

# Contents

<b>INTRODUCTION</b>	<b>1</b>
Why study econometrics?	1
Aim of this text	2
Mathematics and statistics prerequisites for studying econometrics	2
Additional resources	3
Econometrics software	4
<b>REVIEW: RANDOM VARIABLES, SAMPLING, AND ESTIMATION</b>	<b>5</b>
<b>R.1 Introduction</b>	<b>5</b>
<b>R.2 Discrete random variables and expectations</b>	<b>6</b>
Discrete random variables	6
Expected values of random variables	8
Expected values of functions of discrete random variables	9
Expected value rules	10
Population variance of a discrete random variable	11
Fixed and random components of a random variable	12
<b>R.3 Continuous random variables</b>	<b>14</b>
Probability density	14
<b>R.4 Population covariance, covariance and variance rules, and correlation</b>	<b>17</b>
Covariance	17
Independence of random variables	19
Covariance rules	19
Variance rules	21
Correlation	22
<b>R.5 Samples, the double structure of a variable, and estimators</b>	<b>23</b>
Sampling	23
Estimators	24
<b>R.6 Unbiasedness and efficiency</b>	<b>27</b>
Unbiasedness	27
Efficiency	28
Conflicts between unbiasedness and minimum variance	30

R.7	Estimators of variance, covariance, and correlation	33
R.8	The normal distribution	34
R.9	Hypothesis testing	36
	Formulation of a null hypothesis and development of its implications	37
	Compatibility, freakiness, and the significance level	38
R.10	Type II error and the power of a test	42
R.11	<i>t</i> tests	47
	The reject/fail-to-reject terminology	50
R.12	Confidence intervals	51
R.13	One-sided tests	56
	$H_0: \mu = \mu_0, H_1: \mu = \mu_1$	57
	One percent significance test	60
	Generalizing from $H_0: \mu = \mu_0, H_1: \mu = \mu_1$ to $H_0: \mu = \mu_0, H_1: \mu > \mu_0$	62
	$H_0: \mu = \mu_0, H_1: \mu < \mu_0$	63
	One-sided <i>t</i> tests	63
	Special case: $H_0: \mu = 0$	63
	Anomalous results	64
	Justification of the use of a one-sided test	65
R.14	Probability limits and consistency	66
	Probability limits	67
	Consistency	68
	Why is consistency of interest?	70
	Simulations	72
R.15	Convergence in distribution and central limit theorems	74
	Key terms	79
Appendix R.1:	Unbiased estimators of the population covariance and variance	79
Appendix R.2:	Density functions of transformed random variables	81
1.	SIMPLE REGRESSION ANALYSIS	83
1.1	The simple linear model	83
1.2	Least squares regression with one explanatory variable	85
1.3	Derivation of the regression coefficients	88
	Least squares regression with one explanatory variable:	
	the general case	90
	Two decompositions of the dependent variable	92
	Regression model without an intercept	94
1.4	Interpretation of a regression equation	95
	Changes in the units of measurement	97
1.5	Two important results relating to OLS regressions	103
	The mean value of the residuals is zero	103

The sample correlation between the observations on $X$ and the residuals is zero	103
<b>1.6 Goodness of fit: <math>R^2</math></b>	104
Example of how $R^2$ is calculated	107
Alternative interpretation of $R^2$	107
<b>Key terms</b>	108
 <b>2. PROPERTIES OF THE REGRESSION COEFFICIENTS AND HYPOTHESIS TESTING</b>	 110
<b>2.1 Types of data and regression model</b>	110
<b>2.2 Assumptions for regression models with nonstochastic regressors</b>	111
<b>2.3 The random components and unbiasedness of the OLS regression coefficients</b>	114
The random components of the OLS regression coefficients	114
The unbiasedness of the OLS regression coefficients	118
Normal distribution of the regression coefficients	120
<b>2.4 A Monte Carlo experiment</b>	121
<b>2.5 Precision of the regression coefficients</b>	125
Variances of the regression coefficients	125
Standard errors of the regression coefficients	129
The Gauss–Markov theorem	132
<b>2.6 Testing hypotheses relating to the regression coefficients</b>	134
0.1 percent tests	139
<p><math>p</math> values</p>	139
One-sided tests	140
Confidence intervals	142
<b>2.7 The <math>F</math> test of goodness of fit</b>	145
Relationship between the $F$ test and the $t$ test on the slope coefficient in simple regression analysis	147
<b>Key terms</b>	148
<b>Appendix 2.1 The Gauss–Markov theorem</b>	149
 <b>3. MULTIPLE REGRESSION ANALYSIS</b>	 151
<b>3.1 Illustration: a model with two explanatory variables</b>	151
<b>3.2 Derivation and interpretation of the multiple regression coefficients</b>	153
The general model	155
Interpretation of the multiple regression coefficients	156
<b>3.3 Properties of the multiple regression coefficients</b>	159
Unbiasedness	160

