

# Contents

<b>List of tables</b>	<b>xv</b>
<b>List of figures</b>	<b>xvii</b>
<b>Preface to the Second Edition</b>	<b>xxvii</b>
<b>Preface to the First Edition</b>	<b>xxix</b>
<b>Acknowledgments</b>	<b>xxxi</b>
<b>1 Introduction</b>	<b>1</b>
1.1 Read me first . . . . .	1
1.2 The GSS dataset . . . . .	4
1.2.1 Income . . . . .	5
1.2.2 Age . . . . .	6
1.2.3 Education . . . . .	10
1.2.4 Gender . . . . .	12
1.3 The pain datasets . . . . .	12
1.4 The optimism datasets . . . . .	13
1.5 The school datasets . . . . .	13
1.6 The sleep datasets . . . . .	13
1.7 Overview of the book . . . . .	13
<b>I Continuous predictors</b>	<b>17</b>
<b>2 Continuous predictors: Linear</b>	<b>19</b>
2.1 Chapter overview . . . . .	19
2.2 Simple linear regression . . . . .	19
2.2.1 Computing predicted means using the margins command . .	22
2.2.2 Graphing predicted means using the marginsplot command	24
2.3 Multiple regression . . . . .	27

2.3.1	Computing adjusted means using the margins command . . . . .	28
2.3.2	Some technical details about adjusted means . . . . .	30
2.3.3	Graphing adjusted means using the marginsplot command . .	31
2.4	Checking for nonlinearity graphically . . . . .	32
2.4.1	Using scatterplots to check for nonlinearity . . . . .	33
2.4.2	Checking for nonlinearity using residuals . . . . .	33
2.4.3	Checking for nonlinearity using locally weighted smoother .	35
2.4.4	Graphing outcome mean at each level of predictor . . . . .	36
2.4.5	Summary . . . . .	39
2.5	Checking for nonlinearity analytically . . . . .	39
2.5.1	Adding power terms . . . . .	40
2.5.2	Using factor variables . . . . .	42
2.6	Summary . . . . .	46
<b>3</b>	<b>Continuous predictors: Polynomials</b>	<b>49</b>
3.1	Chapter overview . . . . .	49
3.2	Quadratic (squared) terms . . . . .	49
3.2.1	Overview . . . . .	49
3.2.2	Examples . . . . .	53
3.3	Cubic (third power) terms . . . . .	59
3.3.1	Overview . . . . .	59
3.3.2	Examples . . . . .	60
3.4	Fractional polynomial regression . . . . .	66
3.4.1	Overview . . . . .	66
3.4.2	Example using fractional polynomial regression . . . . .	70
3.5	Main effects with polynomial terms . . . . .	79
3.6	Summary . . . . .	81
<b>4</b>	<b>Continuous predictors: Piecewise models</b>	<b>83</b>
4.1	Chapter overview . . . . .	83
4.2	Introduction to piecewise regression models . . . . .	84
4.3	Piecewise with one known knot . . . . .	86

4.3.1	Overview . . . . .	86
4.3.2	Examples using the GSS . . . . .	87
4.4	Piecewise with two known knots . . . . .	95
4.4.1	Overview . . . . .	95
4.4.2	Examples using the GSS . . . . .	95
4.5	Piecewise with one knot and one jump . . . . .	100
4.5.1	Overview . . . . .	100
4.5.2	Examples using the GSS . . . . .	101
4.6	Piecewise with two knots and two jumps . . . . .	106
4.6.1	Overview . . . . .	106
4.6.2	Examples using the GSS . . . . .	106
4.7	Piecewise with an unknown knot . . . . .	113
4.8	Piecewise model with multiple unknown knots . . . . .	117
4.9	Piecewise models and the marginsplot command . . . . .	124
4.10	Automating graphs of piecewise models . . . . .	127
4.11	Summary . . . . .	130
<b>5</b>	<b>Continuous by continuous interactions</b>	<b>131</b>
5.1	Chapter overview . . . . .	131
5.2	Linear by linear interactions . . . . .	131
5.2.1	Overview . . . . .	131
5.2.2	Example using GSS data . . . . .	136
5.2.3	Interpreting the interaction in terms of age . . . . .	137
5.2.4	Interpreting the interaction in terms of education . . . . .	139
5.2.5	Interpreting the interaction in terms of age slope . . . . .	141
5.2.6	Interpreting the interaction in terms of the educ slope . . . . .	142
5.3	Linear by quadratic interactions . . . . .	144
5.3.1	Overview . . . . .	144
5.3.2	Example using GSS data . . . . .	147
5.4	Summary . . . . .	152

