

# Contents

<b>1</b>	<b>Introduction</b> . . . . .	<b>1</b>
1.1	Purpose . . . . .	1
1.2	Background . . . . .	4
1.3	Overview of the Adaptive Modeling Process . . . . .	5
	References . . . . .	8
<b>Part I Adaptive Regression Modeling</b>		
<b>2</b>	<b>Adaptive Regression Modeling of Univariate Continuous Outcomes</b> . . . . .	<b>11</b>
2.1	Chapter Overview . . . . .	11
2.2	The Death Rate Data . . . . .	12
2.3	The Bivariate Regression Model and Its Parameter Estimates . . . . .	12
2.4	Power Transformed Predictors . . . . .	13
2.5	Cross-Validation . . . . .	14
2.5.1	PRESS Formulation . . . . .	15
2.5.2	PRESS Assessment of the Death Rate as a Function of the Nitric Oxide Pollution Index . . . . .	15
2.5.3	Formulation for Other Types of Cross-Validation . . . . .	15
2.6	Death Rate as a Function of the Nitric Oxide Pollution Index . . . . .	17
2.7	Model Comparisons . . . . .	18
2.8	Choosing the Number of Cross-Validation Folds . . . . .	19
2.9	Comparison to Standard Polynomial Models . . . . .	21
2.10	Penalized Likelihood Criteria for Model Selection . . . . .	21
2.10.1	Formulation . . . . .	22
2.10.2	Adaptive Analyses Using Penalized Likelihood Criteria . . . . .	23

2.11	Monotonic Models . . . . .	24
2.12	Comparison to Standard Fractional Polynomial Modeling . . . . .	25
2.13	Log Transforms . . . . .	28
2.13.1	Recommended Degree 2 Fractional Polynomials . . . . .	29
2.13.2	Limits of Fractional Polynomials . . . . .	30
2.14	Impact of the Intercept . . . . .	30
2.15	Impact of Bounding the Nitric Oxide Pollution Index . . . . .	31
2.16	Death Rate as a Function of Other Predictors . . . . .	33
2.17	The Multiple Regression Model . . . . .	36
2.18	Residual Analysis . . . . .	37
2.19	Modeling Variances as well as Means . . . . .	37
2.19.1	Formulation . . . . .	38
2.19.2	Analysis of Death Rate Means and Variances . . . . .	39
2.19.3	Analysis of Means and Variances for the Simulated Data . . . . .	39
2.20	Overview of Analyses of Death Rates . . . . .	39
2.21	Overview of Analyses of the Simulated Outcome . . . . .	41
2.22	Chapter Summary . . . . .	41
	References . . . . .	43
<b>3</b>	<b>Adaptive Regression Modeling of Univariate Continuous Outcomes in SAS . . . . .</b>	<b>45</b>
3.1	Chapter Overview . . . . .	45
3.2	Loading in the Death Rate Data . . . . .	46
3.3	Adaptive Models Based on NOindex . . . . .	46
3.4	Setting the Number of Cross-Validation Folds . . . . .	48
3.5	Standard Polynomial Models in NOindex . . . . .	49
3.6	Selecting Models in NOindex Using Penalized Likelihood Criteria . . . . .	49
3.7	Monotonic Model in NOindex . . . . .	50
3.8	Recommended Fractional Polynomials in NOindex . . . . .	50
3.9	Impact of the Log Transform of NOindex . . . . .	52
3.10	Zero-Intercept Models in NOindex . . . . .	52
3.11	Models Bounding the Impact of NOindex . . . . .	53
3.12	Models in Other Available Predictors . . . . .	54
3.13	Residual Analysis . . . . .	56
3.14	Modeling Variances as Well as Means . . . . .	59
3.15	Practice Exercises . . . . .	60
	References . . . . .	62
<b>4</b>	<b>Adaptive Regression Modeling of Multivariate Continuous Outcomes . . . . .</b>	<b>63</b>
4.1	Chapter Overview . . . . .	63
4.2	The Dental Measurement Data . . . . .	64