Efficiency	161
Precision of the multiple regression coefficients	161
<i>t</i> tests and confidence intervals	164
<b>3.4 Multicollinearity</b>	165
Multicollinearity in models with more than two explanatory variables	168
Example of multicollinearity	169
What can you do about multicollinearity?	169
<b>3.5 Goodness of fit: <math>R^2</math></b>	176
<i>F</i> tests	177
Further analysis of variance	180
Relationship between <i>F</i> statistic and <i>t</i> statistic	182
Adjusted $R^2$	183
<b>3.6 Prediction</b>	185
Properties of least squares predictors	187
Key terms	190
<b>4. NONLINEAR MODELS AND TRANSFORMATIONS OF VARIABLES</b>	192
<b>4.1 Linearity and nonlinearity</b>	192
<b>4.2 Logarithmic transformations</b>	196
Logarithmic models	196
Semilogarithmic models	200
The disturbance term	202
Comparing linear and logarithmic specifications	205
<b>4.3 Models with quadratic and interactive variables</b>	209
Quadratic variables	209
Higher-order polynomials	211
Interactive explanatory variables	213
Ramsey's RESET test of functional misspecification	216
<b>4.4 Nonlinear regression</b>	218
Key terms	222
<b>5. DUMMY VARIABLES</b>	224
<b>5.1 Illustration of the use of a dummy variable</b>	224
Standard errors and hypothesis testing	227
<b>5.2 Extension to more than two categories and to multiple sets of dummy variables</b>	230
Joint explanatory power of a group of dummy variables	233
Change of reference category	234

The dummy variable trap	235
Multiple sets of dummy variables	237
5.3 Slope dummy variables	240
Joint explanatory power of the intercept and slope dummy variables	243
5.4 The Chow test	245
Relationship between the Chow test and the $F$ test of the explanatory power of a set of dummy variables	247
Key terms	249
 6. SPECIFICATION OF REGRESSION VARIABLES	 250
6.1 Model specification	250
6.2 The effect of omitting a variable that ought to be included	251
The problem of bias	251
Invalidation of the statistical tests	254
$R^2$ in the presence of omitted variable bias	256
6.3 The effect of including a variable that ought not to be included	260
6.4 Proxy variables	263
Unintentional proxies	266
6.5 Testing a linear restriction	268
$F$ test of a linear restriction	270
The reparameterization of a regression model	270
$t$ test of a linear restriction	273
Multiple restrictions	274
Zero restrictions	275
6.6 Getting the most out of your residuals	278
Key terms	279
 7. HETEROSCEDASTICITY	 280
7.1 Heteroscedasticity and its implications	280
Possible causes of heteroscedasticity	283
7.2 Detection of heteroscedasticity	285
The Goldfeld–Quandt test	285
The White test	286
7.3 Remedies for heteroscedasticity	288
Nonlinear models	292
White's heteroscedasticity-consistent standard errors	294
How serious are the consequences of heteroscedasticity?	295
Key terms	297

<b>8. STOCHASTIC REGRESSORS AND MEASUREMENT ERRORS</b>	<b>300</b>
8.1 Assumptions for models with stochastic regressors	300
8.2 Finite sample properties of the OLS regression estimators	302
Precision and efficiency	303
8.3 Asymptotic properties of the OLS regression estimators	303
Consistency	304
Asymptotic normality of the regression coefficients	305
8.4 The consequences of measurement errors	306
Measurement errors in the explanatory variable(s)	306
Measurement errors in the dependent variable	309
Imperfect proxy variables	310
8.5 Instrumental variables	316
Asymptotic distribution of the IV estimator	318
Monte Carlo illustration	320
Multiple instruments	325
The Durbin–Wu–Hausman specification test	326
Key terms	329
<b>9. SIMULTANEOUS EQUATIONS ESTIMATION</b>	<b>331</b>
9.1 Simultaneous equations models: structural and reduced form equations	331
9.2 Simultaneous equations bias	333
A Monte Carlo experiment	335
9.3 Instrumental variables estimation	338
Underidentification	341
Overidentification	342
Two-stage least squares	343
The order condition for identification	344
Unobserved heterogeneity	345
Durbin–Wu–Hausman test	346
Key terms	350
<b>10. BINARY CHOICE AND LIMITED DEPENDENT VARIABLE MODELS, AND MAXIMUM LIKELIHOOD ESTIMATION</b>	<b>354</b>
10.1 The linear probability model	354
10.2 Logit analysis	359
Generalization to more than one explanatory variable	361
Goodness of fit and statistical tests	362
10.3 Probit analysis	365
10.4 Censored regressions: tobit analysis	368