<b>6</b>	<b>Continuous by continuous by continuous interactions</b>	<b>153</b>
6.1	Chapter overview . . . . .	153
6.2	Overview . . . . .	153
6.3	Examples using the GSS data . . . . .	158
6.3.1	A model without a three-way interaction . . . . .	158
6.3.2	A three-way interaction model . . . . .	162
6.4	Summary . . . . .	169
<b>II</b>	<b>Categorical predictors</b>	<b>171</b>
<b>7</b>	<b>Categorical predictors</b>	<b>173</b>
7.1	Chapter overview . . . . .	173
7.2	Comparing two groups using a t test . . . . .	174
7.3	More groups and more predictors . . . . .	175
7.4	Overview of contrast operators . . . . .	181
7.5	Compare each group against a reference group . . . . .	182
7.5.1	Selecting a specific contrast . . . . .	183
7.5.2	Selecting a different reference group . . . . .	184
7.5.3	Selecting a contrast and reference group . . . . .	185
7.6	Compare each group against the grand mean . . . . .	185
7.6.1	Selecting a specific contrast . . . . .	187
7.7	Compare adjacent means . . . . .	188
7.7.1	Reverse adjacent contrasts . . . . .	192
7.7.2	Selecting a specific contrast . . . . .	193
7.8	Comparing the mean of subsequent or previous levels . . . . .	194
7.8.1	Comparing the mean of previous levels . . . . .	198
7.8.2	Selecting a specific contrast . . . . .	199
7.9	Polynomial contrasts . . . . .	200
7.10	Custom contrasts . . . . .	202
7.11	Weighted contrasts . . . . .	206
7.12	Pairwise comparisons . . . . .	208

7.13	Interpreting confidence intervals . . . . .	210
7.14	Testing categorical variables using regression . . . . .	212
7.15	Summary . . . . .	215
<b>8</b>	<b>Categorical by categorical interactions</b>	<b>217</b>
8.1	Chapter overview . . . . .	217
8.2	Two by two models: Example 1 . . . . .	219
8.2.1	Simple effects . . . . .	224
8.2.2	Estimating the size of the interaction . . . . .	225
8.2.3	More about interaction . . . . .	226
8.2.4	Summary . . . . .	227
8.3	Two by three models . . . . .	227
8.3.1	Example 2 . . . . .	227
8.3.2	Example 3 . . . . .	232
8.3.3	Summary . . . . .	237
8.4	Three by three models: Example 4 . . . . .	237
8.4.1	Simple effects . . . . .	240
8.4.2	Simple contrasts . . . . .	240
8.4.3	Partial interaction . . . . .	242
8.4.4	Interaction contrasts . . . . .	243
8.4.5	Summary . . . . .	245
8.5	Unbalanced designs . . . . .	245
8.6	Main effects with interactions: anova versus regress . . . . .	250
8.7	Interpreting confidence intervals . . . . .	253
8.8	Summary . . . . .	255
<b>9</b>	<b>Categorical by categorical by categorical interactions</b>	<b>257</b>
9.1	Chapter overview . . . . .	257
9.2	Two by two by two models . . . . .	258
9.2.1	Simple interactions by season . . . . .	260
9.2.2	Simple interactions by depression status . . . . .	261
9.2.3	Simple effects . . . . .	263

