# Contents

Preface xi  

1 Introduction 1  
   1.1 About Econometrics 1  
   1.2 The Structure of this Book 3  
   1.3 Illustrations and Exercises 4  

2 An Introduction to Linear Regression 7  
   2.1 Ordinary Least Squares as an Algebraic Tool 8  
      2.1.1 Ordinary Least Squares 8  
      2.1.2 Simple Linear Regression 10  
      2.1.3 Example: Individual Wages 11  
      2.1.4 Matrix Notation 12  
   2.2 The Linear Regression Model 13  
   2.3 Small Sample Properties of the OLS Estimator 16  
      2.3.1 The Gauss–Markov Assumptions 16  
      2.3.2 Properties of the OLS Estimator 17  
      2.3.3 Example: Individual Wages (Continued) 20  
   2.4 Goodness-of-fit 21  
   2.5 Hypothesis Testing 23  
      2.5.1 A Simple t-Test 24  
      2.5.2 Example: Individual Wages (Continued) 26  
      2.5.3 Testing One Linear Restriction 26  
      2.5.4 A Joint Test of Significance of Regression Coefficients 27  
      2.5.5 Example: Individual Wages (Continued) 29  
      2.5.6 The General Case 30  
      2.5.7 Size, Power and p-Values 31  
   2.6 Asymptotic Properties of the OLS Estimator 32
CONTENTS

4.4.5 Which Test? 100
4.5 Illustration: Explaining Labour Demand 100
4.6 Autocorrelation 104
4.6.1 First-order Autocorrelation 105
4.6.2 Unknown $\rho$ 108
4.7 Testing for First-order Autocorrelation 109
4.7.1 Asymptotic Tests 109
4.7.2 The Durbin–Watson Test 110
4.8 Illustration: The Demand for Ice Cream 111
4.9 Alternative Autocorrelation Patterns 114
4.9.1 Higher-order Autocorrelation 114
4.9.2 Moving Average Errors 115
4.10 What to do When you Find Autocorrelation? 116
4.10.1 Misspecification 116
4.10.2 Heteroskedasticity-and-autocorrelation-consistent Standard Errors for OLS 118
4.11 Illustration: Risk Premia in Foreign Exchange Markets 120
4.11.1 Notation 120
4.11.2 Tests for Risk Premia in the 1 Month Market 121
4.11.3 Tests for Risk Premia Using Overlapping Samples 124
Exercises 127

5 Endogeneity, Instrumental Variables and GMM 129
5.1 A Review of the Properties of the OLS Estimator 130
5.2 Cases Where the OLS Estimator Cannot be Saved 133
5.2.1 Autocorrelation with a Lagged Dependent Variable 134
5.2.2 An Example with Measurement Error 134
5.2.3 Endogeneity and Omitted Variable Bias 137
5.2.4 Simultaneity and Reverse Causality 138
5.3 The Instrumental Variables Estimator 140
5.3.1 Estimation with a Single Endogenous Regressor and a Single Instrument 140
5.3.2 Back to the Keynesian model 144
5.3.3 Back to the Measurement Error Problem 145
5.3.4 Multiple Endogenous Regressors 145
5.4 Illustration: Estimating the Returns to Schooling 146
5.5 The Generalized Instrumental Variables Estimator 150
5.5.1 Multiple Endogenous Regressors with an Arbitrary Number of Instruments 151
5.5.2 Two-stage Least Squares and the Keynesian Model Again 154
5.5.3 Specification Tests 155
5.5.4 Weak Instruments 156
5.6 The Generalized Method of Moments 157
5.6.1 Example 158
5.6.2 The Generalized Method of Moments 159
5.6.3 Some Simple Examples 162
CONTENTS

5.6.4 Weak Identification 163
5.7 Illustration: Estimating Intertemporal Asset Pricing Models 164
5.8 Concluding Remarks 167
Exercises 167

