

---

# Introduction to Econometrics

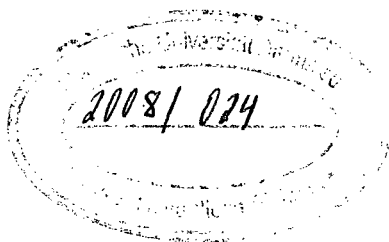
---

---

**Third Edition**

**G.S. Maddala**

*Formerly of Ohio State University*



JOHN WILEY & SONS, LTD

Chichester • New York • Weinheim • Brisbane • Toronto • Singapore

---

# Contents

---

---

<b>Foreword</b>	<b>xvii</b>
<b>Preface to the Second Edition</b>	<b>xix</b>
<b>Preface to the Third Edition</b>	<b>xxiii</b>
<b>Obituary</b>	<b>xxv</b>
<b>PART I INTRODUCTION AND THE LINEAR REGRESSION MODEL</b>	<b>1</b>
<b>1 What is Econometrics?</b>	<b>3</b>
What is in this Chapter?	3
1.1 What is Econometrics?	3
1.2 Economic and Econometric Models	4
1.3 The Aims and Methodology of Econometrics	6
1.4 What Constitutes a Test of an Economic Theory?	9
Summary and an Outline of the Book	9
<b>2 Statistical Background and Matrix Algebra</b>	<b>11</b>
What is in this Chapter?	11
2.1 Introduction	12
2.2 Probability	12
Addition Rules of Probability	13
Conditional Probability and the Multiplication Rule	14
Bayes' Theorem	15
Summation and Product Operations	15
2.3 Random Variables and Probability Distributions	17
Joint, Marginal, and Conditional Distributions	18
Illustrative Example	18
2.4 The Normal Probability Distribution and Related Distributions	19
The Normal Distribution	19
Related Distributions	20

2.5	Classical Statistical Inference	21
	Point Estimation	22
2.6	Properties of Estimators	23
	Unbiasedness	23
	Efficiency	24
	Consistency	24
	Other Asymptotic Properties	25
2.7	Sampling Distributions for Samples from a Normal Population	26
2.8	Interval Estimation	27
2.9	Testing of Hypotheses	28
2.10	Relationship Between Confidence Interval Procedures and Tests of Hypotheses	32
2.11	Combining Independent Tests	33
	Summary	33
	Exercises	34
	Appendix to Chapter 2	41
	Matrix Algebra	41
	Exercises on Matrix Algebra	56
<b>3</b>	<b>Simple Regression</b>	<b>59</b>
	What is in this Chapter?	59
3.1	Introduction	59
3.2	Specification of the Relationships	61
3.3	The Method of Moments	65
	Illustrative Example	66
3.4	The Method of Least Squares	68
	Reverse Regression	71
	Illustrative Example	72
3.5	Statistical Inference in the Linear Regression Model	75
	Illustrative Example	77
	Confidence Intervals for $\alpha$ , $\beta$ , and $\sigma^2$	78
	Testing of Hypotheses	79
	Example of Comparing Test Scores from the GRE and GMAT Tests	81
	Regression with No Constant Term	82
3.6	Analysis of Variance for the Simple Regression Model	83
3.7	Prediction with the Simple Regression Model	84
	Prediction of Expected Values	86
	Illustrative Example	87
3.8	Outliers	88
	Some Illustrative Examples	89
3.9	Alternative Functional Forms for Regression Equations	94
	Illustrative Example	97
*3.10	Inverse Prediction in the Least Squares Regression Model	99
*3.11	Stochastic Regressors	101

