Graphics Companion

for

Latent Variable Models

An Introduction to Factor, Path, and Structural Equation Analysis

Fifth Edition

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NEW YORK AND LONDON

Contents

Preface to Graphics Companion

This document contains all the chapter figures from *Latent variable models: An introduction to factor, path, and structural equation analysis* (5th edition). They are presented and numbered in the same order as they are in the book.

We placed each figure on a separate page within the designated chapter. Many pdf-reading programs can save the pages as graphics files (e.g, JPEG, TIFF). Alternatively, some slideshow programs can import pdf files directly.

All figures were created in LaTeX using the TikZ and PGF packages. Beaujean (2014) provides example LaTeX syntax for creating a path model in TikZ.

If you notice any errors, please bring them to our attention: Alex_Beaujean@baylor.edu or loehlin@utexas.edu.

References

Beaujean, A. A. (2014). Creating path model diagrams. In *Latent variable modeling using **R**: A step by step guide*. New York, NY: Taylor & Francis. Retrieved from: blogs.baylor.edu/rlatentvariable/sample-page/book-extensions

Chapter 1:
Path Models in Factor, Path, and Structural Equation Analysis

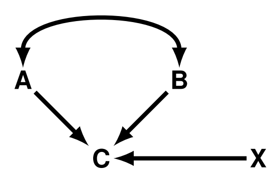


Figure 1.1 Example of a simple path diagram.

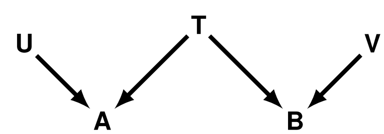


Figure 1.2 Another path diagram: test reliability.

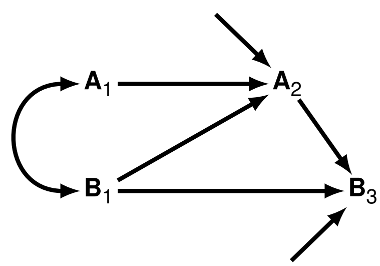


Figure 1.3 A path diagram involving events over time.

Figure 1.4 Path diagrams illustrating the implication of an omitted residual arrow.

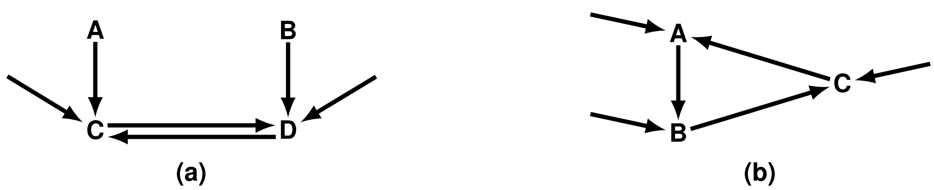


Figure 1.5 Path diagrams with (a) mutual influences and (b) a feedback loop.

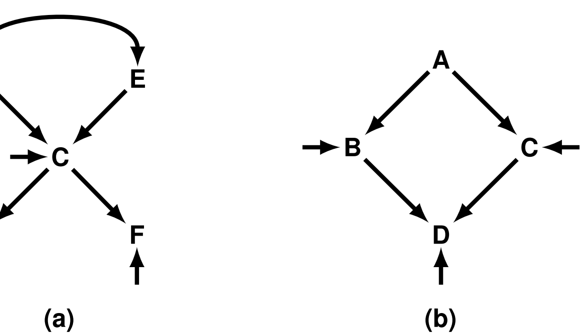


Figure 1.6 Illustrations of Wright's tracing rules.

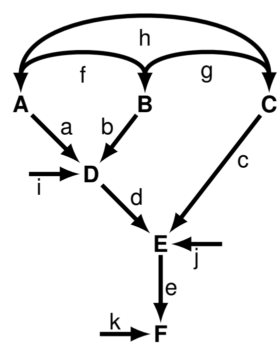
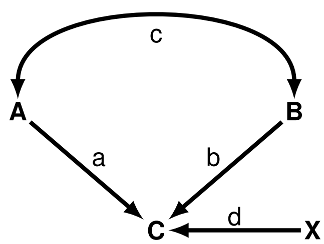


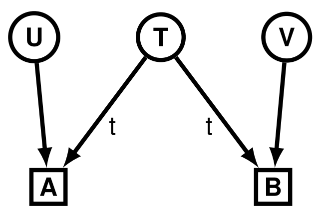
Figure 1.7 Examples of tracing paths in a path diagram.



