

■ CONTENTS

LIST OF TABLES	xvii
1 Introduction	1
1.1 Types of panel variables and data	1
1.2 Virtues of panel data: Transformations	3
1.3 Panel data versus experimental data	8
1.4 Other virtues of panel data and some limitations	9
1.5 Overview	11
2 Regression analysis: Fixed effects models	14
2.1 Simple regression model: One-way heterogeneity	15
2.1.1 Individual-specific intercepts and coefficients	15
2.1.2 Individual-specific intercepts, common coefficient	16
2.1.3 Homogeneous benchmark model	19
2.1.4 How are the estimators related?	21
2.2 Multiple regression model: One-way heterogeneity	23
2.2.1 Individual-specific intercepts and coefficients	23
2.2.2 Individual-specific intercepts, common coefficients	25
2.2.3 Homogeneous benchmark model	27
2.2.4 How are the estimators related?	30
2.3 Simple regression model: Two-way heterogeneity	33
2.3.1 Individual- and period-specific intercepts	33
2.3.2 Homogeneous benchmark model	36
2.3.3 How are the estimators related?	39
2.4 Multiple regression model: Two-way heterogeneity	41
2.4.1 An excursion into Kronecker-products: Definition	41
2.4.2 Matrix formulae with Kronecker-products: Examples	42
2.4.3 Panel data 'operators': Bilinear and quadratic forms	43
2.4.4 Individual- and period-specific intercepts	46
2.4.5 Homogeneous benchmark model	49
2.4.6 How are the estimators related?	50
2.5 Testing for fixed heterogeneity	53
2.5.1 One-way intercept and coefficient heterogeneity	54
2.5.2 Two-way intercept heterogeneity	55

Appendix 2A. Properties of GLS	56
Appendix 2B. Kronecker-product operations: Examples	61
3 Regression analysis: Random effects models	65
3.1 One-way variance component model	66
3.1.1 Basic model	66
3.1.2 Some implications	67
3.2 GLS with known variance components	68
3.2.1 The GLS problem and its reformulation	68
3.2.2 GLS as OLS on transformed data	70
3.2.3 Four estimators and a synthesis	71
3.3 GLS with unknown variance components	74
3.3.1 The problem	74
3.3.2 'Estimation' of variance components from disturbances	75
3.3.3 Synthesis: Stepwise estimation	76
3.3.4 Testing for random one-way heterogeneity	78
3.3.5 Disturbance serial correlation and heteroskedasticity	79
3.4 Maximum Likelihood estimation	81
3.4.1 The problem	81
3.4.2 Simplifying the log-likelihood	82
3.4.3 Stepwise solution	83
3.5 Two-way variance component model	84
3.5.1 Basic assumptions	84
3.5.2 Some implications	85
3.6 GLS with known variance components	87
3.6.1 The problem and its reformulation	87
3.6.2 GLS as OLS on transformed data	88
3.6.3 Five estimators and a synthesis	89
3.7 GLS with unknown variance components	92
3.7.1 The problem	92
3.7.2 'Estimation' of variance components from disturbances	93
3.7.3 Synthesis: Stepwise estimation	95
3.7.4 Testing for random two-way heterogeneity	95
3.8 Maximum Likelihood estimation	96
3.8.1 The problem	96
3.8.2 Simplifying the log-likelihood	96
3.8.3 Stepwise solution	97
Appendix 3A. Two theorems related to GLS Estimation	99
Appendix 3B. Efficiency in the one-regressor case	100