4.3	The Marginal Multivariate Regression Model and Its Parameter Estimates . . . . .	64
4.3.1	Complete Data . . . . .	65
4.3.2	Incomplete Data . . . . .	65
4.3.3	Marginal Maximum Likelihood Modeling of Dependence . . . . .	66
4.4	LCV for Marginal Models . . . . .	67
4.4.1	LCV Formulation . . . . .	67
4.4.2	LCV Ratio Tests . . . . .	68
4.5	Marginal Order 1 Autoregressive Modeling of the Dental Measurement Data . . . . .	69
4.5.1	Order 1 Autoregressive Correlations . . . . .	69
4.5.2	Setting the Number of Cross-Validation Folds . . . . .	70
4.5.3	Moderation of the Effect of Age by Gender . . . . .	70
4.5.4	Geometric Combinations . . . . .	72
4.6	General Power Transforms . . . . .	73
4.6.1	Formulation . . . . .	74
4.6.2	The Royston and Sauerbrei Approach . . . . .	75
4.7	Transition Modeling of Dependence . . . . .	75
4.7.1	Formulation Using Averages of Prior Outcome Measurements . . . . .	76
4.7.2	Transition Model Induced by the Marginal AR1 Model with Constant Means . . . . .	78
4.7.3	Using Weighted Averages of Prior Outcome Measurements . . . . .	78
4.8	Transition Modeling of the Dental Measurement Data . . . . .	79
4.8.1	Using the Prior Dental Measurement . . . . .	79
4.8.2	Comparison to the Marginal Model with Exchangeable Correlations . . . . .	79
4.8.3	Using Multiple Prior Dental Measurements . . . . .	80
4.8.4	Transition Model Selection with Penalized Likelihood Criteria . . . . .	82
4.9	General Conditional Modeling of Dependence . . . . .	83
4.9.1	Formulation . . . . .	84
4.9.2	Conditional Models Induced by Marginal Models . . . . .	85
4.10	General Conditional Modeling of the Dental Measurement Data . . . . .	86
4.11	Adaptive GEE-Based Modeling of Multivariate Continuous Outcomes . . . . .	87
4.11.1	Formulation . . . . .	88
4.11.2	Adaptive GEE-Based Modeling of the Dental Measurement Data . . . . .	89
4.11.3	Assessment of the Quasi-Likelihood Information Criterion . . . . .	90

4.12	Analysis of the Exercise Data . . . . .	92
4.13	LCV with Measurement-Wise Deletion . . . . .	94
4.14	Revised Analysis of the Exercise Data . . . . .	95
4.15	Modeling Variances as Well as Means . . . . .	96
4.15.1	Formulation . . . . .	96
4.15.2	Analysis of Dental Measurement Means and Variances . . . . .	97
4.15.3	Transition Modeling of Strength Measurement Means with Adjusted Variances . . . . .	99
4.15.4	Analysis of Strength Measurement Means and Variances . . . . .	99
4.16	Overview of Analyses of Dental Measurements . . . . .	102
4.17	Overview of Analyses of Strength Measurements . . . . .	104
4.18	Chapter Summary . . . . .	105
	References . . . . .	108
<b>5</b>	<b>Adaptive Regression Modeling of Multivariate Continuous Outcomes in SAS . . . . .</b>	<b>109</b>
5.1	Chapter Overview . . . . .	109
5.2	Loading the Dental Measurement Data . . . . .	110
5.3	Marginal Modeling of Means for the Dental Measurement Data . . . . .	111
5.3.1	Marginal Models of Mean Dental Measurement in Age of the Child . . . . .	111
5.3.2	Marginal Moderation Models of Mean Dental Measurement in Age and Gender of the Child . . . . .	113
5.3.3	Residual Analysis of the Adaptive Marginal Moderation Model . . . . .	117
5.4	Conditional Modeling of Means for the Dental Measurement Data . . . . .	121
5.4.1	Transition Models for Mean Dental Measurement . . . . .	121
5.4.2	Residual Analysis of the Adaptive Transition Model . . . . .	122
5.4.3	General Conditional Models for Mean Dental Measurement . . . . .	124
5.5	Analyzing the Exercise Data . . . . .	125
5.6	Modeling Variances as Well as Means . . . . .	125
5.6.1	Marginal Models for Dental Measurements . . . . .	125
5.6.2	Transition Models for Dental Measurements . . . . .	127
5.6.3	Clock Time Assessments . . . . .	128
5.7	Practice Exercises . . . . .	129
	References . . . . .	132