*3.12	The Regression Fallacy	102
	The Bivariate Normal Distribution	102
	Galton's Result and the Regression Fallacy	104
	A Note on the Term: "Regression"	104
	Summary	105
	Exercises	106
	Appendix to Chapter 3	112
<b>4</b>	<b>Multiple Regression</b>	<b>127</b>
	What is in this Chapter?	127
4.1	Introduction	127
4.2	A Model with Two Explanatory Variables	129
	The Least Squares Method	130
	Illustrative Example	132
4.3	Statistical Inference in the Multiple Regression Model	134
	Illustrative Example	135
	Formulas for the General Case of $k$ Explanatory Variables	139
	Some Illustrative Examples	140
4.4	Interpretation of the Regression Coefficients	143
	Illustrative Example	145
4.5	Partial Correlations and Multiple Correlation	146
4.6	Relationships Among Simple, Partial, and Multiple Correlation Coefficients	147
	Two Illustrative Examples	148
4.7	Prediction in the Multiple Regression Model	153
	Illustrative Example	153
4.8	Analysis of Variance and Tests of Hypotheses	154
	Nested and Nonnested Hypotheses	156
	Tests for Linear Functions of Parameters	157
	Illustrative Example	158
4.9	Omission of Relevant Variables and Inclusion of Irrelevant Variables	159
	Omission of Relevant Variables	160
	Example 1: Demand for Food in the United States	161
	Example 2: Production Functions and Management Bias	162
	Inclusion of Irrelevant Variables	163
4.10	Degrees of Freedom and $\bar{R}^2$	164
4.11	Tests for Stability	168
	The Analysis of Variance Test	168
	Example 1: Stability of the Demand for Food Function	169
	Example 2: Stability of Production Functions	170
	Predictive Tests for Stability	173
	Illustrative Example	173
*4.12	The LR, W, and LM Tests	176
	Illustrative Example	176

Summary	177
Exercises	179
Appendix to Chapter 4	185
The Multiple Regression Model in Matrix Notation	185
Data Sets	192
PART II VIOLATION OF THE ASSUMPTIONS OF THE BASIC MODEL	197
<b>5 Heteroskedasticity</b>	<b>199</b>
What is in this Chapter?	199
5.1 Introduction	199
Illustrative Example	200
5.2 Detection of Heteroskedasticity	202
Illustrative Example	202
Some Other Tests	203
Illustrative Example	205
An Intuitive Justification for the Breusch–Pagan Test	206
5.3 Consequences of Heteroskedasticity	207
Estimation of the Variance of the OLS Estimator Under Heteroskedasticity	209
5.4 Solutions to the Heteroskedasticity Problem	209
Illustrative Example	211
5.5 Heteroskedasticity and the Use of Deflators	212
Illustrative Example: The Density Gradient Model	215
*5.6 Testing the Linear Versus Log-Linear Functional Form	217
The Box–Cox Test	217
The BM Test	219
The PE Test	219
Summary	220
Exercises	221
Appendix to Chapter 5	224
Generalized Least Squares	224
<b>6 Autocorrelation</b>	<b>227</b>
What is in this Chapter?	227
6.1 Introduction	227
6.2 Durbin–Watson Test	228
Illustrative Example	229
6.3 Estimation in Levels Versus First Differences	230
Some Illustrative Examples	232
6.4 Estimation Procedures with Autocorrelated Errors	234
Iterative Procedures	236
Grid-Search Procedures	237
Illustrative Example	238
6.5 Effect of AR(1) Errors on OLS Estimates	238