Correlations

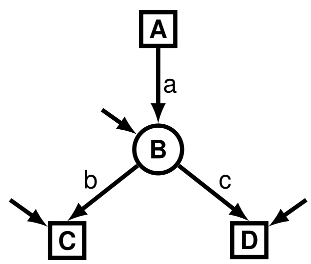
	A	B	C
A	1.00	.50	.65
B		1.00	.70
C			1.00

Figure 1.8 Example of Fig. 1.1, with observed correlations of A, B, and C.



$r_{AB} = .80$

Figure 1.9 The example of Fig. 1.2, with observed correlation of .80 between alternate forms A and B of a test.



	A	C	D
A	1.00	.20	.24
C		1.00	.30
D			1.00

Figure 1.10 Another simple path diagram with a latent variable.

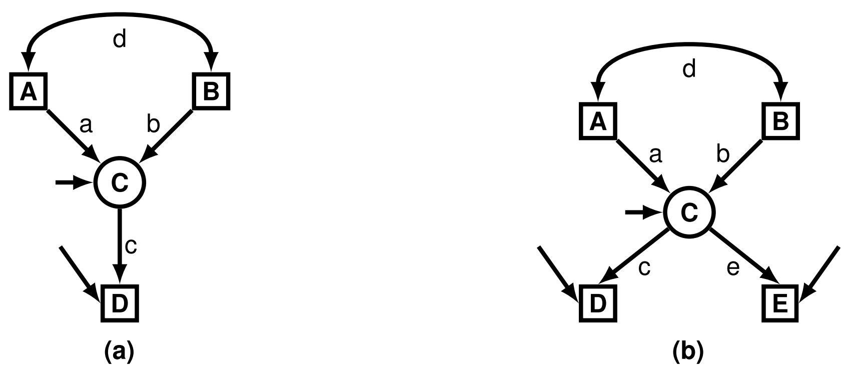


Figure 1.11 Path diagrams that are underdetermined (a) and overdetermined (b).

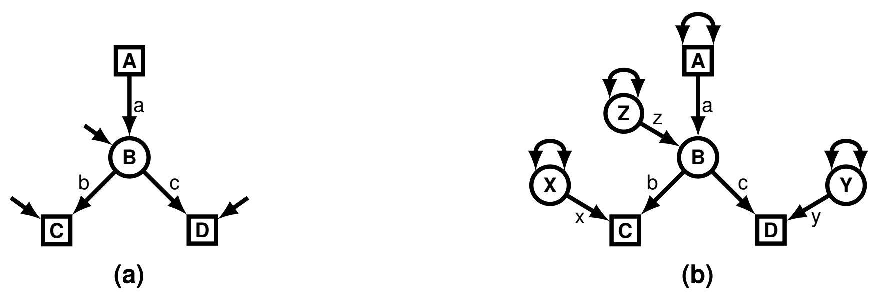


Figure 1.12 The path model of Fig. 1.10 (a) shown in RAM symbolism (b).

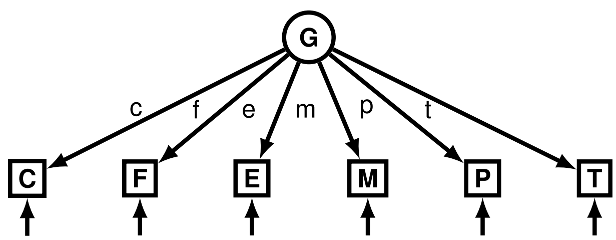
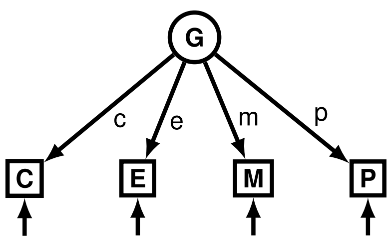


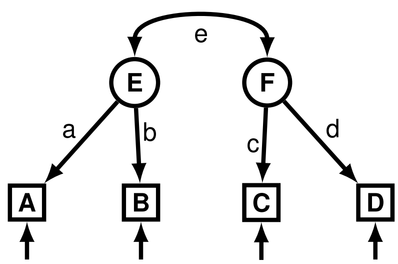
Figure 1.13 Path representation of Spearman's two-factor theory.



Correlations

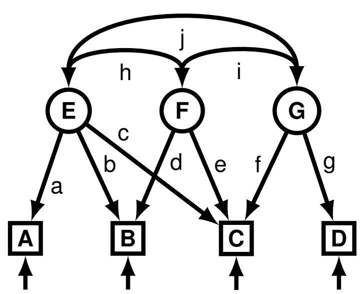
	C	E	M	P
C	1.00	.78	.70	.66
E		1.00	.64	.54
M			1.00	.45
P				1.00

Figure 1.14 Data to illustrate the method of triads.