<b>6</b>	<b>Adaptive Transformation of Positive Valued Continuous Outcomes . . . . .</b>	<b>133</b>
6.1	Chapter Overview . . . . .	133
6.2	Transformation of the Outcome Variable . . . . .	133
6.3	Formulation for Power-Adjusted Likelihoods and LCV Scores . . . . .	134
6.3.1	Univariate Outcomes . . . . .	134
6.3.2	Multivariate Outcomes . . . . .	135
6.4	Analyses of Transformed Death Rates . . . . .	137
6.5	Analyses of the Transformed Simulated Outcome . . . . .	137
6.6	Analyses of Transformed Dental Measurements . . . . .	138
6.7	Analyses of Transformed Strength Measurements . . . . .	139
6.8	The Plasma Beta-Carotene Data . . . . .	140
6.9	Analyses of Untransformed Plasma Beta-Carotene Levels . . . . .	141
6.10	Analyses of Transformed Plasma Beta-Carotene Levels . . . . .	142
6.11	Overview of Analyses of Death Rates . . . . .	143
6.12	Overview of Analyses of the Simulated Outcome . . . . .	144
6.13	Overview of Analyses of Dental Measurements . . . . .	144
6.14	Overview of Analyses of Strength Measurements . . . . .	144
6.15	Overview of Analyses of Plasma Beta-Carotene Levels . . . . .	144
6.16	Chapter Summary . . . . .	145
	References . . . . .	146
<b>7</b>	<b>Adaptive Transformation of Positive Valued Continuous Outcomes in SAS . . . . .</b>	<b>149</b>
7.1	Chapter Overview . . . . .	149
7.2	Loading in the Plasma Beta-Carotene Data . . . . .	149
7.3	Adaptive Transformation of Plasma Beta-Carotene Levels . . . . .	150
7.4	Adaptive Transformation of Dental Measurements . . . . .	153
7.4.1	Using Transition Models . . . . .	153
7.4.2	Using Marginal Models . . . . .	154
7.5	Practice Exercises . . . . .	155
	References . . . . .	157
<b>Part II Adaptive Logistic Regression Modeling</b>		
<b>8</b>	<b>Adaptive Logistic Regression Modeling of Univariate Dichotomous and Polytomous Outcomes . . . . .</b>	<b>161</b>
8.1	Chapter Overview . . . . .	161
8.2	The Mercury Level Data . . . . .	162
8.3	Multiple Logistic Regression Modeling of Dichotomous Outcomes . . . . .	162
8.3.1	Multiple Logistic Regression Model Formulation . . . . .	162
8.3.2	Odds Ratio Function Formulation . . . . .	163

