

	Preface	xvii
	Acknowledgments	xxiii
I	INTRODUCTION AND BACKGROUND	1
1	Introduction	3
1.1	Causal Relationships and Ceteris Paribus Analysis	3
1.2	The Stochastic Setting and Asymptotic Analysis	4
1.2.1	Data Structures	4
1.2.2	Asymptotic Analysis	7
1.3	Some Examples	7
1.4	Why Not Fixed Explanatory Variables?	9
2	Conditional Expectations and Related Concepts in Econometrics	13
2.1	The Role of Conditional Expectations in Econometrics	13
2.2	Features of Conditional Expectations	14
2.2.1	Definition and Examples	14
2.2.2	Partial Effects, Elasticities, and Semielasticities	15
2.2.3	The Error Form of Models of Conditional Expectations	18
2.2.4	Some Properties of Conditional Expectations	19
2.2.5	Average Partial Effects	22
2.3	Linear Projections	24
	Problems	27
	Appendix 2A	29
2.A.1	Properties of Conditional Expectations	29
2.A.2	Properties of Conditional Variances	31
2.A.3	Properties of Linear Projections	32
3	Basic Asymptotic Theory	35
3.1	Convergence of Deterministic Sequences	35
3.2	Convergence in Probability and Bounded in Probability	36
3.3	Convergence in Distribution	38
3.4	Limit Theorems for Random Samples	39
3.5	Limiting Behavior of Estimators and Test Statistics	40
3.5.1	Asymptotic Properties of Estimators	40
3.5.2	Asymptotic Properties of Test Statistics	43
	Problems	45

II	LINEAR MODELS	47
4	The Single-Equation Linear Model and OLS Estimation	49
4.1	Overview of the Single-Equation Linear Model	49
4.2	Asymptotic Properties of OLS	51
4.2.1	Consistency	52
4.2.2	Asymptotic Inference Using OLS	54
4.2.3	Heteroskedasticity-Robust Inference	55
4.2.4	Lagrange Multiplier (Score) Tests	58
4.3	OLS Solutions to the Omitted Variables Problem	61
4.3.1	OLS Ignoring the Omitted Variables	61
4.3.2	The Proxy Variable-OLS Solution	63
4.3.3	Models with Interactions in Unobservables	67
4.4	Properties of OLS under Measurement Error	70
4.4.1	Measurement Error in the Dependent Variable	71
4.4.2	Measurement Error in an Explanatory Variable	73
	Problems	76
5	Instrumental Variables Estimation of Single-Equation Linear Models	83
5.1	Instrumental Variables and Two-Stage Least Squares	83
5.1.1	Motivation for Instrumental Variables Estimation	83
5.1.2	Multiple Instruments: Two-Stage Least Squares	90
5.2	General Treatment of 2SLS	92
5.2.1	Consistency	92
5.2.2	Asymptotic Normality of 2SLS	94
5.2.3	Asymptotic Efficiency of 2SLS	96
5.2.4	Hypothesis Testing with 2SLS	97
5.2.5	Heteroskedasticity-Robust Inference for 2SLS	100
5.2.6	Potential Pitfalls with 2SLS	101
5.3	IV Solutions to the Omitted Variables and Measurement Error Problems	105
5.3.1	Leaving the Omitted Factors in the Error Term	105
5.3.2	Solutions Using Indicators of the Unobservables	105
	Problems	107
6	Additional Single-Equation Topics	115
6.1	Estimation with Generated Regressors and Instruments	115