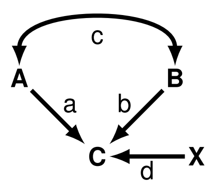
$$r_{AB} = ab = .60 \qquad a = .658$$
$$r_{AC} = aec = .15 \qquad b = .912$$
$$r_{AD} = aed = .10 \qquad c = .833$$
$$r_{BC} = bec = .20 \qquad d = .600$$
$$r_{BD} = bed = .15 \qquad e = .267$$
$$r_{CD} = cd = .50$$

Figure 1.15 A simple factor model with two correlated factors (E and F).



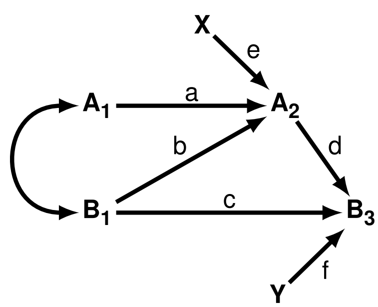
$$r_{AB} = ab + ahd$$
$$r_{AC} = ac + ahe + ajf$$
$$r_{AD} = ajg$$
$$r_{BC} = bc + de + bhe + dif + dhc + bjf$$
$$r_{BD} = dig + bjg$$
$$r_{CD} = fg + cjg + eig$$

Figure 1.16 A more complex three-factor model.



$$C = aA + bB + dX$$

Figure 1.17 A structural equation based on a path diagram.



$$A_2 = aA_1 + bB_1 + eX$$
$$B_3 = dA_2 + cB_1 + fY$$

Figure 1.18 Structural equations based on the path diagram of Fig. 1.3.

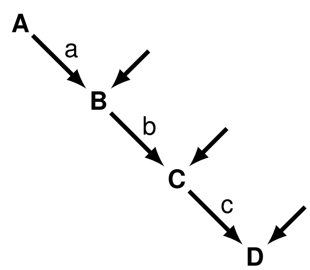


Figure 1.19 Path diagram to illustrate raw-score and standardized path coefficients.

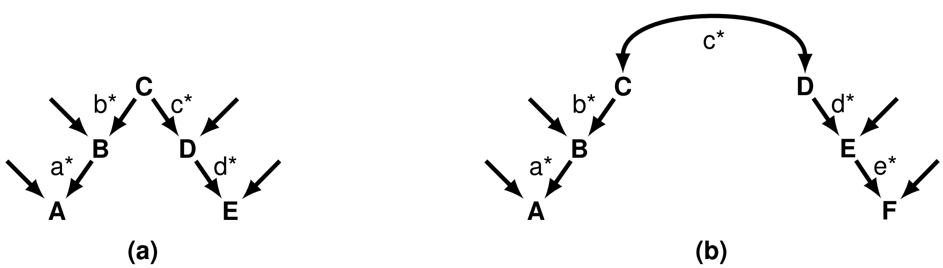


Figure 1.20 Raw-score paths with (a) a variance and (b) a covariance. (Paths a*, b*, c*, etc. represent raw-score coefficients.)

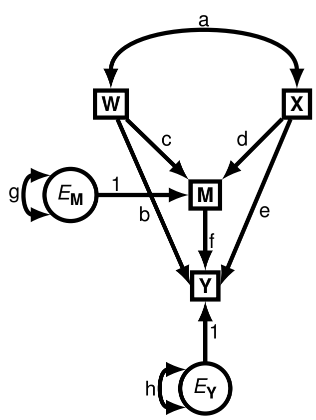


Figure 1.21 Path diagram for extended example.

	M	W	X	Y
M	1.00			
W	.50	1.00		
X	.64	.40	1.00	
Y	.60	.36	.59	1.00

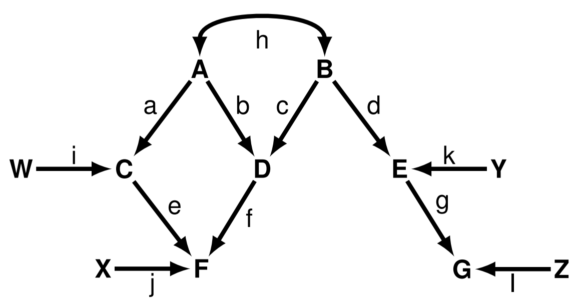


Figure 1.22 Path diagram for problems 4 to 10 (all variables standardized unless otherwise specified).