6 Maximum Likelihood Estimation and Specification Tests 171
6.1 An Introduction to Maximum Likelihood 172
   6.1.1 Some Examples 172
   6.1.2 General Properties 176
   6.1.3 An Example (Continued) 179
   6.1.4 The Normal Linear Regression Model 180
6.2 Specification Tests 181
   6.2.1 Three Test Principles 181
   6.2.2 Lagrange Multiplier Tests 183
   6.2.3 An Example (Continued) 187
6.3 Tests in the Normal Linear Regression Model 188
   6.3.1 Testing for Omitted Variables 188
   6.3.2 Testing for Heteroskedasticity 189
   6.3.3 Testing for Autocorrelation 191
6.4 Quasi-maximum Likelihood and Moment Conditions Tests 192
   6.4.1 Quasi-maximum Likelihood 192
   6.4.2 Conditional Moment Tests 194
   6.4.3 Testing for Normality 195
Exercises 195

7 Models with Limited Dependent Variables 199
7.1 Binary Choice Models 200
   7.1.1 Using Linear Regression? 200
   7.1.2 Introducing Binary Choice Models 200
   7.1.3 An Underlying Latent Model 202
   7.1.4 Estimation 203
   7.1.5 Goodness-of-fit 205
   7.1.6 Illustration: the Impact of Unemployment Benefits on Recipiency 207
   7.1.7 Specification Tests in Binary Choice Models 210
   7.1.8 Relaxing Some Assumptions in Binary Choice Models 212
7.2 Multiresponse Models 213
   7.2.1 Ordered Response Models 213
   7.2.2 About Normalization 214
   7.2.3 Illustration: Explaining Firms’ Credit Ratings 215
   7.2.4 Illustration: Willingness to Pay for Natural Areas 217
   7.2.5 Multinomial Models 220
7.3 Models for Count Data 223
   7.3.1 The Poisson and Negative Binomial Models 224
   7.3.2 Illustration: Patents and R&D Expenditures 228
7.4 Tobit Models
  7.4.1 The Standard Tobit Model 231
  7.4.2 Estimation 233
  7.4.3 Illustration: Expenditures on Alcohol and Tobacco
    (Part 1) 235
  7.4.4 Specification Tests in the Tobit Model 238
7.5 Extensions of Tobit Models 240
  7.5.1 The Tobit II Model 240
  7.5.2 Estimation 243
  7.5.3 Further Extensions 245
  7.5.4 Illustration: Expenditures on Alcohol and Tobacco
    (Part 2) 245
7.6 Sample Selection Bias 249
  7.6.1 The Nature of the Selection Problem 250
  7.6.2 Semi-parametric Estimation of the Sample-Selection
    Model 252
7.7 Estimating Treatment Effects 253
7.8 Duration Models 257
  7.8.1 Hazard Rates and Survival Functions 257
  7.8.2 Samples and Model Estimation 260
  7.8.3 Illustration: Duration of Bank Relationships 262
    Exercises 264

8 Univariate Time Series Models 269
  8.1 Introduction 270
    8.1.1 Some Examples 270
    8.1.2 Stationarity and the Autocorrelation Function 272
  8.2 General ARMA Processes 275
    8.2.1 Formulating ARMA Processes 275
    8.2.2 Invertibility of Lag Polynomials 278
    8.2.3 Common Roots 279
  8.3 Stationarity and Unit Roots 280
  8.4 Testing for Unit Roots 283
    8.4.1 Testing for Unit Roots in a First-order Autoregressive
      Model 283
    8.4.2 Testing for Unit Roots in Higher-order Autoregressive
      Models 286
    8.4.3 Extensions 287
    8.4.4 Illustration: Annual Price/Earnings Ratio 288
  8.5 Illustration: Long-run Purchasing Power Parity (Part 1) 290
  8.6 Estimation of ARMA Models 293
    8.6.1 Least Squares 293
    8.6.2 Maximum Likelihood 294
  8.7 Choosing a Model 295
    8.7.1 The Autocorrelation Function 296
    8.7.2 The Partial Autocorrelation Function 298
    8.7.3 Diagnostic Checking 299
8.7.4 Criteria for Model Selection 299
8.7.5 Illustration: Modelling the Price/Earnings Ratio 300
8.8 Predicting with ARMA Models 302
  8.8.1 The Optimal Predictor 303
  8.8.2 Prediction Accuracy 305
8.9 Illustration: The Expectations Theory of the Term Structure 307
8.10 Autoregressive Conditional Heteroskedasticity 311
  8.10.1 ARCH and GARCH Models 312
  8.10.2 Estimation and Prediction 315
  8.10.3 Illustration: Volatility in Daily Exchange Rates 317
8.11 What about Multivariate Models? 319
Exercises 320

