



LATENT CLASS AND LATENT TRANSITION ANALYSIS

**With Applications in the Social,
Behavioral, and Health Sciences**

Linda M. Collins

Stephanie T. Lanza

The Pennsylvania State University



WILEY

A JOHN WILEY & SONS, INC., PUBLICATION

This Page Intentionally Left Blank

LATENT CLASS AND LATENT TRANSITION ANALYSIS

WILEY SERIES IN PROBABILITY AND STATISTICS

Established by WALTER A. SHEWHART and SAMUEL S. WILKS

Editors: *David J. Balding, Noel A. C. Cressie, Garrett M. Fitzmaurice,
Iain M. Johnstone, Geert Molenberghs, David W. Scott, Adrian F. M. Smith,
Ruey S. Tsay, Sanford Weisberg*

Editors Emeriti: *Vic Barnett, J. Stuart Hunter, Jozef L. Teugels*

A complete list of the titles in this series appears at the end of this volume.

LATENT CLASS AND LATENT TRANSITION ANALYSIS

**With Applications in the Social,
Behavioral, and Health Sciences**

Linda M. Collins

Stephanie T. Lanza

The Pennsylvania State University



WILEY

A JOHN WILEY & SONS, INC., PUBLICATION

Copyright © 2010 by John Wiley & Sons, Inc. All rights reserved.

Published by John Wiley & Sons, Inc., Hoboken, New Jersey.
Published simultaneously in Canada.

No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, scanning, or otherwise, except as permitted under Section 107 or 108 of the 1976 United States Copyright Act, without either the prior written permission of the Publisher, or authorization through payment of the appropriate per-copy fee to the Copyright Clearance Center, Inc., 222 Rosewood Drive, Danvers, MA 01923, (978) 750-8400, fax (978) 750-4470, or on the web at www.copyright.com. Requests to the Publisher for permission should be addressed to the Permissions Department, John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, (201) 748-6011, fax (201) 748-6008, or online at <http://www.wiley.com/go/permission>.

Limit of Liability/Disclaimer of Warranty: While the publisher and author have used their best efforts in preparing this book, they make no representations or warranties with respect to the accuracy or completeness of the contents of this book and specifically disclaim any implied warranties of merchantability or fitness for a particular purpose. No warranty may be created or extended by sales representatives or written sales materials. The advice and strategies contained herein may not be suitable for your situation. You should consult with a professional where appropriate. Neither the publisher nor author shall be liable for any loss of profit or any other commercial damages, including but not limited to special, incidental, consequential, or other damages.

For general information on our other products and services or for technical support, please contact our Customer Care Department within the United States at (800) 762-2974, outside the United States at (317) 572-3993 or fax (317) 572-4002.

Wiley also publishes its books in a variety of electronic formats. Some content that appears in print may not be available in electronic format. For information about Wiley products, visit our web site at www.wiley.com.

Library of Congress Cataloging-in-Publication Data:

Collins, Linda M.

Latent class and latent transition analysis / Linda M. Collins, Stephanie T. Lanza.
p. cm.

Includes bibliographical references and index.

ISBN 978-0-470-22839-5 (cloth)

1. Latent structure analysis. 2. Latent variables. 3. Statistical methods. I. Lanza, Stephanie T., 1969– II. Title.

QA278.6.C65 2010

519.5'35—dc22

2009025970

Printed in the United States of America.

10 9 8 7 6 5 4 3 2 1

*For David and Kathy
with admiration
(LMC)*

*For Dad
my first math teacher
(STL)*

This Page Intentionally Left Blank

CONTENTS

List of Figures	xvii
List of Tables	xxi
Acknowledgments	xxxii
Acronyms	xxxiii

PART I FUNDAMENTALS

1	General Introduction	3
1.1	Overview	3
1.2	Conceptual foundation and brief history of the latent class model	4
1.2.1	LCA and other latent variable models	6
1.2.2	Some historical milestones in LCA	7
1.2.3	LCA as a person-oriented approach	8
1.3	Why select a categorical latent variable approach?	8
1.4	Scope of this book	9
1.5	Empirical example of LCA: Adolescent delinquency	10
1.6	Empirical example of LTA: Adolescent delinquency	14
1.7	About this book	17
		vii