10.5	Sample selection bias	374
10.6	An introduction to maximum likelihood estimation	378
	Generalization to a sample of $n$ observations	382
	Generalization to the case where $\sigma$ is unknown	383
	Application to the simple regression model	385
	Goodness of fit and statistical tests	386
	Key terms	387
Appendix 10.1	Comparing linear and logarithmic specifications	388
11.	MODELS USING TIME SERIES DATA	391
11.1	Assumptions for regressions with time series data	391
11.2	Static models	393
11.3	Models with lagged explanatory variables	398
	Estimating long-run effects	400
11.4	Models with a lagged dependent variable	401
	The partial adjustment model	404
	The error correction model	405
	The adaptive expectations model	406
	More general autoregressive models	409
11.5	Assumption C.7 and the properties of estimators in autoregressive models	411
	Consistency	414
	Limiting distributions	415
	$t$ tests in an autoregressive model	417
11.6	Simultaneous equations models	419
11.7	Alternative dynamic representations of time series processes	422
	Time series analysis	423
	Vector autoregressions	425
	Key terms	427
12.	AUTOCORRELATION	429
12.1	Definition and consequences of autocorrelation	429
	Consequences of autocorrelation	431
	Autocorrelation with a lagged dependent variable	433
12.2	Detection of autocorrelation	434
	The Breusch–Godfrey test	435
	The Durbin–Watson test	436
	Durbin’s $h$ test	438
12.3	Fitting a model subject to AR(1) autocorrelation	440
	Issues	441
	Inference	442
	The common factor test	445

12.4	<b>Apparent autocorrelation</b>	451
12.5	<b>Model specification: specific-to-general versus general-to-specific</b>	457
	Comparison of alternative models	458
	The general-to-specific approach to model specification	460
	Key terms	461
Appendix 12.1:	<b>Demonstration that the Durbin–Watson statistic approximates <math>2 - 2\rho</math> in large samples</b>	462
13.	<b>INTRODUCTION TO NONSTATIONARY TIME SERIES</b>	463
13.1	<b>Stationarity and nonstationarity</b>	463
	Stationary time series	463
	Nonstationary time series	469
	Deterministic trend	472
	Difference-stationarity and trend-stationarity	473
13.2	<b>Spurious regressions</b>	475
	Spurious regressions with variables possessing deterministic trends	475
	Spurious regressions with variables that are random walks	476
13.3	<b>Graphical techniques for detecting nonstationarity</b>	484
13.4	<b>Tests of nonstationarity</b>	489
	Untrended process	491
	Trended process	497
	Augmented Dickey–Fuller tests	498
	Other tests	500
	Further complications	502
13.5	<b>Cointegration</b>	504
13.6	<b>Fitting models with nonstationary time series</b>	508
	Detrending	509
	Differencing	509
	Error correction models	510
	Key terms	513
14.	<b>INTRODUCTION TO PANEL DATA MODELS</b>	514
14.1	<b>Introduction</b>	514
	Example of the use of a panel data set to investigate dynamics	515
14.2	<b>Fixed effects regressions</b>	518
	Within-groups fixed effects	518
	First differences fixed effects	519
	Least squares dummy variable fixed effects	520



14.3	<b>Random effects regressions</b>	522
	Assessing the appropriateness of fixed effects and random effects estimation	525
	Random effects or OLS?	526
	A note on the random effects and fixed effects terminology	527
	<b>Key terms</b>	527
	 <i>APPENDIX A: Statistical tables</i>	531
	<i>APPENDIX B: Data Sets</i>	548
	<i>Bibliography</i>	559
	<i>Author Index</i>	563
	<i>Subject Index</i>	565