Applied Choice Analysis

The second edition of this popular book brings students fully up to date with the latest methods and techniques in choice analysis. Comprehensive yet accessible, it offers a unique introduction to anyone interested in understanding how to model and forecast the range of choices made by individuals and groups. In addition to a complete rewrite of several chapters, new topics covered include ordered choice, scaled MNL, generalized mixed logit, latent class models, group decision making, heuristics and attribute processing strategies, expected utility theory, and prospect theoretic applications. Many additional case studies are used to illustrate the applications of choice analysis with extensive command syntax provided for all Nlogit applications and datasets available online. With its unique blend of theory, estimation, and application, this book has broad appeal to all those interested in choice modeling methods and will be a valuable resource for students as well as researchers, professionals, and consultants.

David A. Hensher is Professor of Management, and Founding Director of the Institute of Transport and Logistics Studies (ITLS) at The University of Sydney Business School.

John M. Rose was previously Professor of Transport and Logistics Modelling at the Institute of Transport and Logistics Studies (ITLS) at The University of Sydney Business School and moved to The University of South Australia as co-director of the Institute for Choice in early March 2014.

William H. Greene is the Robert Stansky Professor of Economics at the Stern School of Business, New York University.

Applied Choice Analysis

Second Edition

David A. Hensher

The University of Sydney Business School

John M. Rose

The University of Sydney Business School*

William H. Greene

Stern School of Business, New York University

* John Rose completed his contribution to the second edition while at The University of Sydney. He has since relocated to The University of South Australia

CAMBRIDGE
UNIVERSITY PRESS

CAMBRIDGE
UNIVERSITY PRESS

University Printing House, Cambridge CB2 8BS, United Kingdom

Cambridge University Press is part of the University of Cambridge.

It furthers the University's mission by disseminating knowledge in the pursuit of education, learning and research at the highest international levels of excellence.

www.cambridge.org
Information on this title: www.cambridge.org/9781107465923

First published 2005
Second edition 2015

Printed in the United Kingdom by TJ International Ltd. Padstow Cornwall

A catalogue record for this publication is available from the British Library

Library of Congress Cataloguing in Publication data
Hensher, David A., 1947–
Applied choice analysis / David A. Hensher, The University of Sydney Business School, John M. Rose,
The University of Sydney Business School, William H. Greene, Stern School of Business, New York University. – 2nd edition.
pages cm
John M. Rose now at University of South Australia.
Includes bibliographical references and index.
ISBN 978-1-107-09264-8
1. Decision making – Mathematical models. 2. Probabilities – Mathematical models. 3. Choice. I. Rose, John M. II. Greene, William H., 1951– III. Title.
QA279.4.H46 2015
519.5′42–dc23

2014043411

ISBN 978-1-107-09264-8 Hardback
ISBN 978-1-107-46592-3 Paperback

Additional resources for this publication at www.cambridge.org/9781107465923

Contents

List of figures *page* xvii
List of tables xxii
Preface xxix

Part I Getting started 1

1 In the beginning 3
1.1 Choosing as a common event 3
1.2 A brief history of choice modeling 6
1.3 The journey ahead 11

2 Choosing 16
2.1 Introduction 16
2.2 Individuals have preferences and they count 17
2.3 Using knowledge of preferences and constraints in choice analysis 27

3 Choice and utility 30
3.1 Introduction 30
3.2 Some background before getting started 32
3.3 Introduction to utility 45
3.4 The observed component of utility 48
3.4.1 Generic versus alternative-specific parameter estimates 49
3.4.2 Alternative-specific constants 51
3.4.3 Status quo and no choice alternatives 53
3.4.4 Characteristics of respondents and contextual effects in discrete choice models 54
3.4.5 Attribute transformations and non-linear attributes 57
3.4.6 Non-linear parameter utility specifications 71
3.4.7 Taste heterogeneity 75

3.5 Concluding comments 76
Appendix 3A: Simulated data 76
Appendix 3B: Nlogit syntax 78

4 Families of discrete choice models 80
4.1 Introduction 80
4.2 Modeling utility 81
4.3 The unobserved component of utility 83
4.4 Random utility models 86
4.4.1 Probit models based on the multivariate normal distribution 87
4.4.2 Logit models based on the multivariate Extreme value distribution 93
4.4.3 Probit versus logit 98
4.5 Extensions of the basic logit model 98
4.5.1 Heteroskedasticity 100
4.5.2 A multiplicative errors model 101
4.6 The nested logit model 102
4.6.1 Correlation and the nested logit model 104
4.6.2 The covariance heterogeneity logit model 105
4.7 Mixed (random parameters) logit model 106
4.7.1 Cross-sectional and panel mixed multinomial logit models 108
4.7.2 Error components model 109
4.8 Generalized mixed logit 110
4.8.1 Models estimated in willingness to pay space 112
4.9 The latent class model 114
4.10 Concluding remarks 116

5 Estimating discrete choice models 117
5.1 Introduction 117
5.2 Maximum likelihood estimation 117
5.3 Simulated maximum likelihood 126
5.4 Drawing from densities 133
5.4.1 Pseudo-random Monte Carlo simulation 136
5.4.2 Halton sequences 138
5.4.3 Random Halton sequences 145
5.4.4 Shuffled Halton sequences 147
5.4.5 Modified Latin Hypercube sampling 148
5.4.6 Sobol sequences 150