1.7.1	Using this book	19
1.8	The examples in this book	19
1.8.1	Empirical data sets	20
1.9	Software	21
1.10	Additional resources: The book's web site	21
1.11	Suggested supplemental readings	22
1.12	Points to remember	22
1.13	What's next	22
2	The latent class model	23
2.1	Overview	23
2.2	Empirical example: Pubertal development	24
2.2.1	An initial look at the data	24
2.2.2	Why conduct LCA on the pubertal development data?	27
2.2.3	Latent classes in the pubertal development data	28
2.3	The role of item-response probabilities in interpreting latent classes	29
2.3.1	A hypothetical example	29
2.3.2	Interpreting the item-response probabilities to label the latent classes in the pubertal development example	30
2.3.3	Qualitative and quantitative differences among the pubertal development latent classes	34
2.4	Empirical example: Health risk behaviors	34
2.4.1	An initial look at the data	34
2.4.2	LCA of the health risk behavior data	35
2.5	LCA: Model and notation	39
2.5.1	Fundamental expressions	41
2.5.2	The local independence assumption	44
2.6	Suggested supplemental readings	46
2.7	Points to remember	47
2.8	What's next	47
3	The relation between the latent variable and its indicators	49
3.1	Overview	49
3.2	The latent class measurement model	50
3.2.1	Parallels with factor analysis	50
3.2.2	Two criteria for evaluating item-response probabilities for a single variable	50

3.2.3	Hypothetical and empirical examples of independence and weak relations	53
3.2.4	Hypothetical and empirical examples of strong relations	55
3.3	Homogeneity and latent class separation	56
3.3.1	Homogeneity	56
3.3.2	Latent class separation	57
3.3.3	Hypothetical examples of homogeneity and latent class separation	58
3.3.4	How homogeneity and latent class separation are related	64
3.3.5	Homogeneity, latent class separation, and the number of response patterns observed	64
3.3.6	Homogeneity and latent class separation in empirical examples	65
3.4	The precision with which the observed variables measure the latent variable	67
3.4.1	Why posterior probabilities of latent class membership are of interest	67
3.4.2	Bayes' theorem	68
3.4.3	What homogeneity and latent class separation imply about posterior probabilities and classification uncertainty	69
3.4.4	Posterior classification uncertainty even with a high degree of homogeneity and latent class separation	72
3.5	Expressing the degree of uncertainty: Mean posterior probabilities and entropy	73
3.6	Points to remember	75
3.7	What's next	76
4	Parameter estimation and model selection	77
4.1	Overview	77
4.2	Maximum Likelihood estimation	78
4.2.1	Estimating model parameters	78
4.2.2	Options for treatment of individual parameters: Parameter restrictions	79
4.2.3	Missing data and estimation	80
4.3	Model fit and model selection	81
4.3.1	Absolute model fit	82

4.3.2	The likelihood-ratio statistic G^2 and its degrees of freedom	83
4.3.3	Relative model fit	86
4.3.4	Cross-validation	88
4.4	Finding the ML solution	89
4.4.1	Overview of model identification issues	89
4.4.2	Visualizing identification, underidentification, and unidentification	89
4.4.3	Identification and information	92
4.4.4	How to find the ML solution	92
4.4.5	Label switching	94
4.4.6	User-provided starting values	94
4.5	Empirical example of using many starting values	95
4.6	Empirical examples of selecting the number of latent classes	97
4.6.1	Positive health behaviors	97
4.6.2	Past-year delinquency	98
4.6.3	Female pubertal development	99
4.6.4	Health risk behaviors	100
4.7	More about parameter restrictions	102
4.7.1	Reasons for using parameter restrictions	102
4.7.2	Parameter restrictions and model fit	103
4.7.3	Using parameter restrictions to achieve positive degrees of freedom	103
4.8	Standard errors	106
4.9	Suggested supplemental readings	108
4.10	Points to remember	108
4.11	What's next	110

PART II ADVANCED LCA

5	Multiple-group LCA	113
5.1	Overview	113
5.2	Introduction	114
5.3	Multiple-group LCA: Model and notation	114
5.4	Computing the number of parameters estimated	116
5.5	Expressing group differences in the LCA model	116
5.6	Measurement invariance	117
5.7	Establishing whether the number of latent classes is identical across groups	119