6.1.1	OLS with Generated Regressors	115
6.1.2	2SLS with Generated Instruments	116
6.1.3	Generated Instruments and Regressors	117
6.2	Some Specification Tests	118
6.2.1	Testing for Endogeneity	118
6.2.2	Testing Overidentifying Restrictions	122
6.2.3	Testing Functional Form	124
6.2.4	Testing for Heteroskedasticity	125
6.3	Single-Equation Methods under Other Sampling Schemes	128
6.3.1	Pooled Cross Sections over Time	128
6.3.2	Geographically Stratified Samples	132
6.3.3	Spatial Dependence	134
6.3.4	Cluster Samples	134
	Problems	135
	Appendix 6A	139
7	Estimating Systems of Equations by OLS and GLS	143
7.1	Introduction	143
7.2	Some Examples	143
7.3	System OLS Estimation of a Multivariate Linear System	147
7.3.1	Preliminaries	147
7.3.2	Asymptotic Properties of System OLS	148
7.3.3	Testing Multiple Hypotheses	153
7.4	Consistency and Asymptotic Normality of Generalized Least Squares	153
7.4.1	Consistency	153
7.4.2	Asymptotic Normality	156
7.5	Feasible GLS	157
7.5.1	Asymptotic Properties	157
7.5.2	Asymptotic Variance of FGLS under a Standard Assumption	160
7.6	Testing Using FGLS	162
7.7	Seemingly Unrelated Regressions, Revisited	163
7.7.1	Comparison between OLS and FGLS for SUR Systems	164
7.7.2	Systems with Cross Equation Restrictions	167
7.7.3	Singular Variance Matrices in SUR Systems	167

7.8	The Linear Panel Data Model, Revisited	169
7.8.1	Assumptions for Pooled OLS	170
7.8.2	Dynamic Completeness	173
7.8.3	A Note on Time Series Persistence	175
7.8.4	Robust Asymptotic Variance Matrix	175
7.8.5	Testing for Serial Correlation and Heteroskedasticity after Pooled OLS	176
7.8.6	Feasible GLS Estimation under Strict Exogeneity	178
	Problems	179
8	System Estimation by Instrumental Variables	183
8.1	Introduction and Examples	183
8.2	A General Linear System of Equations	186
8.3	Generalized Method of Moments Estimation	188
8.3.1	A General Weighting Matrix	188
8.3.2	The System 2SLS Estimator	191
8.3.3	The Optimal Weighting Matrix	192
8.3.4	The Three-Stage Least Squares Estimator	194
8.3.5	Comparison between GMM 3SLS and Traditional 3SLS	196
8.4	Some Considerations When Choosing an Estimator	198
8.5	Testing Using GMM	199
8.5.1	Testing Classical Hypotheses	199
8.5.2	Testing Overidentification Restrictions	201
8.6	More Efficient Estimation and Optimal Instruments	202
	Problems	205
9	Simultaneous Equations Models	209
9.1	The Scope of Simultaneous Equations Models	209
9.2	Identification in a Linear System	211
9.2.1	Exclusion Restrictions and Reduced Forms	211
9.2.2	General Linear Restrictions and Structural Equations	215
9.2.3	Unidentified, Just Identified, and Overidentified Equations	220
9.3	Estimation after Identification	221
9.3.1	The Robustness-Efficiency Trade-off	221
9.3.2	When Are 2SLS and 3SLS Equivalent?	224
9.3.3	Estimating the Reduced Form Parameters	224
9.4	Additional Topics in Linear SEMs	225

9.4.1	Using Cross Equation Restrictions to Achieve Identification	225
9.4.2	Using Covariance Restrictions to Achieve Identification	227
9.4.3	Subtleties Concerning Identification and Efficiency in Linear Systems	229
9.5	SEMs Nonlinear in Endogenous Variables	230
9.5.1	Identification	230
9.5.2	Estimation	235
9.6	Different Instruments for Different Equations	237
	Problems	239
10	Basic Linear Unobserved Effects Panel Data Models	247
10.1	Motivation: The Omitted Variables Problem	247
10.2	Assumptions about the Unobserved Effects and Explanatory Variables	251
10.2.1	Random or Fixed Effects?	251
10.2.2	Strict Exogeneity Assumptions on the Explanatory Variables	252
10.2.3	Some Examples of Unobserved Effects Panel Data Models	254
10.3	Estimating Unobserved Effects Models by Pooled OLS	256
10.4	Random Effects Methods	257
10.4.1	Estimation and Inference under the Basic Random Effects Assumptions	257
10.4.2	Robust Variance Matrix Estimator	262
10.4.3	A General FGLS Analysis	263
10.4.4	Testing for the Presence of an Unobserved Effect	264
10.5	Fixed Effects Methods	265
10.5.1	Consistency of the Fixed Effects Estimator	265
10.5.2	Asymptotic Inference with Fixed Effects	269
10.5.3	The Dummy Variable Regression	272
10.5.4	Serial Correlation and the Robust Variance Matrix Estimator	274
10.5.5	Fixed Effects GLS	276
10.5.6	Using Fixed Effects Estimation for Policy Analysis	278
10.6	First Differencing Methods	279
10.6.1	Inference	279
10.6.2	Robust Variance Matrix	282