5.4.7 Antithetic sequences 153
5.4.8 PMC and QMC rates of convergence 155
5.5 Correlation and drawing from densities 157
5.6 Calculating choice probabilities for models without a closed analytical form 166
5.6.1 Probit choice probabilities 166
5.7 Estimation algorithms 176
5.7.1 Gradient, Hessian and Information matrices 176
5.7.2 Direction, step-length and model convergence 180
5.7.3 Newton–Raphson algorithm 183
5.7.4 BHHH algorithm 184
5.7.5 DFP and BFGS Algorithms 186
5.8 Concluding comment 186
Appendix 5A: Cholesky factorization example 187

6 Experimental design and choice experiments 189
6.1 Introduction 189
6.2 What is an experimental design? 191
6.2.1 Stage 1: problem definition refinement 194
6.2.2 Stage 2: stimuli refinement 195
6.2.3 Stage 3: experimental design considerations 201
6.2.4 Stage 4: generating experimental designs 223
6.2.5 Stage 5: allocating attributes to design columns 228
6.2.6 Generating efficient designs 247
6.3 Some more details on choice experiments 255
6.3.1 Constrained designs 255
6.3.2 Pivot designs 256
6.3.3 Designs with covariates 258
6.4 Best–worst designs 259
6.5 More on sample size and stated choice designs 264
6.5.1 *D*-efficient, orthogonal, and *S*-efficient designs 266
6.5.2 Effect of number of choice tasks, attribute levels, and attribute level range 270
6.5.3 Effect of wrong priors on the efficiency of the design 275
6.6 Ngene syntax for a number of designs 276
6.6.1 Design 1: standard choice set up 276
6.6.2 Design 2: pivot design set up 279
6.6.3 Design 3: *D*-efficient choice design 281
6.7 Conclusions 287

Appendix 6A: Best–worst experiment 290
Appendix 6B: Best–worst designs and Ngene syntax 290
6B.1 Best–worst case 1 291
6B.2 Best–worst case 2 294
6B.3 Best–worst case 3 297
Appendix 6C: An historical overview 301
6C.1 Louviere and Hensher (1983), Louviere and Woodworth (1983), and others 301
6C.2 Fowkes, Toner, Wardman *et al.* (Institute of Transport, Leeds, 1988–2000) 304
6C.3 Bunch, Louviere and Anderson (1996) 305
6C.4 Huber and Zwerina (1996) 306
6C.5 Sándor and Wedel (2001, 2002, 2005) 308
6C.6 Street and Burgess (2001 to current) 309
6C.7 Kanninen (2002, 2005) 312
6C.8 Bliemer, Rose, and Scarpa (2005 to current) 313
6C.9 Kessels, Goos, Vandebroek, and Yu (2006 to current) 318

7 Statistical inference 320
7.1 Introduction 320
7.2 Hypothesis tests 320
7.2.1 Tests of nested models 321
7.2.2 Tests of non-nested models 327
7.2.3 Specification tests 330
7.3 Variance estimation 333
7.3.1 Conventional estimation 334
7.3.2 Robust estimation 335
7.3.3 Bootstrapping of standard errors and confidence intervals 336
7.4 Variances of functions and willingness to pay 340
7.4.1 Delta method 346
7.4.2 Krinsky–Robb method 351

8 Other matters that analysts often inquire about 360
8.1 Demonstrating that the average of the conditional distributions aggregate to the unconditional distribution 360
8.1.1 Observationally equivalent respondents with different unobserved influences 360
8.1.2 Observationally different respondents with different unobserved influences 362
8.2 Random regret instead of random utility maximization 363

8.3 Endogeneity 370
8.4 Useful behavioral outputs 371
8.4.1 Elasticities of choice 371
8.4.2 Partial or marginal effects 374
8.4.3 Willingness to pay 378

Part II Software and data 385

9 Nlogit for applied choice analysis 387
9.1 Introduction 387
9.2 About the software 387
9.2.1 About Nlogit 387
9.2.2 Installing Nlogit 388
9.3 Starting Nlogit and exiting after a session 388
9.3.1 Starting the program 388
9.3.2 Reading the data 388
9.3.3 Input the data 390
9.3.4 The project file 390
9.3.5 Leaving your session 391
9.4 Using Nlogit 391
9.5 How to Get Nlogit to do what you want 392
9.5.1 Using the Text Editor 392
9.5.2 Command format 393
9.5.3 Commands 395
9.5.4 Using the project file box 396
9.6 Useful hints and tips 397
9.6.1 Limitations in Nlogit 398
9.7 Nlogit software 398

10 Data set up for Nlogit 400
10.1 Reading in and setting up data 400
10.1.1 The basic data set up 401
10.1.2 Entering multiple data sets: stacking and melding 405
10.1.3 Handling data on the non-chosen alternative in RP data 405
10.2 Combining sources of data 408
10.3 Weighting on an exogenous variable 410
10.4 Handling rejection: the no option 411
10.5 Entering data into Nlogit 414

10.6 Importing data from a file 415
10.6.1 Importing a small data set from the Text Editor 418
10.7 Entering data in the Data Editor 421
10.8 Saving and reloading the data set 422
10.9 Writing a data file to export 424
10.10 Choice data entered on a single line 424
10.11 Data cleaning 427
Appendix 10A: Converting single line data commands 431
Appendix 10B: Diagnostic and error messages 432

Part III The suite of choice models 435

11 Getting started modeling: the workhorse – multinomial logit 437
11.1 Introduction 437
11.2 Modeling choice in Nlogit: the MNL command 437
11.3 Interpreting the MNL model output 444
11.3.1 Determining the sample size and weighting criteria used 445
11.3.2 Interpreting the number of iterations to model convergence 445
11.3.3 Determining overall model significance 446
11.3.4 Comparing two models 453
11.3.5 Determining model fit: the pseudo-R^2 455
11.3.6 Type of response and bad data 456
11.3.7 Obtaining estimates of the indirect utility functions 457
11.4 Handling interactions in choice models 461
11.5 Measures of willingness to pay 463
11.6 Obtaining utility and choice probabilities for the sample 465
Appendix 11A: The labeled choice data set used in the chapter 466