8.4	Dichotomous Mercury Level as a Function of Weight . . . . .	164
8.5	Dichotomous Mercury Level as a Function of Length . . . . .	165
8.6	Dichotomous Mercury Level as a Function of Weight and Length . . . . .	167
8.7	Multiple Logistic Regression Modeling of Polytomous Outcomes . . . . .	169
8.7.1	Multinomial Regression . . . . .	169
8.7.2	Ordinal Regression . . . . .	171
8.8	Mercury Level Categorized into Three Ordinal Levels . . . . .	172
8.9	Polytomous Mercury Level as a Function of Weight . . . . .	172
8.10	Polytomous Mercury Level as a Function of Length . . . . .	173
8.11	Polytomous Mercury Level as a Function of Weight and Length . . . . .	175
8.12	Proportion of Correct Deleted Predictions . . . . .	176
8.12.1	Formulation . . . . .	177
8.12.2	Example Analyses of Dichotomous Mercury Level . . . . .	177
8.12.3	Example Analyses of Polytomous Mercury Level . . . . .	178
8.13	Modeling Dispersions as Well as Means . . . . .	178
8.13.1	Formulation for Dichotomous Outcomes . . . . .	179
8.13.2	Formulation for Polytomous Outcomes . . . . .	180
8.13.3	Analysis of Dichotomous Mercury Level Means and Dispersions . . . . .	182
8.14	Overview of Analyses of Dichotomous Mercury Levels . . . . .	183
8.15	Overview of Analyses of Polytomous Mercury Levels . . . . .	184
8.16	Chapter Summary . . . . .	185
	References . . . . .	186
<b>9</b>	<b>Adaptive Logistic Regression Modeling of Univariate Dichotomous and Polytomous Outcomes in SAS . . . . .</b>	<b>187</b>
9.1	Chapter Overview . . . . .	187
9.2	Loading in the Mercury Level Data . . . . .	188
9.3	Modeling Means for Merchigh Based on Weight . . . . .	189
9.4	Modeling Means for Merchigh Based on Length . . . . .	193
9.5	Grouped Residuals for Univariate Dichotomous Outcomes . . . . .	194
9.6	Grouped Residual Analysis of Merchigh as a Function of Length . . . . .	196
9.7	Modeling Means for Merchigh Based on Weight and Length . . . . .	198
9.8	Modeling Means for Merclevel Based on Weight and Length . . . . .	198
9.9	Grouped Residuals for Univariate Polytomous Outcomes . . . . .	201
9.9.1	Multinomial Regression . . . . .	201
9.9.2	Ordinal Regression . . . . .	202

9.10	Grouped Residual Analysis of Merclevel as a Function of Length . . . . .	203
9.11	Modeling Dispersions as Well as Means for the Dichotomous Outcome Merchigh . . . . .	204
9.12	Modeling Dispersions as Well as Means for the Polytomous Outcome Merclevel . . . . .	206
9.13	Practice Exercises . . . . .	211
	References . . . . .	212
<b>10</b>	<b>Adaptive Logistic Regression Modeling of Multivariate Dichotomous and Polytomous Outcomes . . . . .</b>	<b>213</b>
10.1	Chapter Overview . . . . .	213
10.2	The Respiratory Status Data . . . . .	214
10.3	Conditional Modeling of Multivariate Dichotomous Outcomes . . . . .	215
10.3.1	Conditional Modeling of Means Assuming Unit Dispersions . . . . .	215
10.3.2	Conditional Modeling of Dispersions as Well as Means . . . . .	217
10.4	Transition Modeling of Post-Baseline Dichotomous Respiratory Status . . . . .	218
10.4.1	Unit Dispersions Models . . . . .	218
10.4.2	Non-Unit Dispersions Models . . . . .	221
10.5	Conditional Modeling of Multivariate Polytomous Outcomes . . . . .	223
10.6	Transition Modeling of Post-Baseline Polytomous Respiratory Status . . . . .	224
10.6.1	Unit Dispersions Models . . . . .	224
10.6.2	Non-Unit Dispersions Models . . . . .	226
10.7	Adaptive GEE-Based Modeling of Multivariate Dichotomous and Polytomous Outcomes . . . . .	227
10.7.1	Dichotomous Outcomes . . . . .	227
10.7.2	Polytomous Outcomes . . . . .	231
10.7.3	Comparing Transition Models to Marginal GEE-Based Models . . . . .	233
10.8	Adaptive GEE-Based Modeling of Post-Baseline Respiratory Status . . . . .	234
10.9	Overview of Analyses of Post-Baseline Dichotomous Respiratory Status . . . . .	235
10.10	Overview of Analyses of Post-Baseline Polytomous Respiratory Status . . . . .	236
10.11	Chapter Summary . . . . .	237
	References . . . . .	237