5.7.1	Empirical example: Adolescent delinquency	120
5.8	Establishing invariance of item-response probabilities across groups	121
5.8.1	Specifying parameter restrictions	122
5.8.2	Test of measurement invariance in the delinquency example	125
5.9	Interpretation when measurement invariance does not hold	126
5.10	Strategies when measurement invariance does not hold	129
5.10.1	Partial measurement invariance	129
5.10.2	When measurement invariance holds in a subset of groups	131
5.11	Significant differences and important differences	131
5.11.1	Empirical example: Positive health behaviors	133
5.12	Testing equivalence of latent class prevalences across groups	139
5.12.1	Empirical example: Adolescent delinquency	140
5.12.2	Empirical example: Health risk behaviors	141
5.13	Suggested supplemental readings	147
5.14	Points to remember	147
5.15	What's next	148
6	LCA with Covariates	149
6.1	Overview	149
6.2	Empirical example: Positive health behaviors	150
6.3	Preparing to conduct LCA with covariates	151
6.3.1	Preparing variables for use as covariates	151
6.4	LCA with covariates: Model and notation	153
6.4.1	What is estimated	154
6.4.2	Treatment of item-response probabilities in LCA with covariates	154
6.5	Hypothesis testing in LCA with covariates	154
6.6	Interpretation of the intercepts and regression coefficients	155
6.6.1	Understanding odds and odds ratios	155
6.6.2	The correspondence between regression coefficients and odds/odds ratios	157
6.7	Empirical examples of LCA with a single covariate	159
6.7.1	Results of logistic regression using gender as a covariate	159
6.7.2	Results of logistic regression using maternal education as a covariate	161

6.8	Empirical example of multiple covariates and interaction terms	163
6.8.1	Interpretation of the interaction between gender and maternal education	165
6.9	Multiple-group LCA with covariates: Model and notation	166
6.9.1	Empirical example: Positive health behaviors	167
6.10	Grouping variable or covariate?	167
6.10.1	How the multiple-group and covariate models are different	168
6.10.2	When the multiple-group and covariate models are mathematically equivalent	169
6.11	Use of a Bayesian prior to stabilize estimation	171
6.12	Binomial logistic regression	172
6.12.1	Empirical example: Positive health behaviors	173
6.12.2	Comparison of binomial multiple groups and covariate models	176
6.13	Suggested supplemental readings	176
6.14	Points to remember	176
6.15	What's next	177

PART III LATENT CLASS MODELS FOR LONGITUDINAL DATA

7	RMLCA and LTA	181
7.1	Overview	181
7.2	RMLCA	182
7.2.1	Adding a grouping variable	185
7.2.2	RMLCA and growth mixture modeling	186
7.3	LTA	187
7.3.1	Empirical example: Adolescent delinquency	187
7.3.2	Why conduct LTA on the adolescent delinquency data?	188
7.3.3	Estimation and assessing model fit	189
7.3.4	Model fit in the adolescent delinquency example	190
7.4	LTA model parameters	192
7.4.1	Latent status prevalences	192
7.4.2	Item-response probabilities	193
7.4.3	Transition probabilities	195
7.5	LTA: Model and notation	196
7.5.1	Fundamental expression	198
7.6	Degrees of freedom associated with latent transition models	199

7.6.1	Computing the number of latent status prevalences estimated	199
7.6.2	Computing the number of item-response probabilities estimated	200
7.6.3	Computing the number of transition probabilities estimated	200
7.7	Empirical example: Adolescent depression	201
7.7.1	Latent status prevalences	203
7.7.2	Item-response probabilities	204
7.7.3	Transition probabilities	205
7.8	Empirical example: Dating and sexual risk behavior	207
7.9	Interpreting what a latent transition model reveals about change	209
7.10	Parameter restrictions in LTA	211
7.11	Testing the hypothesis of measurement invariance across times	212
7.11.1	Empirical example: Adolescent depression	213
7.12	Testing hypotheses about change between times	214
7.13	Relation between RMLCA and LTA	217
7.13.1	Relation between RMLCA and LTA when there are two times	217
7.13.2	Relation between RMLCA and LTA when there are three or more times	218
7.13.3	When to use RMLCA versus LTA	220
7.14	Invariance of the transition probability matrix	221
7.15	Suggested supplemental readings	221
7.16	Points to remember	223
7.17	What's next	224
8	Multiple-Group LTA and LTA with Covariates	225
8.1	Overview	225
8.2	LTA with a grouping variable	226
8.2.1	Empirical example: Adolescent depression	226
8.3	Multiple-group LTA: Model and notation	226
8.4	Computing the number of parameters estimated in multiple-group latent transition models	228
8.5	Hypothesis tests concerning group differences: General considerations	229
8.6	Overall hypothesis tests about group differences in LTA	230