6.6	Some Further Comments on the DW Test	242
	The von Neumann Ratio	243
	The Berenblut–Webb Test	243
6.7	Tests for Serial Correlation in Models with Lagged Dependent Variables	245
	Durbin's $h$ -Test	246
	Durbin's Alternative Test	246
	Illustrative Example	247
6.8	A General Test for Higher-Order Serial Correlation: The LM Test	248
6.9	Strategies When the DW Test Statistic is Significant	249
	Errors Not AR(1)	249
	Autocorrelation Caused by Omitted Variables	250
	Serial Correlation Due to Misspecified Dynamics	252
	The Wald Test	253
	Illustrative Example	254
*6.10	Trends and Random Walks	255
	Spurious Trends	257
	Differencing and Long-Run Effects: The Concept of Cointegration	258
*6.11	ARCH Models and Serial Correlation	260
6.12	Some Comments on the DW Test and Durbin's $h$ -Test and $t$ -Test	262
	Summary	262
	Exercises	264
<b>7</b>	<b>Multicollinearity</b>	<b>267</b>
	What is in this Chapter?	267
7.1	Introduction	268
7.2	Some Illustrative Examples	268
7.3	Some Measures of Multicollinearity	272
7.4	Problems with Measuring Multicollinearity	274
7.5	Solutions to the Multicollinearity Problem: Ridge Regression	278
7.6	Principal Component Regression	281
7.7	Dropping Variables	286
7.8	Miscellaneous Other Solutions	289
	Using Ratios or First Differences	289
	Using Extraneous Estimates	289
	Getting More Data	291
	Summary	291
	Exercises	291
	Appendix to Chapter 7	293
	Linearly Dependent Explanatory Variables	293
<b>8</b>	<b>Dummy Variables and Truncated Variables</b>	<b>301</b>
	What is in this Chapter?	301
8.1	Introduction	301

8.2	Dummy Variables for Changes in the Intercept Term	302
	Illustrative Example	305
	Two More Illustrative Examples	306
8.3	Dummy Variables for Changes in Slope Coefficients	307
8.4	Dummy Variables for Cross-Equation Constraints	310
8.5	Dummy Variables for Testing Stability of Regression Coefficients	313
8.6	Dummy Variables Under Heteroskedasticity and Autocorrelation	316
8.7	Dummy Dependent Variables	317
8.8	The Linear Probability Model and the Linear Discriminant Function	318
	The Linear Probability Model	318
	The Linear Discriminant Function	320
8.9	The Probit and Logit Models	322
	Illustrative Example	324
	The Problem of Disproportionate Sampling	325
	Prediction of Effects of Changes in the Explanatory Variables	327
	Measuring Goodness of Fit	327
8.10	Illustrative Example	329
8.11	Truncated Variables: The Tobit Model	333
	Some Examples	333
	Method of Estimation	334
	Limitations of the Tobit Model	335
	The Truncated Regression Model	336
	Summary	338
	Exercises	339
<b>9</b>	<b>Simultaneous Equations Models</b>	<b>343</b>
	What is in this Chapter?	343
9.1	Introduction	343
9.2	Endogenous and Exogenous Variables	345
9.3	The Identification Problem: Identification through Reduced Form	346
	Illustrative Example	348
9.4	Necessary and Sufficient Conditions for Identification	351
	Illustrative Example	353
9.5	Methods of Estimation: The Instrumental Variable Method	354
	Measuring $R^2$	356
	Illustrative Example <sup>3</sup>	357
9.6	Methods of Estimation: The Two-Stage Least Squares Method	360
	Computing Standard Errors	361
	Illustrative Example	363
9.7	The Question of Normalization	366
*9.8	The Limited-Information Maximum Likelihood Method	367
	Illustrative Example	368

*9.9	On the Use of OLS in the Estimation of Simultaneous Equations Models	369
	Working's Concept of Identification	371
	Recursive Systems	373
	Estimation of Cobb–Douglas Production Functions	373
*9.10	Exogeneity and Causality	375
	Weak Exogeneity	378
	Superexogeneity	378
	Strong Exogeneity	378
	Granger Causality	379
	Granger Causality and Exogeneity	380
	Tests for Exogeneity	380
9.11	Some Problems with Instrumental Variable Methods	381
	Summary	382
	Exercises	383
	Appendix to Chapter 9	386
<b>10</b>	<b>Nonlinear Regressions, Models of Expectations, and Nonnormality</b>	<b>391</b>
	What is in this Chapter?	391
10.1	Introduction	392
10.2	The Newton–Raphson Method	392
10.3	Nonlinear Least Squares	393
	The Gauss–Newton Method	393
10.4	Models of Expectations	394
10.5	Naive Models of Expectations	395
10.6	The Adaptive Expectations Model	397
10.7	Estimation with the Adaptive Expectations Model	399
	Estimation in the Autoregressive Form	399
	Estimation in the Distributed Lag Form	400
10.8	Two Illustrative Examples	401
10.9	Expectational Variables and Adjustment Lags	405
10.10	Partial Adjustment with Adaptive Expectations	409
10.11	Alternative Distributed Lag Models: Polynomial Lags	411
	Finite Lags: The Polynomial Lag	412
	Illustrative Example	415
	Choosing the Degree of the Polynomial	416
10.12	Rational Lags	417
10.13	Rational Expectations	419
10.14	Tests for Rationality	422
10.15	Estimation of a Demand and Supply Model Under Rational Expectations	424
	Case 1	424
	Case 2	425
	Illustrative Example	428
10.16	The Serial Correlation Problem in Rational Expectations Models	431



