
Contents

1	Introduction	1
1.1	Notational conventions	2
1.2	A short review of generalized linear models	3
1.2.1	Historical review	3
1.2.2	Basics	6
1.2.3	Link and variance functions	8
1.2.4	Algorithms	9
1.3	Software	11
1.3.1	S-PLUS	12
1.3.2	SAS	13
1.3.3	Stata	13
1.3.4	SUDAAN	14
1.4	Exercises	15
2	Model Construction and Estimating Equations	17
2.1	Independent data	17
2.1.1	The FIML estimating equation for linear regression	18
2.1.2	The FIML estimating equation for Poisson regression	21
2.1.3	The FIML estimating equation for Bernoulli regression	22
2.1.4	The LIML estimating equation for GLMs	24
2.1.5	The LIMQL estimating equation for GLMs	27
2.2	Estimating the variance of the estimates	28
2.3	Panel data	32
2.3.1	Pooled estimators	33
2.3.2	Fixed-effects and random-effects models	34
2.3.2.1	Unconditional fixed-effects models	35
2.3.2.2	Conditional fixed-effects models	36
2.3.2.3	Random-effects models	42
2.3.3	Population-averaged and subject-specific models	49
2.4	Estimation	50
2.5	Summary	50
2.6	Exercises	52
3	Generalized Estimating Equations	55
3.1	Population-averaged (PA) and subject-specific (SS) models	55
3.2	The PA-GEE for GLMs	57

3.2.1	Parameterizing the working correlation matrix	58
3.2.1.1	Exchangeable correlation	59
3.2.1.2	Autoregressive correlation	66
3.2.1.3	Stationary correlation	68
3.2.1.4	Nonstationary correlation	71
3.2.1.5	Unstructured correlation	72
3.2.1.6	Fixed correlation	73
3.2.1.7	Free specification	73
3.2.2	Estimating the scale variance (dispersion parameter)	76
3.2.2.1	Independence models	77
3.2.2.2	Exchangeable models	82
3.2.3	Estimating the PA-GEE model	85
3.2.4	Convergence of the estimation routine	89
3.2.5	ALR: Estimating correlations for binomial models	89
3.2.6	Summary	93
3.3	The SS-GEE for GLMs	95
3.3.1	Single random-effects	96
3.3.2	Multiple random-effects	98
3.3.3	Applications of the SS-GEE	99
3.3.4	Estimating the SS-GEE model	103
3.3.5	Summary	104
3.4	The GEE2 for GLMs	104
3.5	GEEs for extensions of GLMs	106
3.5.1	Generalized logistic regression	106
3.5.2	Cumulative logistic regression	108
3.6	Further developments and applications	110
3.6.1	The PA-GEE for GLMs with measurement error	110
3.6.2	The PA-EGEE for GLMs	117
3.6.3	The PA-REGEE for GLMs	119
3.7	Missing data	122
3.8	Choosing an appropriate model	128
3.9	Summary	131
3.10	Exercises	134
4	Residuals, Diagnostics, and Testing	137
4.1	Criterion measures	139
4.1.1	Choosing the best correlation structure	139
4.1.2	Choosing the best subset of covariates	142
4.2	Analysis of residuals	142
4.2.1	A nonparametric test of the randomness of residuals	143
4.2.2	Graphical assessment	143
4.2.3	Quasivariance functions for PA-GEE models	154
4.3	Deletion diagnostics	158
4.3.1	Influence measures	159
4.3.2	Leverage measures	165
4.4	Goodness of fit (population-averaged models)	165

4.4.1	Proportional reduction in variation	165
4.4.2	Concordance correlation	166
4.4.3	A χ^2 goodness of fit test for PA-GEE binomial models	167
4.5	Testing coefficients in the PA-GEE model	169
4.5.1	Likelihood ratio tests	170
4.5.2	Wald tests	172
4.5.3	Score tests	174
4.6	Assessing the MCAR assumption of PA-GEE models	174
4.7	Summary	177
4.8	Exercises	179
5	Programs and Datasets	181
5.1	Programs	181
5.1.1	Fitting PA-GEE models in Stata	182
5.1.2	Fitting PA-GEE models in SAS	183
5.1.3	Fitting PA-GEE models in S-PLUS	184
5.1.4	Fitting ALR models in SAS	185
5.1.5	Fitting PA-GEE models in SUDAAN	186
5.1.6	Calculating QIC in Stata	187
5.1.7	Calculating QICu in Stata	188
5.1.8	Graphing the residual runs test in S-PLUS	189
5.1.9	Using the fixed correlation structure in Stata	190
5.1.10	Fitting quasivariance PA-GEE models in S-PLUS	191
5.2	Datasets	192
5.2.1	Wheeze data	192
5.2.2	Ship accident data	194
5.2.3	Progabide data	196
5.2.4	Simulated logistic data	202
5.2.5	Simulated user-specified correlated data	209
5.2.6	Simulated measurement error data for the PA-GEE	212
	References	215
	Author index	219
	Subject index	221