8.6.1	Empirical example: Cohort differences in adolescent depression	230
8.6.2	Empirical example: Gender differences in adolescent depression	233
8.7	Testing the hypothesis of equality of latent status prevalences	235
8.7.1	Empirical example: Gender differences in adolescent depression	236
8.7.2	Empirical example: Gender differences in dating and sexual risk behavior	237
8.8	Testing the hypothesis of equality of transition probabilities	238
8.8.1	Empirical example: Gender differences in adolescent depression	240
8.9	Incorporating covariates in LTA	241
8.9.1	Missing data and preparing variables for use as covariates	241
8.10	LTA with covariates: Model and notation	242
8.10.1	Predicting latent status membership	243
8.10.2	Predicting transitions between latent statuses	243
8.10.3	Hypothetical example of LTA with covariates	244
8.10.4	What is estimated	245
8.11	Hypothesis testing in LTA with covariates	246
8.11.1	Empirical example of predicting latent status membership at Time 1: Adolescent depression	247
8.11.2	Empirical example of predicting latent status membership at Time 1: Dating and sexual risk behavior	250
8.11.3	Empirical example of predicting transitions between latent statuses: Adolescent depression	252
8.11.4	Empirical example of predicting transitions between latent statuses: Dating and sexual risk behavior	256
8.12	Including both a grouping variable and a covariate in LTA	257
8.12.1	Empirical example: Dating and sexual risk behavior	258
8.13	Binomial logistic regression	258
8.13.1	Empirical example: Adolescent depression	259
8.13.2	Empirical example: Dating and sexual risk behavior	261
8.14	The relation between multiple-group LTA and LTA with a covariate	263
8.15	Suggested supplemental readings	263
8.16	Points to remember	264

Topic Index	279
Author Index	283

This Page Intentionally Left Blank

List of Figures

1.1	Latent variable with three observed variables as indicators.	5
1.2	Adolescent delinquency latent class membership probabilities (Add Health public-use data, Wave I; $N = 2,087$). Note that the four probabilities sum to 1.	13
1.3	Probability of a “Yes” response to each delinquency item conditional on latent class membership (Add Health public-use data, Wave I; $N = 2,087$).	14
1.4	Probability of a “Yes” response to each delinquency item conditional on latent status membership (Add Health public-use data, Waves I and II; $N = 2,087$).	16
2.1	Latent class prevalences in pubertal development example (Add Health public-use data, Wave I; $N = 469$).	28
2.2	Item-response probabilities for measurement of Delayed Pubertal Onset latent class (Add Health public-use data, Wave I; $N = 469$). Response category labels appear in Table 2.5.	32

2.3	Item-response probabilities for measurement of Biologically Mature latent class (Add Health public-use data, Wave I; $N = 469$). Response category labels appear in Table 2.5.	32
2.4	Item-response probabilities for measurement of Visibly Mature latent class (Add Health public-use data, Wave I; $N = 469$). Response category labels appear in Table 2.5.	33
2.5	Item-response probabilities for measurement of Mature latent class (Add Health public-use data, Wave I; $N = 469$). Response category labels appear in Table 2.5.	33
2.6	Probability of endorsing alcohol and tobacco use items conditional on latent class membership (Youth Risk Behavior Survey, 2005; $N = 13,840$).	36
2.7	Probability of endorsing other drug use items conditional on latent class membership (Youth Risk Behavior Survey, 2005; $N = 13,840$).	37
2.8	Probability of endorsing sexual behavior items conditional on latent class membership (Youth Risk Behavior Survey, 2005; $N = 13,840$).	37
2.9	Prevalence of health risk behavior latent classes (Youth Risk Behavior Survey, 2005; $N = 13,840$).	38
2.10	Figure 1.1, repeated here for convenience. Latent variable with three observed variables as indicators. This figure illustrates local independence. There are arrows connecting observed variables X_1 , X_2 , and X_3 to the latent variable but no other arrows connecting any components of the observed variables to each other. This signifies that the three observed variables are related only through the latent variable.	44
2.11	Latent variable with three observed variables as indicators. This figure illustrates a violation of local independence. Observed variables X_2 and X_3 are related to each other not only through the latent variable, but also through their error components (e 's).	45
3.1	Probability of endorsing tobacco use behavior items conditional on latent class membership. Hypothetical data from Table 3.5 exhibit high homogeneity and high latent class separation.	59