10.17	Nonnormality of Errors	431
	Tests for Normality	432
10.18	Data Transformations	433
	Summary	433
	Exercises	435
<b>11</b>	<b>Errors in Variables</b>	<b>437</b>
	What is in this Chapter?	437
11.1	Introduction	437
11.2	The Classical Solution for a Single-Equation Model with One Explanatory Variable	438
11.3	The Single-Equation Model with Two Explanatory Variables	441
	Two Explanatory Variables: One Measured with Error	441
	Illustrative Example	444
	Two Explanatory Variables: Both Measured with Error	446
11.4	Reverse Regression	449
11.5	Instrumental Variable Methods	451
11.6	Proxy Variables	454
	Coefficient of the Proxy Variable	456
11.7	Some Other Problems	457
	The Case of Multiple Equations	458
	Correlated Errors	459
	Summary	459
	Exercises	461
	<b>PART III SPECIAL TOPICS</b>	<b>463</b>
<b>12</b>	<b>Diagnostic Checking, Model Selection, and Specification Testing</b>	<b>465</b>
	What is in this Chapter?	465
12.1	Introduction	465
12.2	Diagnostic Tests Based on Least Squares Residuals	466
	Tests for Omitted Variables	467
	Tests for ARCH Effects	468
12.3	Problems with Least Squares Residuals	469
12.4	Some Other Types of Residuals	470
	Predicted Residuals and Studentized Residuals	470
	Dummy Variable Method for Studentized Residuals	471
	BLUS Residuals	472
	Recursive Residuals	472
	Illustrative Example	474
12.5	DFFITS and Bounded Influence Estimation	476
	Illustrative Example	478
12.6	Model Selection	479
	Hypothesis-Testing Search	480
	Interpretive Search	481

Simplification Search	481
Proxy Variable Search	481
Data Selection Search	482
Post-Data Model Construction	482
Hendry's Approach to Model Selection	483
12.7 Selection of Regressors	484
Theil's $\bar{R}^2$ Criterion	486
Criteria Based on Minimizing the Mean-Squared Error of Prediction	486
Akaike's Information Criterion	488
12.8 Implied $F$ -Ratios for the Various Criteria	488
Bayes' Theorem and Posterior Odds for Model Selection	491
12.9 Cross-Validation	492
12.10 Hausman's Specification Error Test	494
An Application: Testing for Errors in Variables or Exogeneity	496
Some Illustrative Examples	497
An Omitted Variable Interpretation of the Hausman Test	498
12.11 The Plosser–Schwert–White Differencing Test	501
12.12 Tests for Nonnested Hypotheses	502
The Davidson and MacKinnon Test	502
The Encompassing Test	505
A Basic Problem in Testing Nonnested Hypotheses	506
Hypothesis Testing Versus Model Selection as a Research Strategy	506
Summary	506
Exercises	508
Appendix to Chapter 12	510
<b>13 Introduction to Time-Series Analysis</b>	<b>513</b>
What is in this Chapter?	513
13.1 Introduction	513
13.2 Two Methods of Time-Series Analysis: Frequency Domain and Time Domain	514
13.3 Stationary and Nonstationary Time Series	514
Strict Stationarity	515
Weak Stationarity	516
Properties of Autocorrelation Function	517
Nonstationarity	517
13.4 Some Useful Models for Time Series	517
Purely Random Process	517
Random Walk	518
Moving Average Process	519
Autoregressive Process	520
Autoregressive Moving Average Process	522
Autoregressive Integrated Moving Average Process	524