10.6.3	Testing for Serial Correlation	282
10.6.4	Policy Analysis Using First Differencing	283
10.7	Comparison of Estimators	284
10.7.1	Fixed Effects versus First Differencing	284
10.7.2	The Relationship between the Random Effects and Fixed Effects Estimators	286
10.7.3	The Hausman Test Comparing the RE and FE Estimators	288
	Problems	291
11	More Topics in Linear Unobserved Effects Models	299
11.1	Unobserved Effects Models without the Strict Exogeneity Assumption	299
11.1.1	Models under Sequential Moment Restrictions	299
11.1.2	Models with Strictly and Sequentially Exogenous Explanatory Variables	305
11.1.3	Models with Contemporaneous Correlation between Some Explanatory Variables and the Idiosyncratic Error	307
11.1.4	Summary of Models without Strictly Exogenous Explanatory Variables	314
11.2	Models with Individual-Specific Slopes	315
11.2.1	A Random Trend Model	315
11.2.2	General Models with Individual-Specific Slopes	317
11.3	GMM Approaches to Linear Unobserved Effects Models	322
11.3.1	Equivalence between 3SLS and Standard Panel Data Estimators	322
11.3.2	Chamberlain's Approach to Unobserved Effects Models	323
11.4	Hausman and Taylor-Type Models	325
11.5	Applying Panel Data Methods to Matched Pairs and Cluster Samples	328
	Problems	332
III	GENERAL APPROACHES TO NONLINEAR ESTIMATION	339
12	M-Estimation	341
12.1	Introduction	341
12.2	Identification, Uniform Convergence, and Consistency	345
12.3	Asymptotic Normality	349

12.4	Two-Step M-Estimators	353
12.4.1	Consistency	353
12.4.2	Asymptotic Normality	354
12.5	Estimating the Asymptotic Variance	356
12.5.1	Estimation without Nuisance Parameters	356
12.5.2	Adjustments for Two-Step Estimation	361
12.6	Hypothesis Testing	362
12.6.1	Wald Tests	362
12.6.2	Score (or Lagrange Multiplier) Tests	363
12.6.3	Tests Based on the Change in the Objective Function	369
12.6.4	Behavior of the Statistics under Alternatives	371
12.7	Optimization Methods	372
12.7.1	The Newton-Raphson Method	372
12.7.2	The Berndt, Hall, Hall, and Hausman Algorithm	374
12.7.3	The Generalized Gauss-Newton Method	375
12.7.4	Concentrating Parameters out of the Objective Function	376
12.8	Simulation and Resampling Methods	377
12.8.1	Monte Carlo Simulation	377
12.8.2	Bootstrapping	378
	Problems	380
13	Maximum Likelihood Methods	385
13.1	Introduction	385
13.2	Preliminaries and Examples	386
13.3	General Framework for Conditional MLE	389
13.4	Consistency of Conditional MLE	391
13.5	Asymptotic Normality and Asymptotic Variance Estimation	392
13.5.1	Asymptotic Normality	392
13.5.2	Estimating the Asymptotic Variance	395
13.6	Hypothesis Testing	397
13.7	Specification Testing	398
13.8	Partial Likelihood Methods for Panel Data and Cluster Samples	401
13.8.1	Setup for Panel Data	401
13.8.2	Asymptotic Inference	405
13.8.3	Inference with Dynamically Complete Models	408
13.8.4	Inference under Cluster Sampling	409