12 Handling unlabeled discrete choice data 472
12.1 Introduction 472
12.2 Introducing unlabeled data 472
12.3 The basics of modeling unlabeled choice data 473
12.4 Moving beyond design attributes when using unlabeled choice data 478
Appendix 12A: Unlabeled discrete choice data Nlogit syntax and output 483

13 Getting more from your model 492
13.1 Introduction 492

13.2 Adding to our understanding of the data 494
13.2.1 Descriptive output (Dstats) 494
13.2.2 ;Show 496
13.2.3 ;Descriptives 499
13.2.4 ;Crosstab 501
13.3 Adding to our understanding of the model parameters 502
13.3.1 Starting values 503
13.3.2 ;effect: elasticities 504
13.3.3 Elasticities: direct and cross – extended format 507
13.3.4 Calculating arc elasticities 512
13.3.5 Partial or marginal effects 513
13.3.6 Partial or marginal effects for binary choice 515
13.4 Simulation and "what if" scenarios 518
13.4.1 The binary choice application 522
13.4.2 Arc elasticities obtained using ;simulation 524
13.5 Weighting 527
13.5.1 Endogenous weighting 527
13.5.2 Weighting on an exogenous variable 535
13.6 Willingness to pay 543
13.6.1 Calculating change in consumer surplus associated with an attribute change 546
13.7 Empirical distributions: removing one observation at a time 547
13.8 Application of random regret model versus random utility model 547
13.8.1 Nlogit syntax for random regret model 553
13.9 The Maximize command 554
13.10 Calibrating a model 555

14 Nested logit estimation 560
14.1 Introduction 560
14.2 The nested logit model commands 561
14.2.1 Normalizing and constraining IV parameters 565
14.2.2 Specifying IV start values for the NL model 567
14.3 Estimating a NL model and interpreting the output 567
14.3.1 Estimating the probabilities of a two-level NL model 575
14.4 Specifying utility functions at higher levels of the NL tree 577
14.5 Handling degenerate branches in NL models 583
14.6 Three-level NL models 587
14.7 Elasticities and partial effects 590
14.8 Covariance nested logit 593

14.9 Generalized nested logit 597
14.10 Additional commands 600

15 Mixed logit estimation 601
15.1 Introduction 601
15.2 The mixed logit model basic commands 601
15.3 Nlogit output: interpreting the ML model 608
15.3.1 Model 2: mixed logit with unconstrained distributions 611
15.3.2 Model 3: restricting the sign and range of a random parameter 621
15.3.3 Model 4: heterogeneity in the mean of random parameters 626
15.3.4 Model 5: heterogeneity in the mean of selective random parameters 629
15.3.5 Model 6: heteroskedasticity and heterogeneity in the variances 633
15.3.6 Model 7: allowing for correlated random parameters 636
15.4 How can we use random parameter estimates? 643
15.4.1 Starting values for random parameter estimation 645
15.5 Individual-specific parameter estimates: conditional parameters 646
15.6 Conditional confidence limits for random parameters 651
15.7 Willingness to pay issues 652
15.7.1 WTP based on conditional estimates 652
15.7.2 WTP based on unconditional estimates 658
15.8 Error components in mixed logit models 660
15.9 Generalized mixed logit: accounting for scale and taste heterogeneity 672
15.10 GMX model in utility and WTP space 676
15.11 SMNL and GMX models in utility space 697
15.12 Recognizing scale heterogeneity between pooled data sets 704

16 Latent class models 706
16.1 Introduction 706
16.2 The standard latent class model 707
16.3 Random parameter latent class model 711
16.4 A case study 714
16.4.1 Results 715
16.4.2 Conclusions 722
16.5 Nlogit commands 724
16.5.1 Standard command structure 724

16.5.2 Command structure for the models in Table 16.2 725
16.5.3 Other useful latent class model forms 733

17 Binary choice models 742
17.1 Introduction 742
17.2 Basic binary choice 742
17.2.1 Stochastic specification of random utility for binary choice 745
17.2.2 Functional form for binary choice 747
17.2.3 Estimation of binary choice models 750
17.2.4 Inference-hypothesis tests 752
17.2.5 Fit measures 753
17.2.6 Interpretation: partial effects and simulations 754
17.2.7 An application of binary choice modeling 756
17.3 Binary choice modeling with panel data 767
17.3.1 Heterogeneity and conventional estimation: the cluster correction 768
17.3.2 Fixed effects 769
17.3.3 Random effects and correlated random effects 771
17.3.4 Parameter heterogeneity 772
17.4 Bivariate probit models 775
17.4.1 Simultaneous equations 777
17.4.2 Sample selection 782
17.4.3 Application I: model formulation of the *ex ante* link between acceptability and voting intentions for a road pricing scheme 784
17.4.4 Application II: partial effects and scenarios for bivariate probit 800

18 Ordered choices 804
18.1 Introduction 804
18.2 The traditional ordered choice model 805
18.3 A generalized ordered choice model 807
18.3.1 Modeling observed and unobserved heterogeneity 810
18.3.2 Random thresholds and heterogeneity in the ordered choice model 812
18.4 Case study 817
18.4.1 Empirical analysis 820
18.5 Nlogit commands 830