13.5	Estimation of AR, MA, and ARMA Models	524
	Estimation of MA Models	524
	Estimation of ARMA Models	525
	Residuals from the ARMA Models	526
	Testing Goodness of Fit	527
13.6	The Box–Jenkins Approach	529
	Forecasting from Box–Jenkins Models	531
	Illustrative Example	532
	Trend Elimination: The Traditional Method	534
	A Summary Assessment	535
	Seasonality in the Box–Jenkins Modeling	535
13.7	$R^2$ Measures in Time-Series Models	536
	Summary	540
	Exercises	540
	Data Sets	541
<b>14</b>	<b>Vector Autoregressions, Unit Roots, and Cointegration</b>	<b>543</b>
	What is in this Chapter?	543
14.1	Introduction	543
14.2	Vector Autoregressions	544
14.3	Problems with VAR Models in Practice	546
14.4	Unit Roots	547
14.5	Unit Root Tests	548
	Dickey–Fuller Test	548
	The Serial Correlation Problem	549
	The Low Power of Unit Root Tests	550
	The DF-GLS Test	550
	What are the Null and Alternative Hypotheses in Unit Root Tests?	550
	Tests with Stationarity as Null	552
	Confirmatory Analysis	553
	Panel Data Unit Root Tests	554
	Structural Change and Unit Roots	555
14.6	Cointegration	556
14.7	The Cointegrating Regression	557
14.8	Vector Autoregressions and Cointegration	560
14.9	Cointegration and Error Correction Models	564
14.10	Tests for Cointegration	565
14.11	Cointegration and Testing of the REH and MEH	566
14.12	A Summary Assessment of Cointegration	568
	Summary	569
	Exercises	570

<b>15 Panel Data Analysis</b>	<b>573</b>
What is in this Chapter?	573
15.1 Introduction	573
15.2 The LSDV or Fixed Effects Model	574
15.3 The Random Effects Model	575
15.4 Fixed Effects Versus Random Effects	578
Hausman Test	578
Breusch and Pagan Test	579
15.5 The SUR Model	579
15.6 Dynamic Panel Data Models	580
15.7 The Random Coefficient Model	581
Summary	583
<b>16 Large-Sample Theory</b>	<b>585</b>
What is in this Chapter?	585
16.1 The Maximum Likelihood Method	585
16.2 Methods of Solving the Likelihood Equations	586
16.3 The Cramer–Rao Lower Bound	588
16.4 Large-Sample Tests Based on ML	588
16.5 GIVE and GMM	589
Summary	591
<b>17 Small-Sample Inference: Resampling Methods</b>	<b>593</b>
What is in this Chapter?	593
17.1 Introduction	593
17.2 Monte Carlo Methods	594
More Efficient Monte Carlo Methods	595
Response Surfaces	595
17.3 Resampling Methods: Jackknife and Bootstrap	595
Some Illustrative Examples	597
Other Issues Relating to Bootstrap	598
17.4 Bootstrap Confidence Intervals	599
17.5 Hypothesis Testing with the Bootstrap	599
17.6 Bootstrapping Residuals Versus Bootstrapping the Data	600
17.7 NonIID Errors and Nonstationary Models	601
Heteroskedasticity and Autocorrelation	601
Unit Root Tests Based on the Bootstrap	601
Cointegration Tests	601
17.8 Miscellaneous Other Applications	602

Summary	602
<b>Appendices</b>	<b>605</b>
Appendix A: Data Sets	605
Appendix B: Data Sets on the Web	613
Appendix C: Computer Programs	615
<b>Index</b>	<b>617</b>