13.9	Panel Data Models with Unobserved Effects	410
13.9.1	Models with Strictly Exogenous Explanatory Variables	410
13.9.2	Models with Lagged Dependent Variables	412
13.10	Two-Step MLE	413
	Problems	414
	Appendix 13A	418
14	Generalized Method of Moments and Minimum Distance Estimation	421
14.1	Asymptotic Properties of GMM	421
14.2	Estimation under Orthogonality Conditions	426
14.3	Systems of Nonlinear Equations	428
14.4	Panel Data Applications	434
14.5	Efficient Estimation	436
14.5.1	A General Efficiency Framework	436
14.5.2	Efficiency of MLE	438
14.5.3	Efficient Choice of Instruments under Conditional Moment Restrictions	439
14.6	Classical Minimum Distance Estimation	442
	Problems	446
	Appendix 14A	448
IV	NONLINEAR MODELS AND RELATED TOPICS	451
15	Discrete Response Models	453
15.1	Introduction	453
15.2	The Linear Probability Model for Binary Response	454
15.3	Index Models for Binary Response: Probit and Logit	457
15.4	Maximum Likelihood Estimation of Binary Response Index Models	460
15.5	Testing in Binary Response Index Models	461
15.5.1	Testing Multiple Exclusion Restrictions	461
15.5.2	Testing Nonlinear Hypotheses about β	463
15.5.3	Tests against More General Alternatives	463
15.6	Reporting the Results for Probit and Logit	465
15.7	Specification Issues in Binary Response Models	470
15.7.1	Neglected Heterogeneity	470
15.7.2	Continuous Endogenous Explanatory Variables	472

15.7.3	A Binary Endogenous Explanatory Variable	477
15.7.4	Heteroskedasticity and Nonnormality in the Latent Variable Model	479
15.7.5	Estimation under Weaker Assumptions	480
15.8	Binary Response Models for Panel Data and Cluster Samples	482
15.8.1	Pooled Probit and Logit	482
15.8.2	Unobserved Effects Probit Models under Strict Exogeneity	483
15.8.3	Unobserved Effects Logit Models under Strict Exogeneity	490
15.8.4	Dynamic Unobserved Effects Models	493
15.8.5	Semiparametric Approaches	495
15.8.6	Cluster Samples	496
15.9	Multinomial Response Models	497
15.9.1	Multinomial Logit	497
15.9.2	Probabilistic Choice Models	500
15.10	Ordered Response Models	504
15.10.1	Ordered Logit and Ordered Probit	504
15.10.2	Applying Ordered Probit to Interval-Coded Data Problems	508
		509
16	Corner Solution Outcomes and Censored Regression Models	517
16.1	Introduction and Motivation	517
16.2	Derivations of Expected Values	521
16.3	Inconsistency of OLS	524
16.4	Estimation and Inference with Censored Tobit	525
16.5	Reporting the Results	527
16.6	Specification Issues in Tobit Models	529
16.6.1	Neglected Heterogeneity	529
16.6.2	Endogenous Explanatory Variables	530
16.6.3	Heteroskedasticity and Nonnormality in the Latent Variable Model	533
16.6.4	Estimation under Conditional Median Restrictions	535
16.7	Some Alternatives to Censored Tobit for Corner Solution Outcomes	536
16.8	Applying Censored Regression to Panel Data and Cluster Samples	538
16.8.1	Pooled Tobit	538
16.8.2	Unobserved Effects Tobit Models under Strict Exogeneity	540