19 Combining sources of data 836
19.1 Introduction 836

19.2 The nested logit "trick" 844
19.3 Beyond the nested logit "trick" 848
19.4 Case study 853
19.4.1 Nlogit command syntax for Table 19.2 models 858
19.5 Even more advanced SP–RP models 860
19.6 Hypothetical bias 868
19.6.1 Key themes 871
19.6.2 Evidence from contingent valuation to guide choice experiments 874
19.6.3 Some background evidence in transportation studies 880
19.6.4 Pivot designs: elements of RP and CE 886
19.6.5 Conclusions 893

Part IV Advanced topics 897

20 Frontiers of choice analysis 899
20.1 Introduction 899
20.2 A mixed multinomial logit model with non-linear utility functions 899
20.3 Expected utility theory and prospect theory 905
20.3.1 Risk or uncertainty? 906
20.3.2 The appeal of prospect theory 908
20.4 Case study: travel time variability and the value of expected travel time savings 912
20.4.1 Empirical application 914
20.4.2 Empirical analysis: mixed multinomial logit model with non-linear utility functions 917
20.5 NLRPLogit commands for Table 20.6 model 923
20.6 Hybrid choice models 927
20.6.1 An overview of hybrid choice models 927
20.6.2 The main elements of a hybrid choice model 931

21 Attribute processing, heuristics, and preference construction 937
21.1 Introduction 937
21.2 A review of common decision processes 943
21.3 Embedding decision processes in choice models 946
21.3.1 Two-stage models 946
21.3.2 Models with "fuzzy" constraints 947
21.3.3 Other approaches 952

21.4 Relational heuristics 955
21.4.1 Within choice set heuristics 955
21.4.2 Between choice set dependence 958
21.5 Process data 963
21.5.1 Motivation for process data collection 963
21.5.2 Monitoring information acquisition 963
21.6 Synthesis so far 966
21.7 Case study I: incorporating attribute processing heuristics through non-linear processing 968
21.7.1 Common-metric attribute aggregation 970
21.7.2 Latent class specification: non-attendance and dual processing of common-metric attributes in choice analysis 977
21.7.3 Evidence on marginal willingness to pay: value of travel time savings 979
21.7.4 Evidence from self-stated processing response for common-metric addition 981
21.8 Case study II: the influence of choice response certainty, alternative acceptability, and attribute thresholds 987
21.8.1 Accounting for response certainty, acceptability of alternatives, and attribute thresholds 989
21.8.2 The choice experiment and survey process 993
21.8.3 Empirical results 997
21.8.4 Conclusions 1008
21.9 Case study III: interrogation of responses to stated choice experiments – is there sense in what respondents tell us? 1009
21.9.1 The data setting 1013
21.9.2 Investigating candidate evidential rules 1015
21.9.3 Derivative willingness to pay 1023
21.9.4 Pairwise alternative "plausible choice" test and dominance 1025
21.9.5 Influences of non-trading 1029
21.9.6 Dimensional versus holistic processing strategies 1035
21.9.7 Influence of the relative attribute levels 1051
21.9.8 Revision of the reference alternative as value learning 1052
21.9.9 A revised model for future stated choice model estimation 1054
21.9.10 Conclusions 1057
21.10 The role of multiple heuristics in representing attribute processing as a way of conditioning modal choices 1058
Appendix 21A: Nlogit command syntax for NLWLR and RAM heuristics 1062

Appendix 21B: Experimental design in Table 21.15 1066
Appendix 21C: Data associated with Table 21.15 1066

22 Group decision making 1072
22.1 Introduction 1072
22.2 Interactive agency choice experiments 1073
22.3 Case study data on automobile purchases 1079
22.4 Case study results 1082
22.5 Nlogit commands and outputs 1091
22.5.1 Estimating a model with power weights 1091
22.5.2 Pass 1, round 1 (agent 1) and round 2 (agent 2) ML model 1091
22.5.3 Pass 1, round 1 (agent 1) and round 2 (agent 2) agree model 1093
22.5.4 Sorting probabilities for two agents into a single row 1094
22.5.5 Creating cooperation and non-cooperation probabilities for the pairs 1094
22.5.6 Removing all but line 1 of the four choice sets per person in pair 1094
22.5.7 Getting utilities on 1 line (note: focusing only on overall utilities at this stage) 1095
22.5.8 Writing out new file for power weight application 1096
22.5.9 Reading new data file 1096
22.5.10 Estimating OLS power weight model (weights sum to 1.0) 1096
22.5.11 Pass #2 (repeating same process as for pass#1) 1098
22.5.12 Pass #3 (same set up as pass#1) 1103
22.5.13 Group equilibrium 1108
22.5.14 Joint estimation of power weights and preference parameters 1113

Select glossary 1116
References 1128
Index 1163

Figures

2.1	Identification of an individual's preferences for bus use	*page* 20
2.2	The budget or resource constraint	22
2.3	Changes to the budget or resource constraint	23
2.4	Individual preferences subject to a budget constraint	23
2.5	Indifference curves with budget constraints	24
2.6	Demand curve construction	26
2.7	Changes in demand and changes in quantity demanded	27
3.1	Example: log versus linear relationship	33
3.2	Plot of Congressional party affiliation against proportion of minority groups in voting districts	35
3.3	Linear regression model of Congressional party affiliation against proportion of minority groups in voting districts	36
3.4	PDF and CDFs for Normal distribution: 1	38
3.5	PDF and CDFs for Normal distribution: 2	39
3.6	Probit model of Congressional party affiliation against proportion of minority groups in voting districts	41
3.7	Sigmoid curve examples of alternative probit models	42
3.8	Logit and probit models of Congressional party affiliation against proportion of minority groups in voting districts	44
3.9	Marginal utility for season (linear coding)	61
3.10	Marginal utility for season (dummy and effects coding)	66
3.11	Plots of orthogonal polynomial coding example results	72
4.1	Multivariate Normal distribution for two alternatives	87
4.2	GEV distribution for two alternatives	95
4.3	EV1 distributions under different scale assumptions	96
5.1	Log-likelihood function surfaces	125
5.2	Example for drawing from two different PDFs	135
5.3	Example for drawing from two different CDFs	135
5.4	Example of PMC draws	137
5.5	Coverage of Halton sequences using different Primes (R = 1,000)	143