3.2	Probability of endorsing tobacco use behavior items conditional on latent class membership. Hypothetical data from Table 3.6 exhibit high homogeneity overall and low separation between the Regular I and II latent classes.	61
3.3	Probability of endorsing tobacco use behavior items conditional on latent class membership. Hypothetical data from Table 3.7 exhibit low homogeneity and low latent class separation.	63
4.1	Unimodal likelihood function for a single parameter θ , indicative of good identification.	90
4.2	Multimodal likelihood function for a single parameter θ , indicative of underidentification.	91
4.3	Likelihood function for a single parameter θ . This function has a flat region, which suggests that the model being fit is unidentified.	91
4.4	Distribution of log-likelihood values for five-latent-class model of positive health behaviors based on 100 random sets of starting values (Monitoring the Future data, 2004; $N = 2,065$).	96
4.5	G^2 , AIC, and BIC for models of positive health behaviors (Monitoring the Future data, 2004; $N = 2,065$).	98
4.6	G^2 , AIC, and BIC for models of female pubertal development (Add Health public-use data, Wave I; $N = 469$).	101
4.7	G^2 , AIC, and BIC for models of health risk behaviors (Youth Risk Behavior Survey, 2005; $N = 13,840$).	102
5.1	Prevalence of latent classes of positive health behaviors by gender (Monitoring the Future data, 2004; $N = 2,065$).	139
5.2	Prevalence of health risk behavior latent classes for each grade (Youth Risk Behavior Survey, 2005; $N = 13,840$).	144
6.1	Overall effect of one-standard-deviation increase in maternal education in positive health behavior example (Monitoring the Future data, 2004; $N = 2,065$). The Typical latent class is the reference group.	162
6.2	Effect of one-standard-deviation increase in maternal education for males and females in positive health behavior example (Monitoring the Future data, 2004; $N = 2,065$).	165

6.3	Effect of one-standard-deviation increase in maternal education on odds of membership in Healthy latent class as compared to membership in other latent classes combined, by gender (Monitoring the Future data, 2004; $N = 2,065$).	175
7.1	Patterns of heavy drinking across four developmental periods, corresponding to the latent classes in Table 7.2 (from Lanza and Collins, 2006). Note that more precise values for item-response probabilities appear in Table 7.1.	184
7.2	G^2 , AIC, and BIC for latent transition models of adolescent delinquency (Add Health public-use data, Waves I and II; $N = 2,087$).	191
7.3	G^2 , AIC, and BIC for latent transition models of adolescent depression (Add Health public-use data, Waves I and II; $N = 2,061$).	203
7.4	Transition probabilities for latent transition model of adolescent depression (Add Health public-use data, Waves I and II; $N = 2,061$).	206
8.1	Prevalences of latent statuses of adolescent depression at Time 1 by gender (Add Health public-use data, Waves I and II; $N = 2,061$).	237
8.2	Odds ratios associated with current cigarette use and lifetime marijuana use. Although not estimated, the odds ratio of 1 associated with the reference latent status, Not Depressed, is shown here for comparison purposes (Add Health public-use data, Waves I and II; $N = 2,061$).	250

List of Tables

1.1	Four Different Latent Variable Models	7
1.2	Proportion of Adolescents Responding “Yes” to Questions About Delinquent Behaviors (Add Health Public-Use Data, Wave I; $N = 2,087$)	11
1.3	Four-Latent-Class Model of Past-Year Delinquency (Add Health Public-Use Data, Wave I; $N = 2,087$)	12
1.4	Five-Latent-Status Model of Past-Year Delinquency (Add Health Public-Use Data, Waves I and II; $N = 2,087$)	15
2.1	Marginal Response Proportions for Female Pubertal Development Variables (Add Health Public-Use Data, Wave I; $N = 469$)	24
2.2	Response Patterns and Frequencies for Add Health Pubertal Development Data (Add Health Public-Use Data, Wave I; $N = 469$)	26
2.3	Item-Response Probabilities for a Hypothetical Two-Latent-Class Model	30
2.4	Item-Response Probabilities for a Hypothetical Three-Latent-Class Model	30