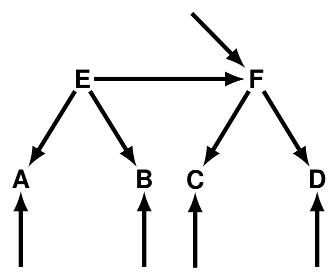
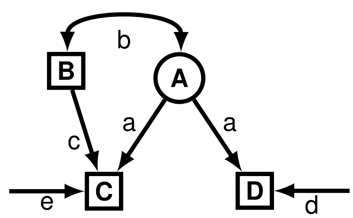


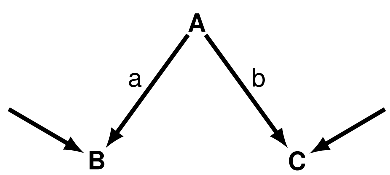
Figure 1.23 Path diagram for problem 11.



	B	C	D
B	1.00	.70	.30
C		1.00	.48
D			1.00

Figure 1.24 Path diagram for problem 12.

Chapter 2:
Fitting Path Models



$r_{AB} = .61$
$r_{AC} = .42$
$r_{BC} = .23$

Figure 2.1 A simple path diagram illustrating an iterative solution.

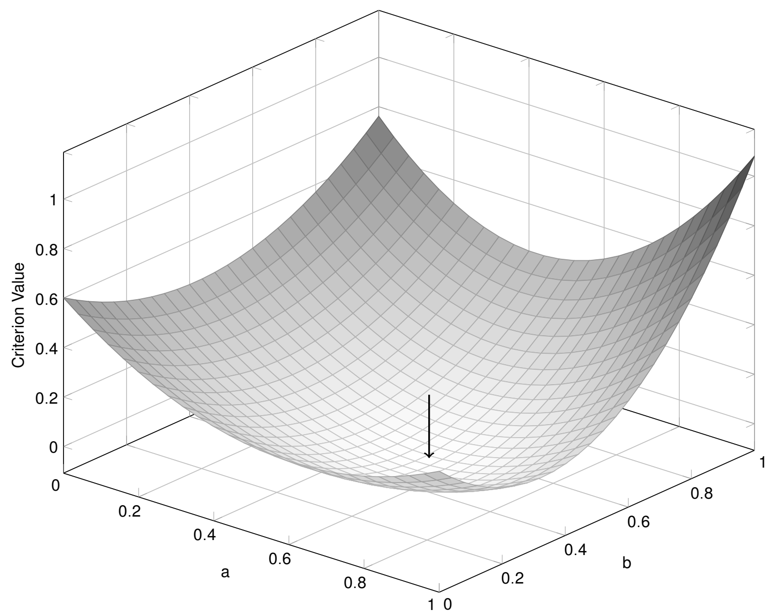


Figure 2.2 Graphical representation of search space for Fig. 2.1 problem, for values 0 to 1 of both variables.

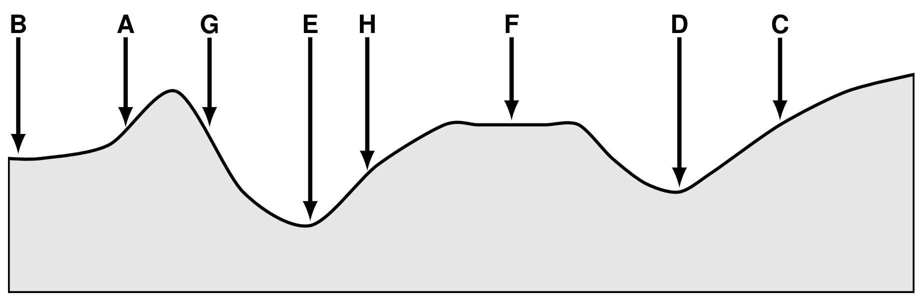
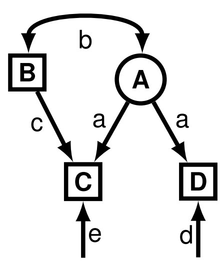


Figure 2.3 Cross section of a less hospitable search terrain.



$r_{BC} = ba + c$ $\qquad r_{BD} = ba$

$r_{CD} = a^2 + cba$ $\qquad s_D^2 = a^2 + d^2$

$s_C^2 = c^2 + a^2 + 2abc + e^2$

Figure 2.4 A path diagram for the matrix example of Tables Table 2-2 and Table 2-3.