9.3	Two by two by three models . . . . .	263
9.3.1	Simple interactions by depression status . . . . .	266
9.3.2	Simple partial interaction by depression status . . . . .	266
9.3.3	Simple contrasts . . . . .	268
9.3.4	Partial interactions . . . . .	268
9.4	Three by three by three models and beyond . . . . .	270
9.4.1	Partial interactions and interaction contrasts . . . . .	272
9.4.2	Simple interactions . . . . .	276
9.4.3	Simple effects and simple comparisons . . . . .	279
9.5	Summary . . . . .	280
<b>III</b>	<b>Continuous and categorical predictors</b>	<b>281</b>
<b>10</b>	<b>Linear by categorical interactions</b>	<b>283</b>
10.1	Chapter overview . . . . .	283
10.2	Linear and two-level categorical: No interaction . . . . .	283
10.2.1	Overview . . . . .	283
10.2.2	Examples using the GSS . . . . .	286
10.3	Linear by two-level categorical interactions . . . . .	291
10.3.1	Overview . . . . .	291
10.3.2	Examples using the GSS . . . . .	294
10.4	Linear by three-level categorical interactions . . . . .	299
10.4.1	Overview . . . . .	299
10.4.2	Examples using the GSS . . . . .	301
10.5	Summary . . . . .	308
<b>11</b>	<b>Polynomial by categorical interactions</b>	<b>311</b>
11.1	Chapter overview . . . . .	311
11.2	Quadratic by categorical interactions . . . . .	311
11.2.1	Overview . . . . .	312
11.2.2	Quadratic by two-level categorical . . . . .	315
11.2.3	Quadratic by three-level categorical . . . . .	323

11.3	Cubic by categorical interactions . . . . .	329
11.4	Summary . . . . .	334
<b>12</b>	<b>Piecewise by categorical interactions</b>	<b>335</b>
12.1	Chapter overview . . . . .	335
12.2	One knot and one jump . . . . .	338
12.2.1	Comparing slopes across gender . . . . .	342
12.2.2	Comparing slopes across education . . . . .	343
12.2.3	Difference in differences of slopes . . . . .	343
12.2.4	Comparing changes in intercepts . . . . .	344
12.2.5	Computing and comparing adjusted means . . . . .	344
12.2.6	Graphing adjusted means . . . . .	347
12.3	Two knots and two jumps . . . . .	351
12.3.1	Comparing slopes across gender . . . . .	356
12.3.2	Comparing slopes across education . . . . .	357
12.3.3	Difference in differences of slopes . . . . .	358
12.3.4	Comparing changes in intercepts by gender . . . . .	359
12.3.5	Comparing changes in intercepts by education . . . . .	360
12.3.6	Computing and comparing adjusted means . . . . .	361
12.3.7	Graphing adjusted means . . . . .	364
12.4	Comparing coding schemes . . . . .	366
12.4.1	Coding scheme #1 . . . . .	367
12.4.2	Coding scheme #2 . . . . .	368
12.4.3	Coding scheme #3 . . . . .	370
12.4.4	Coding scheme #4 . . . . .	372
12.4.5	Choosing coding schemes . . . . .	373
12.5	Summary . . . . .	374
<b>13</b>	<b>Continuous by continuous by categorical interactions</b>	<b>375</b>
13.1	Chapter overview . . . . .	375
13.2	Linear by linear by categorical interactions . . . . .	376
13.2.1	Fitting separate models for males and females . . . . .	376