5.6	Multivariate Normal distributions for 100 Halton sequences based on different Primes	144
5.7	Multivariate Normal distributions for 1,000 Halton sequences based on different Primes	144
5.8	Multivariate Normal distribution for 5,000 Halton draws based on Primes 61 and 67	145
5.9	Example of randomized Halton draws based on Primes 61 and 67	147
5.10	Example of 1,000 shuffled Halton draws based on Primes 61 and 67	148
5.11	Example of 5,000 shuffled Halton draws based on Primes 61 and 67	149
5.12	Example of generating MLHS draws in Microsoft Excel	149
5.13	Randomization of MLHS draws in Microsoft Excel	150
5.14	Coverage of Sobol sequences	153
5.15	Multivariate Normal distributions for 250 Sobol draws based on different dimensions	154
5.16	Draw *R* uniformly distributed random numbers on the interval [0,1]	162
5.17	Transforming random draws to standard normal draws	163
5.18	Correlating the random draws	165
5.19	Correlated random draws	165
5.20	Correlated uniform draws	166
6.1	Experimental design process	192
6.2	Mapping part-worth utility	200
6.3	Stages in deriving fractional factorial designs	209
6.4	Estimation of linear versus quadratic effects	216
6.5	Generating designs using SPSS	225
6.6	Specifying the number of attribute levels per attribute	226
6.7	Specifying the minimum number of treatment combinations to generate	227
6.8	Calculating interaction design codes using Microsoft Excel	230
6.9	Microsoft Excel commands to generate correlations	231
6.10	Microsoft Excel Data Analysis and Correlation dialog boxes	231
6.11	Modified Federov algorithm	252
6.12	RSC algorithm	253
6.13	Example best–worst scenario for design statements	262
6.14	Asymptotic *t*-ratios for different sample sizes for the (a) *D*-efficient design, (b) orthogonal design, and (c) *S*-efficient design	270
6.15	Impact of prior misspecification on the sample size for the (a) *D*-efficient design, (b) orthogonal design, and (c) *S*-efficient design	275
6.16	Implications of prior parameter misspecification and loss of efficiency	288
6B.1	Example best–worst case 1 task	291

6B.2	Example best–worst case 2 task	294
6B.3	Example best–worst case 3 task	299
6C.1	Locally optimal parameter priors and parameter prior misspecification	304
6C.2	Different definitions of attribute level balance	307
6C.3	Bayesian versus locally optimal designs	309
6C.4	Comparison of investing in larger sample sizes versus more efficient designs	315
7.1	Kernel plot of the WTP distribution using Krinsky–Robb derived standard errors	358
7.2	Kernel plot of the inverse of a cost parameter	359
8.1	Visualization of attribute level regret (for β_m= 1)	368
8.2	Marginal effects as the slopes of the Tangent lines to the cumulative probability curve	378
8.3	Marginal effects for a categorical (dummy coded) variable	378
8.4	WTP as a trade-off between attributes	379
9.1	Initial Nlogit desktop	389
9.2	File Menu on Main Desktop and Open Project. . .Explorer	389
9.3	Nlogit desktop after Project File Input	390
9.4	Dialog for Exiting Nlogit and Saving the Project File	391
9.5	Dialog for Opening the Text Editor	393
9.6	Text Editor Ready for Command Entry	394
9.7	Commands in the Text Editor	395
10.1	Choice set with the no travel alternative	412
10.2	Importing variables	416
10.3	Variables in untitled project	417
10.4	Importing CSV data	417
10.5	Excel data set	419
10.6	Import command	420
10.7	Imported data	420
10.8	Names of variables to be created	421
10.9	View data in Editor	422
10.10	Data Editor button	423
10.11	Saving data	423
10.12	Editing data	426
10.13	Data shown in Data Editor	426
10.14	Data converter	427
10.15	Finalized data	427
10.16	Summary of converted data	428

11.1	The sigmoid curve	448
11.2	-2LL Chi-square test	452
11.3	Mapping the pseudo-R^2 to the linear R^2	456
11A.1	Example screen to establish current car mode trip profile	469
11A.2	Example screen to establish new public mode station and access profile	469
11A.3	Example inter-regional stated choice screen	470
11A.4	Example intra-regional stated choice screen	470
12.1	Example of unlabeled choice task screen	474
13.1	Experiment I: simulated scenario with confidence intervals	523
13.2	Experiment II: simulated scenario with confidence intervals	524
13.3	Profile of choice probabilities for RUM and RRM	551
13.4	Profile of petrol choice probabilities for RUM and RRM	551
13.5	Profile of diesel choice probabilities for RUM and RRM	551
13.6	Profile of hybrid choice probabilities for RUM and RRM	552
14.1	Example of an NL tree structure	563
14.2	Example tree structure	563
14.3	Example of a 3-level tree structure	564
14.4	An NL tree structure with a degenerate alternative	583
14.5	An NL tree structure with two degenerate alternatives	584
14.6	A 3-level NL tree structure with degenerate branches	587
15.1	Testing dispersion of the *accbusf* random parameter	616
15.2	Unconstrained distribution of invehicle time for public transport modes	617
15.3	Constrained distribution of invehicle time for public transport modes	623
15.4	Random parameter distributions allowing for correlated random parameters	644
15.5	Estimates of the marginal utility of invehicle time together with confidence intervals	653
16.1	An illustrative choice scenario	715
16.2	Distribution of VTTS for all models	721
17.1	Model simulation	766
17.2	Illustrative voting and acceptance choice screen	787
17.3	Confidence limits on conditional means of random parameters in Model 3	794
17.4	Confidence limits on conditional means of random parameters in Model 4	795
17.5	Impact of (a) cordon-based and (b) distance-based charging per week given that all revenue is hypothecated to public transport	799