9 Multivariate Time Series Models 323
  9.1 Dynamic Models with Stationary Variables 324
  9.2 Models with Nonstationary Variables 327
    9.2.1 Spurious Regressions 327
    9.2.2 Cointegration 328
    9.2.3 Cointegration and Error-correction Mechanisms 332
  9.3 Illustration: Long-run Purchasing Power Parity (Part 2) 333
  9.4 Vector Autoregressive Models 335
  9.5 Cointegration: the Multivariate Case 338
    9.5.1 Cointegration in a VAR 338
    9.5.2 Example: Cointegration in a Bivariate VAR 341
    9.5.3 Testing for Cointegration 342
    9.5.4 Illustration: Long-run Purchasing Power Parity (Part 3) 345
  9.6 Illustration: Money Demand and Inflation 347
  9.7 Concluding Remarks 353
Exercises 353

10 Models Based on Panel Data 355
  10.1 Introduction to Panel Data Modeling 356
    10.1.1 Efficiency of Parameter Estimators 357
    10.1.2 Identification of Parameters 358
  10.2 The Static Linear Model 359
    10.2.1 The Fixed Effects Model 359
    10.2.2 The First-difference Estimator 362
    10.2.3 The Random Effects Model 364
    10.2.4 Fixed Effects or Random Effects? 367
    10.2.5 Goodness-of-fit 369
    10.2.6 Alternative Instrumental Variables Estimators 370
    10.2.6 Robust Inference 372
    10.2.7 Testing for Heteroskedasticity and Autocorrelation 373
  10.3 Illustration: Explaining Individual Wages 375
  10.4 Dynamic Linear Models 377
    10.4.1 An Autoregressive Panel Data Model 377
# CONTENTS

10.4.2 Dynamic Models with Exogenous Variables 382  
10.5 Illustration: Explaining Capital Structure 383  
10.6 Nonstationarity, Unit Roots and Cointegration 389  
10.6.1 Panel Data Unit Root Tests 390  
10.6.2 Panel Data Cointegration Tests 392  
10.7 Models with Limited Dependent Variables 393  
10.7.1 Binary Choice Models 394  
10.7.2 The Fixed Effects Logit Model 395  
10.7.3 The Random Effects Probit Model 396  
10.7.4 Tobit Models 398  
10.7.5 Dynamics and the Problem of Initial Conditions 398  
10.7.6 Semi-parametric Alternatives 400  
10.8 Incomplete Panels and Selection Bias 401  
10.8.1 Estimation with Randomly Missing Data 402  
10.8.2 Selection Bias and Some Simple Tests 403  
10.8.3 Estimation with Nonrandomly Missing Data 405  
10.9 Pseudo Panels and Repeated Cross-sections 406  
10.9.1 The Fixed Effects Model 407  
10.9.2 An Instrumental Variables Interpretation 409  
10.9.3 Dynamic Models 410  
Exercises 411  

A Vectors and Matrices 417  
A.1 Terminology 417  
A.2 Matrix Manipulations 418  
A.3 Properties of Matrices and Vectors 419  
A.4 Inverse Matrices 420  
A.5 Idempotent Matrices 421  
A.6 Eigenvalues and Eigenvectors 421  
A.7 Differentiation 422  
A.8 Some Least Squares Manipulations 423  

B Statistical and Distribution Theory 425  
B.1 Discrete Random Variables 425  
B.2 Continuous Random Variables 426  
B.3 Expectations and Moments 427  
B.4 Multivariate Distributions 428  
B.5 Conditional Distributions 429  
B.6 The Normal Distribution 431  
B.7 Related Distributions 433  

Bibliography 437  

Index 451