2.5	Four-Latent-Class Model of Female Pubertal Development in Seventh Grade (Add Health Public-Use Data, Wave I; $N = 469$)	31
2.6	Proportion of Students Reporting Each Health Risk Behavior (Youth Risk Behavior Survey, 2005; $N = 13,840$)	35
2.7	Five-Latent-Class Model of Health Risk Behaviors (Youth Risk Behavior Surveillance System Data; $N = 13,840$)	39
2.8	Hypothetical Example with Two Latent Classes and Two Observed Variables	42
2.9	Response Pattern Probabilities for Hypothetical Example in Table 2.8	44
3.1	Item-Response Probabilities from Four-Latent-Class Model of Female Pubertal Development (Add Health Public-Use-Data, Wave I; $N = 469$. From Table 2.5; repeated here for convenience)	52
3.2	Hypothetical Item-Response Probabilities Reflecting Independence of Observed Variables and Latent Variable	53
3.3	Item-Response Probabilities from Five-Latent-Class Model of Health Risk Behaviors (Youth Risk Behavior Survey, 2005; $N = 13,840$. From Table 2.7; repeated here for convenience)	54
3.4	Item-Response Probabilities for a Hypothetical Three-Latent-Class Model	55
3.5	Item-Response Probabilities for a Hypothetical Three-Latent-Class Model with High Homogeneity and High Latent Class Separation	58
3.6	Item-Response Probabilities for a Hypothetical Three-Latent-Class Model with High Homogeneity and Low Latent Class Separation	60
3.7	Item-Response Probabilities for a Hypothetical Three-Latent-Class Model with Low Homogeneity and Low Latent Class Separation	62
4.1	Marginal Response Proportions for Indicators of Positive Health Behavior (Monitoring the Future Data, 2004; $N = 2,065$)	95
4.2	Summary of Information for Selecting Number of Latent Classes of Positive Health Behaviors (Monitoring the Future Data, 2004; $N = 2,065$)	97

4.3	Summary of Information for Selecting Number of Latent Classes of Past-Year Delinquency (Add Health Public-Use Data, Wave I; $N = 2,087$)	99
4.4	Summary of Information for Selecting Number of Latent Classes of Female Pubertal Development (Add Health Public-Use Data, Wave I; $N = 469$)	100
4.5	Summary of Information for Selecting Number of Latent Classes of Health Risk Behaviors (Youth Risk Behavior Survey, 2005; $N = 13,840$)	101
4.6	Item-Response Probabilities for a Hypothetical Three-Latent-Class Model (Table 3.4 repeated for convenience)	104
4.7	Type A and Type B Errors for Hypothetical Three-Latent-Class Model in Table 4.6	105
5.1	Four-Latent-Class Model of Past-Year Delinquency (Add Health Public-Use Data, Wave I; $N = 2,087$; Table 1.3 repeated for convenience)	115
5.2	Selecting Number of Latent Classes in Multiple-Group Delinquency Example (Add Health Public-Use Data, Wave I; $N = 2,087$)	121
5.3	Parameter Restrictions Specifying Item-Response Probabilities Are Equal Across Grades in Adolescent Delinquency Example	123
5.4	Parameter Restrictions for Testing Measurement Invariance When Other Parameter Restrictions Are Present	124
5.5	Fit Statistics for Test of Measurement Invariance for Adolescent Delinquency Example (Add Health Public-Use Data, Wave I; $N = 2,087$)	125
5.6	Hypothetical Item-Response Probabilities for Delinquency Example Illustrating Pronounced Group Differences in Measurement	127
5.7	Hypothetical Item-Response Probabilities for Delinquency Example Illustrating Moderate Group Differences in Measurement	128
5.8	Parameter Restrictions Constraining Most, But Not All, Item-Response Probabilities to Be Equal Across Cohorts in Adolescent Delinquency Example	130

5.9	Parameter Restrictions Constraining Item-Response Probabilities to Be Equal Across Cohorts for a Subset of Variables in Adolescent Delinquency Example	130
5.10	Parameter Restrictions Constraining Item-Response Probabilities to Be Equal Across Only Grades 10 and 11 in a Hypothetical Adolescent Delinquency Example with Three Grades	132
5.11	Five Latent Classes of Positive Health Behaviors (Monitoring the Future Data, 2004; $N = 2,065$)	134
5.12	Fit Statistics for Test of Measurement Invariance Across Genders for Latent Class Model of Positive Health Behaviors (Monitoring the Future Data, 2004; $N = 2,065$)	135
5.13	Latent Class Prevalences for Model of Positive Health Behaviors with Item-Response Probabilities Allowed to Vary Across Genders (Monitoring the Future Data, 2004; $N = 2,065$)	135
5.14	Item-Response Probabilities Allowed to Vary Across Genders for Model of Positive Health Behaviors (Monitoring the Future Data, 2004; $N = 2,065$)	136
5.15	Latent Class Model of Positive Health Behaviors with Item-Response Probabilities Constrained Equal Across Genders (Monitoring the Future Data, 2004; $N = 2,065$)	137
5.16	Fit Statistics for Test of Gender Differences in Latent Class Prevalences for Latent Class Model of Positive Health Behaviors (Monitoring the Future Data, 2004; $N = 2,065$)	138
5.17	Latent Class Prevalences Across Cohorts in Four-Latent-Class Model of Past-Year Delinquency (Add Health Public-Use Data, Wave I; $N = 2,087$)	140
5.18	Parameter Restrictions Constraining Latent Class Prevalences to Be Equal Across Cohorts in the Adolescent Delinquency Example (Add Health Public-Use Data, Wave I; $N = 2,087$)	141
5.19	Fit Statistics for Test of Cohort Differences in Latent Class Prevalences for Adolescent Delinquency Example (Add Health Public-Use Data, Wave I; $N = 2,087$)	141
5.20	Proportion of Students in Each Cohort Reporting Each Health Risk Behavior (Youth Risk Behavior Survey, 2005; $N = 13,840$)	142