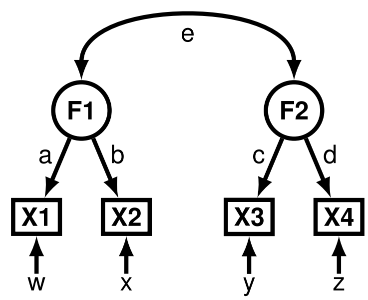


Figure 2.5 Path diagram for example of Table 2-5.

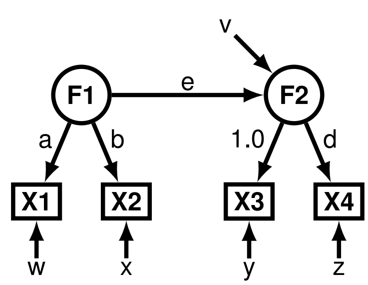
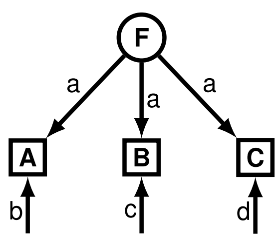


Figure 2.6 A different model for the data of Fig. 2.5.



Implied Variance-Covariance Matrix

	A	B	C
A	$a^2 + b^2$	a^2	a^2
B	a^2	$a^2 + c^2$	a^2
C	a^2	a^2	$a^2 + d^2$

Figure 2.7 Model of single common factor with equal loadings, plus different specifics ("tau-equivalent" tests).

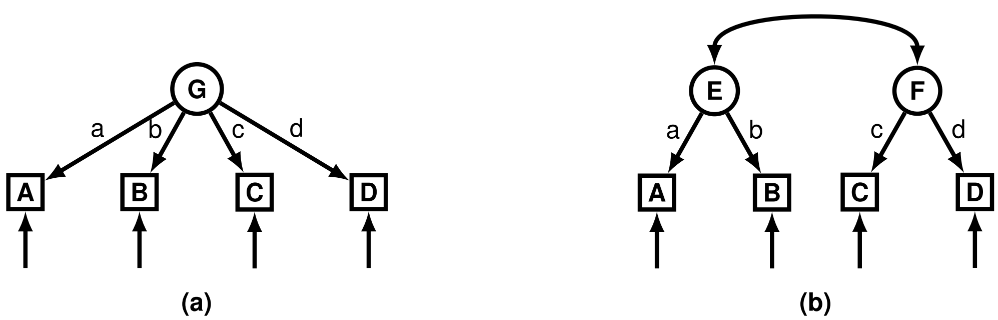


Figure 2.8 Path models for the χ^2 comparisons of Table 2-12.