16.8.3	Dynamic Unobserved Effects Tobit Models	542
	Problems	544
17	Sample Selection, Attrition, and Stratified Sampling	551
17.1	Introduction	551
17.2	When Can Sample Selection Be Ignored?	552
17.2.1	Linear Models: OLS and 2SLS	552
17.2.2	Nonlinear Models	556
17.3	Selection on the Basis of the Response Variable: Truncated Regression	558
17.4	A Probit Selection Equation	560
17.4.1	Exogenous Explanatory Variables	560
17.4.2	Endogenous Explanatory Variables	567
17.4.3	Binary Response Model with Sample Selection	570
17.5	A Tobit Selection Equation	571
17.5.1	Exogenous Explanatory Variables	571
17.5.2	Endogenous Explanatory Variables	573
17.6	Estimating Structural Tobit Equations with Sample Selection	575
17.7	Sample Selection and Attrition in Linear Panel Data Models	577
17.7.1	Fixed Effects Estimation with Unbalanced Panels	578
17.7.2	Testing and Correcting for Sample Selection Bias	581
17.7.3	Attrition	585
17.8	Stratified Sampling	590
17.8.1	Standard Stratified Sampling and Variable Probability Sampling	590
17.8.2	Weighted Estimators to Account for Stratification	592
17.8.3	Stratification Based on Exogenous Variables	596
	Problems	598
18	Estimating Average Treatment Effects	603
18.1	Introduction	603
18.2	A Counterfactual Setting and the Self-Selection Problem	603
18.3	Methods Assuming Ignorability of Treatment	607
18.3.1	Regression Methods	608
18.3.2	Methods Based on the Propensity Score	614
18.4	Instrumental Variables Methods	621
18.4.1	Estimating the ATE Using IV	621

18.4.2	Estimating the Local Average Treatment Effect by IV	633
18.5	Further Issues	636
18.5.1	Special Considerations for Binary and Corner Solution Responses	636
18.5.2	Panel Data	637
18.5.3	Nonbinary Treatments	638
18.5.4	Multiple Treatments	642
	Problems	642
19	Count Data and Related Models	645
19.1	Why Count Data Models?	645
19.2	Poisson Regression Models with Cross Section Data	646
19.2.1	Assumptions Used for Poisson Regression	646
19.2.2	Consistency of the Poisson QMLE	648
19.2.3	Asymptotic Normality of the Poisson QMLE	649
19.2.4	Hypothesis Testing	653
19.2.5	Specification Testing	654
19.3	Other Count Data Regression Models	657
19.3.1	Negative Binomial Regression Models	657
19.3.2	Binomial Regression Models	659
19.4	Other QMLEs in the Linear Exponential Family	660
19.4.1	Exponential Regression Models	661
19.4.2	Fractional Logit Regression	661
19.5	Endogeneity and Sample Selection with an Exponential Regression Function	663
19.5.1	Endogeneity	663
19.5.2	Sample Selection	666
19.6	Panel Data Methods	668
19.6.1	Pooled QMLE	668
19.6.2	Specifying Models of Conditional Expectations with Unobserved Effects	670
19.6.3	Random Effects Methods	671
19.6.4	Fixed Effects Poisson Estimation	674
19.6.5	Relaxing the Strict Exogeneity Assumption	676
	Problems	678

20	Duration Analysis	685
20.1	Introduction	685
20.2	Hazard Functions	686
20.2.1	Hazard Functions without Covariates	686
20.2.2	Hazard Functions Conditional on Time-Invariant Covariates	690
20.2.3	Hazard Functions Conditional on Time-Varying Covariates	691
20.3	Analysis of Single-Spell Data with Time-Invariant Covariates	693
20.3.1	Flow Sampling	694
20.3.2	Maximum Likelihood Estimation with Censored Flow Data	695
20.3.3	Stock Sampling	700
20.3.4	Unobserved Heterogeneity	703
20.4	Analysis of Grouped Duration Data	706
20.4.1	Time-Invariant Covariates	707
20.4.2	Time-Varying Covariates	711
20.4.3	Unobserved Heterogeneity	713
20.5	Further Issues	714
20.5.1	Cox's Partial Likelihood Method for the Proportional Hazard Model	714
20.5.2	Multiple-Spell Data	714
20.5.3	Competing Risks Models	715
	Problems	715
	References	721
	Index	737