4 Regression analysis with heterogeneous coefficients	107
4.1 Introduction	107
4.2 Fixed coefficient models	108
4.2.1 Single-regressor models without intercept	108
4.2.2 Synthesis	113
4.2.3 Including intercepts	114
4.2.4 Multi-regressor models	115
4.3 Random coefficient models	116
4.3.1 Single-regressor models and their estimators	117
4.3.2 Multi-regressor model and its GLS estimator	123
4.3.3 Coefficient prediction	127
Appendix 4A. Matrix inversion and matrix products: Useful results	132
Appendix 4B. A reinterpretation of the GLS estimator	134
5 Regression analysis with unidimensional variables	136
5.1 Introduction	136
5.2 Properties of moment matrices in unidimensional variables	137
5.2.1 Basics	137
5.2.2 Implications for regression analysis	138
5.3 One-way fixed effects models	139
5.3.1 Simple model with two regressors	139
5.3.2 The general case	143
5.4 One-way random effects models	145
5.4.1 Simple model with two regressors	145
5.4.2 The general case	147
5.5 Two-way models	150
5.5.1 Fixed effects two-regressor model	150
5.5.2 Random effects two-regressor model	154
6 Latent heterogeneity correlated with regressors	157
6.1 Introduction	157
6.2 Models with only two-dimensional regressors	158
6.2.1 A simple case	158
6.2.2 Generalization	161
6.3 Models with time-invariant regressors	164
6.3.1 A simple case	164
6.3.2 Generalization	166
6.3.3 The Wu–Hausman test	168
6.4 Exploiting instruments: Initial attempts	171

6.4.1 A simple example	171
6.4.2 Generalization	172
6.4.3 Reinterpretation using a recursive system	173
6.5 Exploiting instruments: Further steps	175
6.5.1 Choosing instruments: General remarks	176
6.5.2 Estimation in case of exact identification	177
6.5.3 Estimation in case of overidentification	181
Appendix 6A. Reinterpretation: Block-recursive system	185
Appendix 6B. Proof of consistency in case of exact identification	187
7 Measurement errors	189
7.1 Introduction	189
7.2 A homogeneous model	190
7.2.1 Model setup: Basic probability limits	191
7.2.2 Basic (disaggregate) estimators	192
7.2.3 Aggregate estimators	194
7.2.4 Combining inconsistent estimators	198
7.2.5 Difference estimators	199
7.3 Extension I: Heterogeneity in the equation	202
7.3.1 Model	202
7.3.2 Between and within estimation	203
7.3.3 Combining inconsistent estimators	204
7.4 Extension II: Heterogeneity in the error	206
7.4.1 Model	206
7.4.2 Estimation	206
7.4.3 Combining inconsistent estimators	209
7.5 Extension III: Memory in the error	209
7.5.1 One-component error with memory	210
7.5.2 Three-component specification	212
7.6 Generalized Method of Moments estimators	215
7.6.1 Generalities on the GMM	215
7.6.2 GMM-estimation of the equation in differences	217
7.6.3 Extensions and modifications	222
7.7 Concluding remarks	223
Appendix 7A. Asymptotics for aggregate estimators	224
8 Dynamic models	227
8.1 Introduction	227
8.2 Fixed effects AR-models	229

8.2.1 A simple model	229
8.2.2 Within estimation: Other difference transformations	230
8.2.3 Equation in differences: Simple estimation by level IVs	234
8.2.4 Equation in differences: System GMM with level IVs	236
8.2.5 Equation in levels: Simple estimation by difference IVs	238
8.2.6 Equation in levels: System GMM with difference IVs	238
8.2.7 Panel unit roots and panel co-integration	240
8.2.8 Bias correction	242
8.3 Fixed effects AR-models with exogenous variables	242
8.3.1 Model	242
8.3.2 Equation in differences: System GMM with level IVs	244
8.3.3 Equation in levels: System GMM with difference IVs	246
8.3.4 GMM estimation: AR-model versus EIV-model	249
8.3.5 Extensions and modifications	250
8.4 Random effects AR(1) models	250
8.4.1 A simple AR(1) model	250
8.4.2 Including exogenous variables	252
8.5 Conclusion	254
Appendix 8A. Within estimation of the AR coefficient: Asymptotics	255
Appendix 8B. Autocovariances and correlograms of y_{it} and Δy_{it}	257
9 Analysis of discrete response	261
9.1 Introduction	261
9.2 Binomial models: Fixed heterogeneity	262
9.2.1 Simple binomial model: Logit and probit parameterizations	263
9.2.2 Binomial model with full fixed heterogeneity	269
9.2.3 Binomial model with fixed intercept heterogeneity	270
9.2.4 Fixed intercept heterogeneity, small T and conditional ML	270
9.3 Binomial model: Random heterogeneity	275
9.3.1 Model	275
9.3.2 ML estimation	277
9.4 Multinomial model: Other extensions	278
9.4.1 Model	279
9.4.2 Likelihood function and ML estimation	281
9.4.3 ML estimation conditional on the individual effects	282
Appendix 9A. The general binomial model: ML Estimation	283
Appendix 9B. The multinomial logit model: Conditional ML estimation	285