18.1	Example of a stated choice screen	822
18.2	CAPI questions on attribute relevance	823
18.3	Distribution of preference heterogeneity for congested time framing	829
19.1	SP and RP data generation process	837
19.2	Enrichment Paradigm 1	839
19.3	Enrichment Paradigm 2	840
19.4	Two-level, two-nest NMNL model	844
19.5	Combining SP and RP data using the NMNL model	845
19.6	Distribution of scale standard deviation for SP and RP choices	864
19.7	Illustrative stated choice screen from a CAPI	889
20.1	Typical PT value functions over monetary gains and losses	910
20.2	Probability weighting functions for gains (W^+) and losses (W^-) from Tversky and Kahneman (1992)	911
20.3	Illustrative stated choice screen	917
20.4	Individual probability weighting function curves (MMNL)	921
20.5	Distribution of VETTS in MMNL model	921
20.6	Incorporating latent variables in discrete choice models using different methods	929
20.7	The integrated latent variable and discrete choice modeling framework	931
21.1	Graphical illustration of possible transitions in a choice experiment	965
21.2	Typical EBA simulation	966
21.3	Example of a stated choice screen	970
21.4	4 CAPI questions on attribute relevance	982
21.5	Illustrative stated choice screen	996
21.6	Attribute threshold questions (preceding the choice set screens)	997
21.7	Example of a stated choice screen	1014

Tables

3.1	Linear regression results	*page* 35
3.2	Probit model results	41
3.3	Odds ratios and log-odds	43
3.4	Logit model results	44
3.5	Utility level versus utility scale	46
3.6	Non-linear coding schemes	63
3.7	Dummy and effects coding marginal utilities	65
3.8	Relationship between effects coding and ASC	65
3.9	Dummy and effects coding rescaling	66
3.10	Dummy and effects coding with a status quo alternative: 1	67
3.11	Dummy and effects coding with a status quo alternative: 2	69
3.12	Dummy, effects, and orthogonal polynomial coding correlation comparisons	70
3.13	Orthogonal polynomial coding example results	71
3.14	Example data set up for dummy, effects, and orthogonal polynomial coding	73
4.1	Estimated probit model for voting choices	92
5.1	Example of likelihood estimation: 1	119
5.2	Example of likelihood estimation: 2	120
5.3	Example of log-likelihood estimation	122
5.4	Example of log-likelihood estimation using count data	122
5.5	Example of log-likelihood estimation using proportion data	123
5.6	Binary choice data example	124
5.7	Example of simulated log-likelihood estimation (cross-sectional model)	130
5.8	Example of simulated log-likelihood estimation (panel model)	132
5.9	Conversion of Base numbers for Primes 2 to 37	139
5.10	Converting the Base values to decimals	141
5.11	Halton sequences for Primes 2 to 37	142
5.12	Example of randomized Halton draws process	146

5.13	Example primitive polynomials	151
5.14	Example calculations for constructing Sobol draws	152
5.15	Sobol draws	153
5.16	Convergence rates of PMC and QMC simulation methods	156
5.17	Correlation structure of Halton sequences for dimensions 1 to 12 for 50 to 1,000 draws	164
6.1	Full factorial design	202
6.2	Full factorial design coding	203
6.3	Comparison of design codes and orthogonal codes	204
6.4	Choice treatment combination	205
6.5	Labeled choice experiment	205
6.6	Attribute levels for expanded number of alternatives	208
6.7	Dummy coding	213
6.8	Effects coding structure	215
6.9	Effects coding formats	215
6.10	Minimum treatment combination requirements for main effects only fractional factorial designs	218
6.11	Enumeration of all two-way interactions	221
6.12	Orthogonal coding of fractional factorial design	229
6.13	Orthogonal codes for main effects plus all two-way interaction columns	232
6.14	Design correlation	236
6.15	Attributes assigned to design columns	239
6.16	Using blocking variables to determine allocation of treatment combinations	241
6.17	Effects coding design of Table 6.15	242
6.18	Correlation matrix for effects coded design	243
6.19	3^4 Fractional factorial design	244
6.20	Randomizing treatment combinations to use for additional design columns	245
6.21	Correlation matrix for randomizing treatment combinations	245
6.22	Using the foldover to generate extra design columns	246
6.23	Correlation matrix for designs using foldovers to generate additional columns	247
6.24	Example dimensions for generating an efficient design	252
6.25	Designs pivoted from a reference alternative	257
6.26	Full list of statements used in construction of a best–worst design	260
6.27	Nlogit syntax for estimating a choice model	262
6.28	The data set up for analysis of best–worst data	263