5.21	Latent Class Prevalences Across Grades in Five-Latent-Class Model of Health Risk Behaviors (Youth Risk Behavior Survey, 2005; $N = 13,840$)	143
5.22	Freely Estimated and Restricted Latent Class Prevalences for Models of Health Risk Behaviors (Youth Risk Behavior Survey, 2005; $N = 13,840$)	145
5.23	Examination of the Impact of Parameter Restrictions on Model Fit for Model of Health Risk Behaviors (Youth Risk Behavior Survey, 2005; $N = 13,840$)	146
5.24	Hypothesis Tests of Equality of Latent Class Prevalences Across Grades in Health Risk Behavior Example (Youth Risk Behavior Survey, 2005; $N = 13,840$)	147
6.1	Latent Class Prevalences and Log-Likelihoods from Previously Fit Models of Positive Health Behaviors (Monitoring the Future Data, 2004; $N = 2,065$)	150
6.2	Example Coding Scheme to Represent a Covariate with Three Response Categories	152
6.3	Gender as a Predictor of Membership in Latent Classes of Positive Health Behaviors (Monitoring the Future Data, 2004; $N = 2,065$)	159
6.4	Maternal Education as a Predictor of Membership in Latent Classes of Positive Health Behaviors (Monitoring the Future Data, 2004; $N = 2,065$)	162
6.5	Gender and Maternal Education as Predictors of Membership in Latent Classes of Positive Health Behaviors (Monitoring the Future Data, 2004; $N = 2,065$)	164
6.6	Hypothesis Tests for Gender, Maternal Education, and Their Interaction for Model of Positive Health Behaviors Reported in Table 6.5 (Monitoring the Future Data, 2004; $N = 2,065$)	164
6.7	Maternal Education as a Predictor of Membership in Latent Classes of Positive Health Behaviors, with Gender as a Grouping Variable (Monitoring the Future Data, 2004; $N = 2,065$)	168
6.8	Binomial Logistic Regression with Gender as a Covariate in Model of Positive Health Behaviors (Monitoring the Future Data, 2004; $N = 2,065$)	173

6.9	Binomial Logistic Regression Model with Gender and Maternal Education as Covariates (Monitoring the Future Data, 2004; $N = 2,065$)	174
6.10	Hypothesis Tests for Gender, Maternal Education, and Their Interaction for Model in Table 6.9 (Monitoring the Future Data, 2004; $N = 2,065$)	174
6.11	Binomial Logistic Regression with Gender as a Grouping Variable and Maternal Education as a Covariate in Model of Positive Health Behavior (Monitoring the Future Data, 2004; $N = 2,065$)	175
7.1	Eight-Latent-Class Model of Heavy Drinking at Six Different Ages (NLSY; $N = 1,265$) (from Lanza and Collins, 2006)	183
7.2	Patterns of Heavy Drinking over Time Corresponding to Eight Latent Classes (NLSY; $N = 1,265$) (from Lanza and Collins, 2006)	185
7.3	Prevalences of Latent Classes Representing Patterns of Heavy Drinking over Time for Those Enrolled in College and Those Not Enrolled in College (NLSY; $N = 1,265$) (from Lanza and Collins, 2006)	186
7.4	Prevalence of Heavy Drinking at Each Developmental Period for Those Enrolled in College and Those Not Enrolled in College (NLSY; $N = 1,265$) (from Lanza and Collins, 2006)	186
7.5	Marginal Response Proportions for Past-Year Delinquency Questionnaire Items (Add Health Public-Use Data, Waves I and II; $N = 2,087$)	188
7.6	Summary of Information for Selecting Number of Latent Statuses of Adolescent Delinquency at Two Times (Add Health Public-Use Data, Waves I and II, $N = 2,087$)	191
7.7	Five-Latent-Status Model of Past-Year Delinquency (Add Health Public-Use Data, Waves I and II; $N = 2,087$; Table 1.4 repeated for convenience)	193
7.8	Marginal Response Proportions for Adolescent Past-Week Depression Questionnaire Items (Add Health Public-Use Data, Waves I and II; $N = 2,061$)	201
7.9	Summary of Information for Selecting Number of Latent Statuses of Adolescent Depression (Add Health Public-Use Data, Waves I and II; $N = 2,061$)	203

