS Estimator 743 Asymptotic Distribution of the OLS Estimator and <i>t</i> -Statistic 744
CHAPTER 18 18.1 ` 18.2	The Theory of Multiple Regression The Linear Multiple Regression Model and OLS Estimator in Matrix Form 740 The Multiple Regression Model in Matrix Notation 740 The Multiple Regression Model in Matrix Notation 740 The Extended Least Squares Assumptions 742 The OLS Estimator 743 Asymptotic Distribution of the OLS Estimator and <i>t</i> -Statistic 744 The Multivariate Central Limit Theorem 744 Asymptotic Normality of $\hat{\beta}$ 745 Heteroskedasticity-Robust Standard Errors 746 Confidence Intervals for Predicted Effects 747 Asymptotic Distribution of the <i>t</i> -Statistic 747
CHAPTER 18 18.1 18.2 18.2	The Theory of Multiple Regression The Linear Multiple Regression Model and OLS Estimator in Matrix Form 740 The Multiple Regression Model in Matrix Notation 740 The Extended Least Squares Assumptions 742 The OLS Estimator 743 Asymptotic Distribution of the OLS Estimator and <i>t</i> -Statistic 744 The Multivariate Central Limit Theorem 744 Asymptotic Normality of $\hat{\beta}$ 745 Heteroskedasticity-Robust Standard Errors 746 Confidence Intervals for Predicted Effects 747 Asymptotic Distribution of the <i>t</i> -Statistic 747 Tests of Joint Hypotheses 748

739

۰.

18.4	Distribution of Regression Statistics with Normal Errors 750 Matrix Representations of OLS Regression Statistics 750 Distribution of $\hat{\beta}$ for Normal Errors 751 Distribution of $s_{\hat{\nu}}^2$ 752 Homoskedasticity-Only Standard Errors 752 Distribution of the <i>t</i> -Statistic 753 Distribution of the <i>F</i> -Statistic 753
18.5	Efficiency of the OLS Estimator with Homoskedastic Errors 754 The Gauss–Markov Conditions for Multiple Regression 754 Linear Conditionally Unbiased Estimators 754 The Gauss–Markov Theorem for Multiple Regression 755
18.6	$\begin{array}{llllllllllllllllllllllllllllllllllll$
18.7	Instrumental Variables and Generalized Method of Moments Estimation 762 The IV Estimator in Matrix Form 763 Asymptotic Distribution of the TSLS Estimator 764 Properties of TSLS When the Errors Are Homoskedastic 765 Generalized Method of Moments Estimation in Linear Models 768 APPENDIX 18.1 Summary of Matrix Algebra 779 APPENDIX 18.2 Multivariate Distributions 783 APPENDIX 18.3 Derivation of the Asymptotic Distribution of $\hat{\beta}$ 784 APPENDIX 18.4 Derivations of Exact Distributions of OLS Test Statistics with Normal Errors 785 APPENDIX 18.5 Proof of the Gauss–Markov Theorem for Multiple Regression 786 APPENDIX 18.6 Proof of Selected Results for IV and GMM
	Estimation 788

•--

Appendix 791 References 799 Glossary 805

Index 813