<b>11 Adaptive Logistic Regression Modeling of Multivariate Dichotomous and Polytomous Outcomes in SAS</b> . . . . .	239
11.1 Chapter Overview . . . . .	239
11.2 Loading in the Respiratory Status Data . . . . .	239
11.3 Transition Modeling of Dichotomous Respiratory Status . . . . .	242
11.4 Marginal GEE-Based Modeling of Dichotomous Respiratory Status . . . . .	246
11.5 Modeling of Polytomous Outcomes . . . . .	248
11.6 Practice Exercises . . . . .	249
References . . . . .	251
<b>Part III Adaptive Poisson Regression Modeling</b>	
<b>12 Adaptive Poisson Regression Modeling of Univariate Count Outcomes</b> . . . . .	255
12.1 Chapter Overview . . . . .	255
12.2 The Skin Cancer Data . . . . .	255
12.3 Multiple Poisson Regression Modeling of Count Outcomes . . . . .	256
12.3.1 Unit Dispersions Formulation . . . . .	256
12.3.2 Non-Unit Dispersions Formulation . . . . .	257
12.4 Skin Cancer Rates as a Function of the Minimum Age and City of Residence . . . . .	258
12.4.1 Modeling Means for Skin Cancer Rates with Constant Dispersions Models . . . . .	258
12.4.2 Modeling Dispersions as Well as Means for Skin Cancer Rates . . . . .	260
12.5 Overview of Analyses of Skin Cancer Rates . . . . .	261
12.6 Chapter Summary . . . . .	262
References . . . . .	263
<b>13 Adaptive Poisson Regression Modeling of Univariate Count Outcomes in SAS</b> . . . . .	265
13.1 Chapter Overview . . . . .	265
13.2 Loading in the Skin Cancer Data . . . . .	265
13.3 Modeling Means for Skin Cancer Rates . . . . .	266
13.4 Modeling Dispersions as Well as Means for Skin Cancer Rates . . . . .	269
13.5 Practice Exercises . . . . .	273
References . . . . .	274
<b>14 Adaptive Poisson Regression Modeling of Multivariate Count Outcomes</b> . . . . .	275
14.1 Chapter Overview . . . . .	275
14.2 The Epileptic Seizures Data . . . . .	276

14.3 Conditional Modeling of Multivariate Count Outcomes . . . . .	276
14.3.1 Conditional Modeling of Means Assuming Unit Dispersions . . . . .	277
14.3.2 Conditional Modeling of Dispersions as Well as Means . . . . .	278
14.4 Transition Modeling of Post-Baseline Seizure Rates . . . . .	280
14.4.1 Constant Dispersions Models . . . . .	280
14.4.2 Non-Constant Dispersions Models . . . . .	282
14.5 Adaptive GEE-Based Modeling of Multivariate Count Outcomes . . . . .	282
14.6 Adaptive GEE-Based Modeling of Post-Baseline Seizure Rates . . . . .	283
14.7 Overview of Analyses of Post-Baseline Seizure Rates . . . . .	284
14.8 Chapter Summary . . . . .	284
References . . . . .	285
<b>15 Adaptive Poisson Regression Modeling of Multivariate Count Outcomes in SAS</b> . . . . .	287
15.1 Chapter Overview . . . . .	287
15.2 Loading in the Epileptic Seizures Data . . . . .	287
15.3 Transition Modeling of Post-Baseline Seizure Rates . . . . .	289
15.4 Marginal GEE-Based Modeling of Post-Baseline Seizure Rates . . . . .	293
15.5 Practice Exercises . . . . .	294
Reference . . . . .	295
<b>Part IV Alternative Nonparametric Regression Modeling</b>	
<b>16 Generalized Additive Modeling</b> . . . . .	299
16.1 Chapter Overview . . . . .	299
16.2 Formulation of GAMs for Univariate Continuous Outcomes . . . . .	300
16.3 Formulation of Likelihood Cross-Validation for GAMs . . . . .	301
16.4 Other Forms of Cross-Validation . . . . .	302
16.5 GAM Analyses of Deathrate as a Function of the Nitric Oxide Pollution Index . . . . .	302
16.6 GAM Analyses of Deathrate as a Function of Other Singleton Predictors . . . . .	305
16.7 GAM Analyses of Deathrate as a Function of Two Predictors . . . . .	306
16.8 GAM Analyses of the Full Deathrate Data . . . . .	308
16.9 Formulation of GAMs for Dichotomous Outcomes . . . . .	310
16.10 GAM Analyses of the Mercury Level Data . . . . .	311
16.11 Overview of Analyses of Death Rates . . . . .	312
16.12 Overview of Analyses of Dichotomous Mercury Levels . . . . .	313
16.13 Chapter Summary . . . . .	313
References . . . . .	314