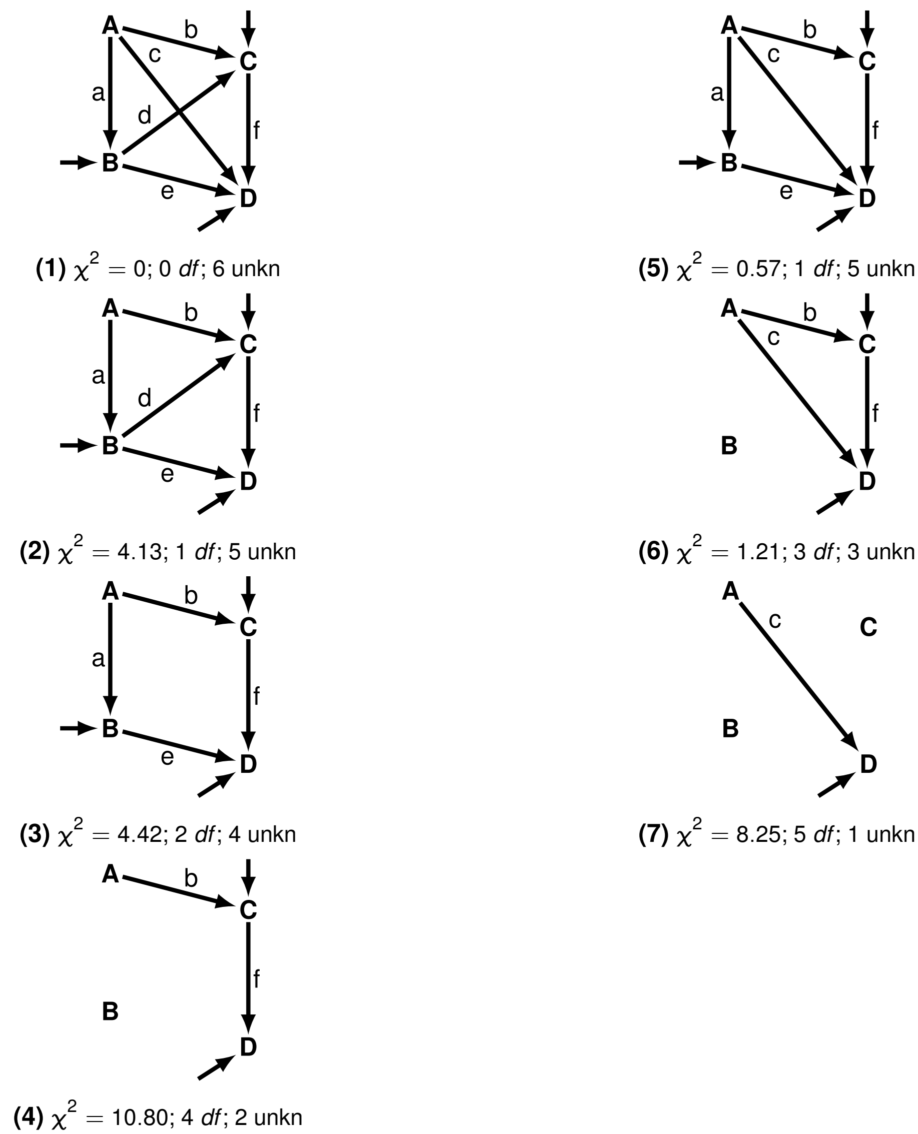


Figure 2.9 Hierarchical series of path models (χ^2 values hypothetical).

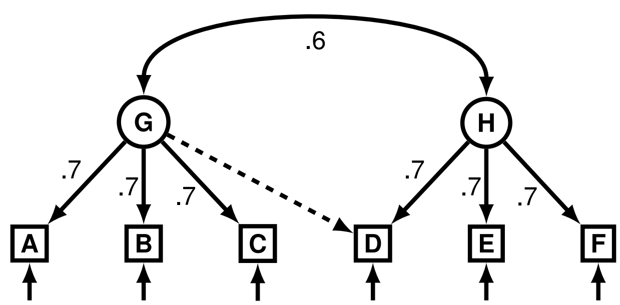


Figure 2.10 Simple factor analysis model for power example. Dashed arrow (- -) additional path to be detected.

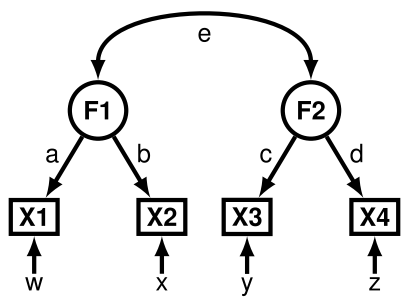
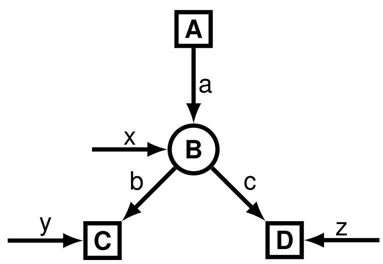


Figure 2.11 Two-factor model illustrating empirical underidentification.



	A	C	D
A	1.00	.30	.40
C		1.00	.35
D			1.00

Figure 2.12 Path model and correlations for Problem 1.

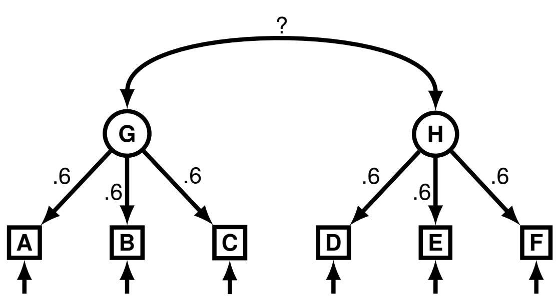
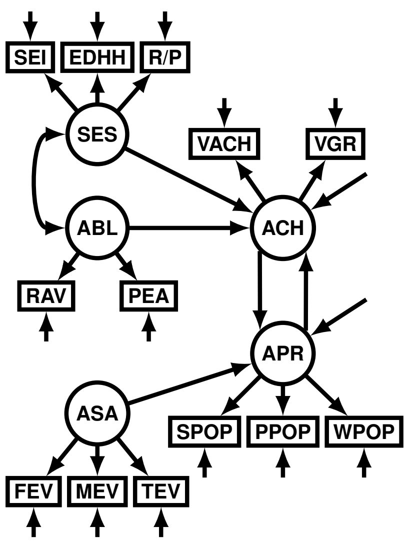


Figure 2.13 Path model for problem 8.