10 Unbalanced panel data	287
10.1 Introduction	287
10.2 Basic model and notation	289
10.2.1 Formalization of the non-balance	289
10.2.2 Individual-specific, period-specific, and global means	291
10.3 The fixed effects case	292
10.3.1 The one-regressor case	292
10.3.2 Between- and OLS-estimation in the one-regressor case	294
10.3.3 The multi-regressor case	296
10.3.4 Between- and OLS-estimation in the general case	297
10.4 The random effects case	298
10.4.1 The one-regressor case	299
10.4.2 The multi-regressor case	302
10.4.3 Estimating the variance components: FGLS	303
10.5 Maximum Likelihood estimation	306
10.5.1 A convenient notation and reordering	306
10.5.2 Reformulating the model	307
10.5.3 'Estimating' the variance components from disturbances	308
10.5.4 The log-likelihood function	309
Appendix 10A. Between estimation: Proofs	312
Appendix 10B. GLS estimation: Proofs	313
Appendix 10C. Estimation of variance components: Details	315
11 Panel data with systematic unbalance	317
11.1 Introduction: Observation rules	317
11.2 Truncation and censoring: Baseline models	320
11.2.1 Basic concepts and point of departure	320
11.2.2 Truncation and truncation bias	321
11.2.3 Censoring and censoring bias	324
11.2.4 Maximum Likelihood in case of truncation	326
11.2.5 Maximum Likelihood in case of censoring	327
11.3 Truncation and censoring: Heterogeneity	328
11.3.1 Truncation: Maximum Likelihood estimation	329
11.3.2 Censoring: Maximum Likelihood estimation	330
11.4 Truncation and censoring: Cross-effects	332
11.4.1 Motivation and common model elements	333
11.4.2 Implied theoretical regressions for the observable variables	334
11.4.3 Stepwise estimation: Examples	335
11.4.4 Extensions: ML estimation—Heterogeneity	338

Appendix 11A. On truncated normal distributions	340
Appendix 11B. Partial effects in censoring models	345
12 Multi-equation models	347
12.1 Introduction	347
12.2 Regression system with one-way random effects	348
12.2.1 Model description	349
12.2.2 Matrix version: Two formulations	349
12.2.3 GLS estimation	353
12.2.4 Maximum Likelihood estimation	355
12.3 Regression system with two-way random effects	358
12.3.1 Model description	358
12.3.2 Matrix version: Two formulations	359
12.3.3 GLS estimation	362
12.4 Interdependent model: One-equation estimation	362
12.4.1 Within and between two-stage least squares	364
12.4.2 Variance components two-stage least squares	366
12.5 Interdependent model: Joint estimation	371
12.5.1 Within and between three-stage least squares	372
12.5.2 Variance components three-stage least squares	374
Appendix 12A. Estimation of error component covariance matrices	376
Appendix 12B. Matrix differentiation: Useful results	378
Appendix 12C. Estimator covariance matrices in interdependent models	379
REFERENCES	383
INDEX	394