6.29	Designs	268
6.30	Effect of the number of choice tasks on *D*-error and *S*-error	272
6.31	Different number of attribute levels and level ranges	273
6.32	Effect of number of levels and level range on *D*-error and sample size	273
6.33	End-point designs	274
6.34	Pre-defined attributes and attribute levels for survey design	282
6B.1	Example B/W case 1 task data set up 1	292
6B.2	Example B/W case 1 task data set up 2	293
6B.3	Example B/W case 2 task attribute levels	294
6B.4	Example B/W case 2 task data set up 1	295
6B.5	Example B/W case 2 task data set up 1 with constants	296
6B.6	Example B/W case 2 task data set up 2	298
6B.7	Example B/W case 3 task data set up 1 (best–best–best–best– . . .)	300
6B.8	Example B/W case 3 task data set up 3 (best–worst–best–worst–) . . .	301
6C.1	Design codes to orthogonal contrast codes	311
6C.2	Optimal choice probability values for specific designs	314
7.1	Non-linearity implications in defining the covariance structure	352
8.1	Relationship between elasticity of demand, change in price and revenue	375
8.2	WTP indicators for base models	383
8.3	WTP indicators for asymmetrical models	384
10.1	Most general choice data format in Nlogit	402
10.2	Varying the alternatives within choice sets	403
10.3	Varying the number of alternatives within choice sets: 1	403
10.4	Varying the number of alternatives within choice sets: 2	404
10.5	Entering socio-demographic characteristics	406
10.6	Combining SP–RP data	409
10.7	Exogenous weights entered	411
10.8	Adding the no choice or delay choice alternative	413
10.9	Data entered into a single line	425
11A.1	Trip attributes in stated choice design	468
12.1	Attributes and priors used in the case 1 experimental design	473
12.2	Model results from unlabeled choice experiment	476
12.3	Descriptive statistics by alternative for unlabeled choice experiment	476
12.4	Model results from unlabeled choice experiment with socio-demographic characteristics	480
12.5	Model results from unlabeled choice experiment with interaction terms	482
13.1	Attribute levels for stated choice experiment	549

13.2	Summary of model results	550
13.3	Direct elasticity contrasts	552
14.1	Useful outputs stored under the project file (data, variables)	578
14.2	Comparison of findings in Table 14.1 with the NL model with upper level variables	582
15.1	A matrix (BETA_I) with the stored conditional individual-specific mean random parameter estimates for the first 20 observations	648
15.2	A matrix (SDBETA_I) with the stored conditional individual-specific standard deviation random parameter estimates for the first 20 observations	649
15.3	A matrix with the stored conditional individual-specific WTP estimates for the first 20 observations (noting that an observation is a respondent and not a choice set in the absence of recognizing the number of choice sets using :pds = <number>)	655
15.4	Summary of empirical results: commuter trips	666
15.5	Mean and standard deviation of random parameter estimates for entire representation of each attribute from relatively simple to more complex models	668
15.6	Direct elasticities (probability weighted)	670
15.7	Value of travel time savings	671
15.8	Summary of model results	691
15.9	Willingness to pay	694
15.10	Lower and upper WTP estimates	695
15.11	Mean estimates of willingness to pay	696
15.12	Summary of model results	699
15.13	Direct time and cost elasticities	701
15.14	Tests of statistical significance between elasticity estimates	703
16.1	Trip attributes in stated choice design	714
16.2	Summary of models	716
16.3	WTP estimates	721
17.1	Panel data sample sizes	756
17.2	Insurance takeup in the GSOEP sample	757
17.3	Descriptive statistics for binary choice analysis	758
17.4	Estimated probit model for add on insurance takeup	758
17.5	Estimated logit model for add on insurance takeup	759
17.6	Fit measures for estimated probit model	760
17.7	Estimated partial effects for logit and probit models	764
17.8	Estimated semi-elasticities	765
17.9	Partial effect on takeup of marital status	765

17.10	Effect of change in age on takeup probability	766
17.11	Fixed effects and conventional estimators	769
17.12	Cluster correction of standard erorrs	770
17.13	Estimated random effects probit model	772
17.14	Random effects probit model with Mundlak correction	773
17.15	Estimated random parameters probit model	774
17.16	Cross-tabulation for health care utilization	776
17.17	Estimated bivariate probit model	778
17.18	Partial effects for bivariate probit model	779
17.19	Estimated recursive bivariate probit model	781
17.20	Decomposition of partial effects in recursive model	782
17.21	Sample selection finding	784
17.22	Models of referendum voting and acceptance of road pricing schemes: 1	789
17.23	Models of referendum voting and acceptance of road pricing schemes: 2	791
17.24	Summary of direct elasticities	797
17.25	Summary of bivariate probit model results	801
17.26	Summary of elasticities	802
17.27	Simulated scenario of role of Canberra and age on preference probability	803
18.1	Attribute profiles for the design	821
18.2	Sub-designs of the overall design for five attributes	822
18.3	Ordered logit models	824
18.4	Marginal effects for three choice levels derived from ordered logit models	826
19.1	Commuter mode share population weights	854
19.2	Model results for “nested logit” trick versus panel mixed logit for combined SP and RP choice data	856
19.3	Summary of model results	862
19.4	Summary of illustrative Australian empirical evidence on VTTS: traditional CE versus RP	881
19.5	Empirical evidence on CE-based VTTS for pivot data paradigm, treating time and cost parameters generic across all alternatives	882
19.6	Summary of findings for pivot-based models	889
20.1	Trip attributes in stated choice design	915
20.2	Profile of the attribute range in the stated choice design	916
20.3	Descriptive socio-economic statistics	918
20.4	Descriptive statistics for costs and time, by segment	918