13.2.2	Fitting a combined model for males and females . . . . .	378
13.2.3	Interpreting the interaction focusing in the age slope . . . . .	380
13.2.4	Interpreting the interaction focusing on the educ slope . . . . .	382
13.2.5	Estimating and comparing adjusted means by gender . . . . .	384
13.3	Linear by quadratic by categorical interactions . . . . .	386
13.3.1	Fitting separate models for males and females . . . . .	386
13.3.2	Fitting a common model for males and females . . . . .	388
13.3.3	Interpreting the interaction . . . . .	389
13.3.4	Estimating and comparing adjusted means by gender . . . . .	390
13.4	Summary . . . . .	392
14	<b>Continuous by categorical by categorical interactions</b>	393
14.1	Chapter overview . . . . .	393
14.2	Simple effects of gender on the age slope . . . . .	398
14.3	Simple effects of education on the age slope . . . . .	399
14.4	Simple contrasts on education for the age slope . . . . .	400
14.5	Partial interaction on education for the age slope . . . . .	400
14.6	Summary . . . . .	401
<b>IV</b>	<b>Beyond ordinary linear regression</b>	403
15	<b>Multilevel models</b>	405
15.1	Chapter overview . . . . .	405
15.2	Example 1: Continuous by continuous interaction . . . . .	406
15.3	Example 2: Continuous by categorical interaction . . . . .	409
15.4	Example 3: Categorical by continuous interaction . . . . .	413
15.5	Example 4: Categorical by categorical interaction . . . . .	417
15.6	Summary . . . . .	421
16	<b>Time as a continuous predictor</b>	423
16.1	Chapter overview . . . . .	423
16.2	Example 1: Linear effect of time . . . . .	424
16.3	Example 2: Linear effect of time by a categorical predictor . . . . .	428

16.4	Example 3: Piecewise modeling of time . . . . .	433
16.5	Example 4: Piecewise effects of time by a categorical predictor . . . . .	438
16.5.1	Baseline slopes . . . . .	443
16.5.2	Change in slopes: Treatment versus baseline . . . . .	444
16.5.3	Jump at treatment . . . . .	445
16.5.4	Comparisons among groups . . . . .	446
16.6	Summary . . . . .	448
<b>17</b>	<b>Time as a categorical predictor</b>	<b>449</b>
17.1	Chapter overview . . . . .	449
17.2	Example 1: Time treated as a categorical variable . . . . .	450
17.3	Example 2: Time (categorical) by two groups . . . . .	455
17.4	Example 3: Time (categorical) by three groups . . . . .	459
17.5	Comparing models with different residual covariance structures . . . . .	464
17.6	Analyses with small samples . . . . .	466
17.7	Summary . . . . .	474
<b>18</b>	<b>Nonlinear models</b>	<b>475</b>
18.1	Chapter overview . . . . .	475
18.2	Binary logistic regression . . . . .	476
18.2.1	A logistic model with one categorical predictor . . . . .	476
18.2.2	A logistic model with one continuous predictor . . . . .	484
18.2.3	A logistic model with covariates . . . . .	486
18.3	Multinomial logistic regression . . . . .	491
18.4	Ordinal logistic regression . . . . .	497
18.5	Poisson regression . . . . .	500
18.6	More applications of nonlinear models . . . . .	503
18.6.1	Categorical by categorical interaction . . . . .	503
18.6.2	Categorical by continuous interaction . . . . .	510
18.6.3	Piecewise modeling . . . . .	516
18.7	Summary . . . . .	522
<b>19</b>	<b>Complex survey data</b>	<b>523</b>

<b>V Appendices</b>	<b>529</b>
<b>A Customizing output from estimation commands</b>	<b>531</b>
A.1 Omission of output . . . . .	531
A.2 Specifying the confidence level . . . . .	533
A.3 Customizing the formatting of columns in the coefficient table . . . . .	534
A.4 Customizing the display of factor variables . . . . .	536
<b>B The margins command</b>	<b>545</b>
B.1 The predict() and expression() options . . . . .	545
B.2 The at() option . . . . .	548
B.3 Margins with factor variables . . . . .	551
B.4 Margins with factor variables and the at() option . . . . .	557
B.5 The dydx() and related options . . . . .	559
B.6 Specifying the confidence level . . . . .	563
B.7 Customizing column formatting . . . . .	564
<b>C The marginsplot command</b>	<b>567</b>
<b>D The contrast command</b>	<b>583</b>
D.1 Inclusion and omission of output . . . . .	584
D.2 Customizing the display of factor variables . . . . .	586
D.3 Adjustments for multiple comparisons . . . . .	588
D.4 Specifying the confidence level . . . . .	588
D.5 Customizing column formatting . . . . .	589
<b>E The pwcompare command</b>	<b>591</b>
<b>References</b>	<b>597</b>
<b>Author index</b>	<b>601</b>
<b>Subject index</b>	<b>603</b>