Chapter 3:
Fitting Path and Structural Models to Data from a Single Group on a Single Occasion



Latent Variables

ABL Ability
ASA Acceptance by adults
ACH Academic achievement
APR Acceptance by peers
SES Socioeconomic status

Observed Variables

EDHH Education of head of household
FEV Father's evaluation
MEV Mothers's evaluation
PEA Peabody Picture Vocabulary Test
PPOP Playground popularity
R/P Rooms per person in house
RAV Raven's Progressive Matrices Test
SEI Socioeconomic index
SPOP Seating popularity
TEV Teacher's evaluation
VACH Verbal achievement score
VGR Verbal grades
WPOP Schoolwork popularity

Figure 3.1 Path model used in a desegregation study.

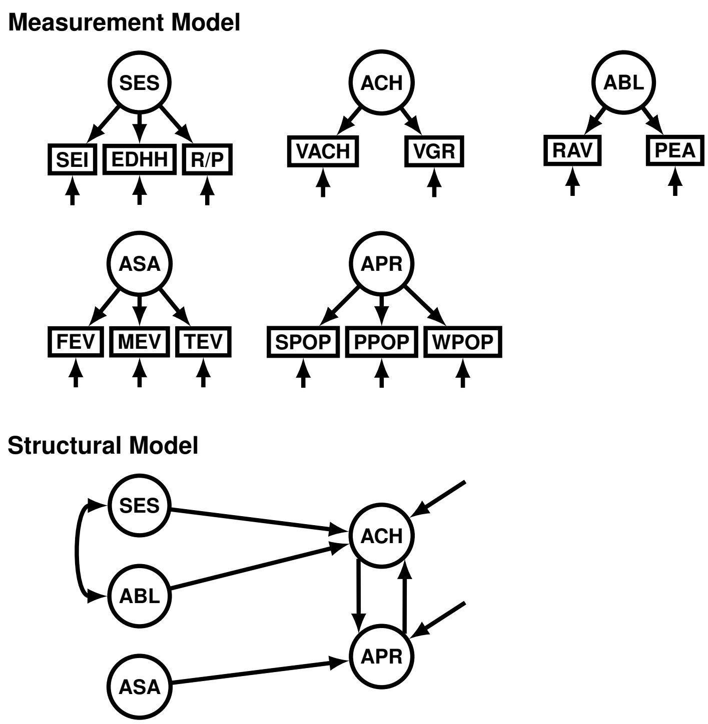
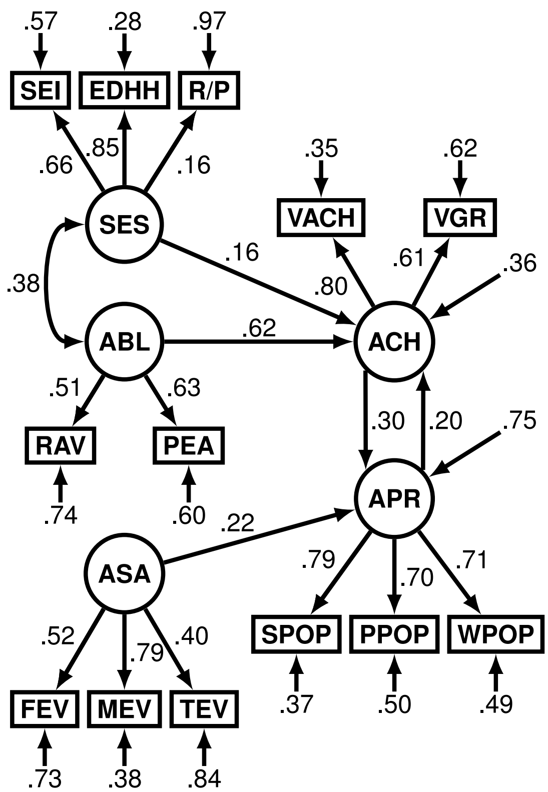


Figure 3.2 Measurement and structural components of path model of Fig. 3.1.



$\chi^2 = 140.30$
59 *df*
$p < .001$

Figure 3.3 Standardized solution to path diagram of Fig. 3.1 from correlations of Table 3-1.

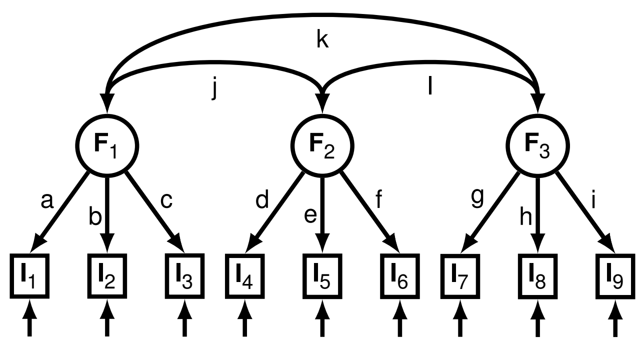


Figure 3.4 Simple three-factor model for data of Table 3-2 from survey on attitudes toward police.