20.5	Travel times and probabilities of occurrence	918
20.6	Mixed multinomial logit (MMNL) within an *EEUT* framework	919
20.7	Example of data arrangements for a hybrid choice model	935
21.1	Typology of decision strategies	939
21.2	Classic decision strategies	944
21.3	Worked example for the contextual concavity model	956
21.4	Summary of candidate heuristics and example model forms testable on existing data sets	967
21.5	Profile of attribute range in stated choice design	970
21.6	Summary of WTP estimates	980
21.7	Values of travel time savings	981
21.8	Influence of self-stated APS on VTTS	983
21.9	Attribute levels for choice experiment	994
21.10	Descriptive overview of key data items	999
21.11	Summary of model results	1002
21.12	Summary of mean direct elasticity results	1007
21.13	Summary of marginal rates of substitution	1008
21.14	Example of 16 choice scenario responses evaluated by one respondent	1011
21.15	Profile of attribute range in choice experiment	1014
21.16	Influence of choice sequence on choice response	1016
21.17	Influences on choice scenario completion time	1018
21.18	Implications of "plausible choice" test on mean VTTS	1024
21.19	Response dominance in full sample	1027
21.20	Respondent and design influences on choice of reference alternative	1030
21.21	Number of strictly best attributes per alternative	1036
21.22	Influence of majority of confirming dimensions	1037
21.23	Identifying role of MCD: latent class model	1045
21.24	Influence of referencing on choice response	1051
21.25	Identifying the role of value learning	1053
21.26	Revised full model for future applications	1054
21.27	Estimation of weighted LPLA and NLWLR decision rules in utility	1062
22.1	Schematic representation of IASP evaluation	1077
22.2	Stated choice design attributes	1080
22.3	Illustrative stated choice screen	1081
22.4	Pass model results	1083
22.5	Sources of agreement	1086
22.6	Group equilibrium model results	1088
22.7	Probability contrasts	1090
22.8	Sources of agreement: passes 2 and 3 versus pass 1 group equilibrium	1091

Preface

I'm all in favor of keeping dangerous weapons out of the hands of fools. Let's start with typewriters.

(Frank Lloyd Wright 1868–1959)

Almost without exception, everything human beings undertake involves a choice (consciously or subconsciously), including the choice not to choose. Some choices are the result of habit while others are fresh decisions made with great care, based on whatever information is available at the time from past experiences and/or current inquiry.

Over the last forty years, there has been a steadily growing interest in the development and application of quantitative statistical methods to study choices made by individuals (and, to a lesser extent, groups of individuals or organizations). With an emphasis on both understanding how choices are made and on forecasting future choice responses, a healthy literature has evolved. Reference works by Louviere *et al.* (2000) and Train (2003, 2009) synthesize the contributions. However while these sources represent the state of the art (and practice), they are technically advanced and often a challenge for both the beginner and practitioners.

Discussions with colleagues have revealed a gap in the choice analysis literature – a book that assumes very little background and offers an entry point for individuals interested in the study of choice regardless of their starting position. Writing such a book increasingly became a challenge for us. It is often more difficult to explain complex ideas in very simple language than to protect one's knowledge base with complicated deliberations. The first edition published in 2005 was written in response to this gap in the literature in order to serve the needs of practitioners, seasoned researchers, and students.

There are many discussion topics that are ignored in most books on choice analysis, yet are issues which students have pointed out in class, and been noted by researchers in general, as important in giving them a better understanding of what is happening in choice modeling. The lament that too many books on

discrete choice analysis are written for the well informed is common, and was sufficient incentive to write the first edition of this book and a subsequent need to revise it to include the many new developments since 2004 (when the first edition was completed), as well as to clarify points presented in the first edition on which many readers sought further advice. The new topics, in addition to a complete rewrite of most previous chapters, include ordered choice, generalized mixed logit, latent class models, statistical tests (including partial effects and model output comparisons), group decision making, heuristics, and attribute processing strategies, expected utility theory, prospect theoretic applications, and extensions to allow for non-linearity in parameters. The single case study has been replaced by a number of case studies, each chosen as an example of data that best illustrate the application of one or more choice models.

This book for beginners in particular, but also of value to seasoned researchers, is our attempt to meet the challenge. We agreed to try and write the first draft of the first edition without referring to any of the existing material as a means (hopefully) of encouraging a flow of explanation. Pausing to consult can often lead to terseness in the code (as writers of novels can attest). Further draft versions leading to the final product did, however, cross-reference to the literature to ensure that we had acknowledged appropriate material. This book in both its first and second edition guises, however, is not about ensuring that all contributors to the literature on choice are acknowledged, but rather ensuring that the novice choice analyst is given a fair go in their first journey through this intriguing topic.

We dedicate this book to the beginners, but we also acknowledge our research colleagues who have influenced our thinking as well as co-authored papers over many years. We thank Michiel Bliemer for his substantial input to Chapter 6 as well as Andrew Collins and Chinh Ho for their case studies using NGene. We also thank Waiyan Leong and Andrew Collins for their substantial contribution to Chapter 21. We especially recognize Dan McFadden (2000 Nobel Laureate in Economics), Ken Train, Chandra Bhat, Jordan Louviere, Andrew Daly, Moshe Ben-Akiva, David Brownstone, Michiel Bliemer, Juan de Dios Ortúzar, Joffre Swait, and Stephane Hess. Colleagues and doctoral students at the University of Sydney read earlier versions. In particular, we thank Andrew Collins, Riccardo Scarpa, Sean Puckett, David Layton, Danny Campbell, Matthew Beck, Zheng Li, Waiyan Leong, Chinh Ho, Kwang Kim and Louise Knowles, and the 2004–2013 graduate classes in Choice Analysis as well as participants in the annual short courses on choice analysis and choice experiments at The University of Sydney and various other locations in Europe, Asia, and the United States, who were guinea pigs for the first full use of the book in a teaching environment.