7.10	Five-Latent-Status Model of Adolescent Depression (Add Health Public-Use Data, Waves I and II; $N = 2,061$)	204
7.11	Summary of Information for Selecting Number of Latent Statuses of Dating and Sexual Risk Behavior (NLSY, Rounds 2–4, $N = 2,937$)	207
7.12	Five-Latent-Status Model of Dating and Sexual Risk Behavior (NLSY, Rounds 2–4, $N = 2,937$)	208
7.13	Parameter Restrictions Constraining Item-Response Probabilities to Be Equal Across Times for Adolescent Depression Example	214
7.14	Fit Statistics for Test of Measurement Invariance Across Times for Adolescent Depression Example (Add Health Public-Use Data, Waves I and II; $N = 2,061$)	214
7.15	Fixed Transition Probability Parameter Values Expressing a Model of No Change in the Five-Latent-Status Model of Adolescent Depression	215
7.16	Fit Statistics for Test of Hypothesis That Latent Status Membership Is Identical at Times 1 and 2 for Adolescent Depression Example (Add Health Public-Use Data, Waves I and II; $N = 2,061$)	216
7.17	Fixed Transition Probability Parameter Values Expressing a Model in Which There Is No Movement Between Sad and Disliked in the Five-Latent-Status Model of Adolescent Depression	216
7.18	Fixed Transition Probability Parameter Values Expressing a Model in Which There Is Only Increasing Depression Across Time in the Five-Latent-Status Model of Adolescent Depression	217
7.19	Parameter Restrictions Constraining Transition Probabilities to Be Equal Across Three Times in a Hypothetical Five-Latent-Status Model of Adolescent Depression	222
7.20	Five-Latent-Status Model of Dating and Sexual Risk Behavior with Transition Probability Matrices Constrained Equal Across Three Times (NLSY, Rounds 2–4, $N = 2,937$)	222
7.21	Fit Statistics for Test of Invariance of Transition Probability Matrices in the Dating and Sexual Risk Behavior Example (NLSY, Rounds 2–4, $N = 2,937$)	223

8.1	Latent Status Prevalences and Transition Probabilities for Five-Latent-Status Model of Adolescent Depression, by Cohort (Add Health Public-Use Data, Waves I and II; $N = 2,061$)	227
8.2	Varying Types of Equivalence Across Groups in Latent Transition Models	229
8.3	Parameter Restrictions Constraining Latent Status Prevalences and Transition Probabilities to Be Equal Across Cohorts in Adolescent Depression Example	231
8.4	Latent Status Prevalences and Transition Probabilities Constrained Equal Across Cohorts for Five-Latent-Status Model of Adolescent Depression (Add Health Public-Use Data, Waves I and II; $N = 2,061$)	232
8.5	Fit Statistics for Test of Cohort Differences in Latent Status Prevalences and Transition Probabilities for Adolescent Depression Example (Add Health Public-Use Data, Waves I and II; $N = 2,061$)	233
8.6	Latent Status Prevalences and Transition Probabilities for Five-Latent-Status Model of Adolescent Depression, by Gender (Add Health Public-Use Data, Waves I and II; $N = 2,061$)	234
8.7	Fit Statistics for Test of Gender Differences in Latent Status Prevalences and Transition Probabilities for Adolescent Depression Example (Add Health Public-Use Data, Waves I and II; $N = 2,061$)	234
8.8	Fit Statistics for Two Approaches to Test of Gender Differences in Latent Status Prevalences for Adolescent Depression Example (Add Health Public-Use Data, Waves I and II; $N = 2,061$)	236
8.9	Fit Statistics for Test of Gender Differences in Latent Status Prevalences Across Gender for Dating and Sexual Risk Behavior Example (NLSY, Rounds 2–4; $N = 2,937$)	238
8.10	Latent Status Prevalences and Transition Probabilities for Five-Latent-Status Model of Dating and Sexual Risk Behavior, by Gender (NLSY, Rounds 2–4; $N = 2,937$)	239
8.11	Fit Statistics for Two Approaches to Test of Gender Differences in Transition Probabilities for Adolescent Depression Example (Add Health Public-Use Data, Waves I and II; $N = 2,061$)	240