<b>17</b>	<b>Generalized Additive Modeling in SAS</b> . . . . .	315
17.1	Chapter Overview . . . . .	315
17.2	Invoking PROC GAM . . . . .	317
17.3	Generating LCV Scores for GAMs . . . . .	319
17.4	Multiple Predictor GAMs . . . . .	323
17.5	GAMs for Dichotomous Outcomes . . . . .	326
17.6	Practice Exercises . . . . .	327
	References . . . . .	329
<b>18</b>	<b>Multivariate Adaptive Regression Spline Modeling</b> . . . . .	329
18.1	Chapter Overview . . . . .	330
18.2	Description of MARS Modeling . . . . .	330
18.3	MARS Analyses of Death Rates . . . . .	330
18.3.1	MARS Analyses Based on NObnded . . . . .	331
18.3.2	MARS Analyses Based on Rain . . . . .	331
18.3.3	MARS Analyses Based on NObnded and Rain . . . . .	332
18.3.4	MARS Analyses Based on the Full Set of Available Predictors . . . . .	332
18.4	MARS Analyses of the Mercury Level Data . . . . .	333
18.4.1	MARS Analyses Based on Weight of Fish . . . . .	333
18.4.2	MARS Analyses Based on Length of Fish . . . . .	334
18.4.3	MARS Analyses Based on Weight and Length of Fish . . . . .	335
18.5	Overview of MARS Analyses of Death Rates . . . . .	336
18.6	Overview of MARS Analyses of Dichotomous Mercury Levels . . . . .	337
18.7	Chapter Summary . . . . .	338
	References . . . . .	339
<b>19</b>	<b>Multivariate Adaptive Regression Spline Modeling in SAS</b> . . . . .	339
19.1	Chapter Overview . . . . .	339
19.2	Invoking PROC ADAPTIVEREG . . . . .	341
19.3	Generating LCV Scores for MARS Models . . . . .	342
19.4	Multiple Predictor MARS Models . . . . .	343
19.5	MARS Models for Dichotomous Outcomes . . . . .	348
19.6	Practice Exercises . . . . .	349
	Reference . . . . .	349
<b>Part V The Adaptive Regression Modeling Process</b>		
<b>20</b>	<b>Adaptive Regression Modeling Formulation</b> . . . . .	353
20.1	Chapter Overview . . . . .	353
20.2	Overview of General Regression Modeling Formulation . . . . .	355
20.3	Overview of Model Selection Approaches . . . . .	355
20.3.1	Using Cross-Validation Based on Likelihood or Likelihood-Like Functions . . . . .	357
20.3.2	Alternate Model Selection Approaches . . . . .	357

20.4	The Adaptive Modeling Process . . . . .	358
20.4.1	Conditional Predictors . . . . .	359
20.4.2	Power Transforms . . . . .	359
20.4.3	Selecting a Power for a Primary Predictor . . . . .	361
20.4.4	Adjusting the Transforms of a Base Model . . . . .	362
20.4.5	Expanding a Base Model . . . . .	363
20.4.6	Considering Geometric Combinations . . . . .	365
20.4.7	Contracting a Base Model . . . . .	366
20.4.8	Tolerance Parameter Settings . . . . .	367
20.4.9	The Complete Adaptive Model Selection Process . . . . .	368
20.4.10	Computing Transforms . . . . .	369
20.4.11	Avoiding Redundant Transforms . . . . .	370
	References . . . . .	371
	<b>Index</b> . . . . .	371