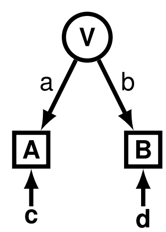


Figure 3.5 Parallel or congeneric tests.

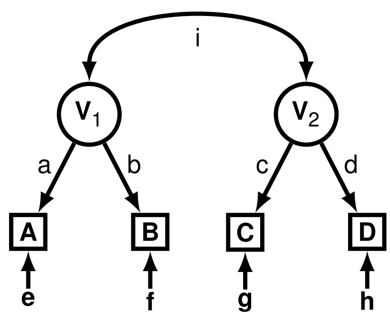


Figure 3.6 Hypotheses about parallel and congeneric tests.

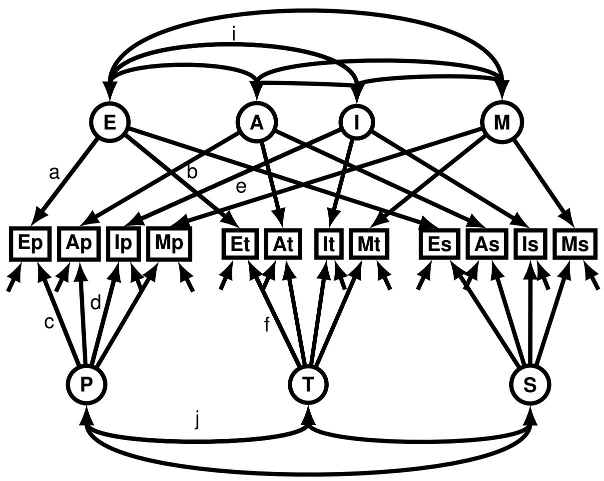
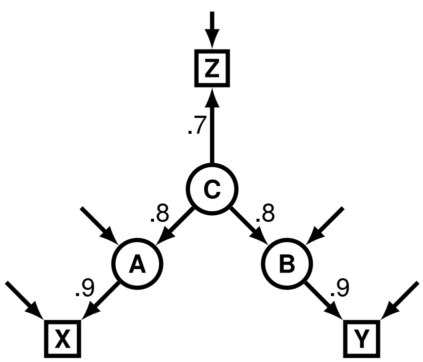


Figure 3.7 Path model of multitrait-multimethod matrix of Table 3-6.



Latent variables A, B, C
$r_{AB} = .64$
$r_{AB \bullet C} = .00$

Observed variables X, Y, Z
$r_{XY} = .5184$
$r_{XZ} = r_{YZ} = .504$

$$r_{XY \bullet Z} = \frac{r_{XY} - r_{XZ} \times r_{YZ}}{\sqrt{(1 - r_{XZ}^2)(1 - r_{YZ}^2)}} = .3544$$

Figure 3.8 Example of misleading partial correlation when partialed variable C is imperfectly measured by Z.

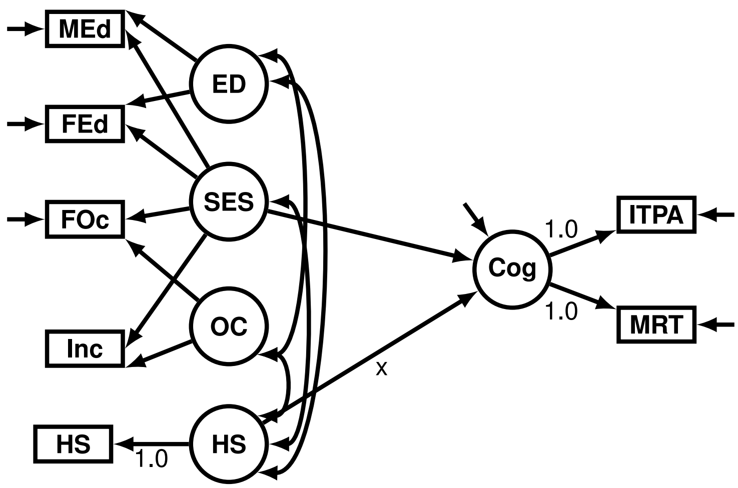


Figure 3.9 Path diagram of a Head Start evaluation. x = path showing effect of Head Start participation on cognitive skills.

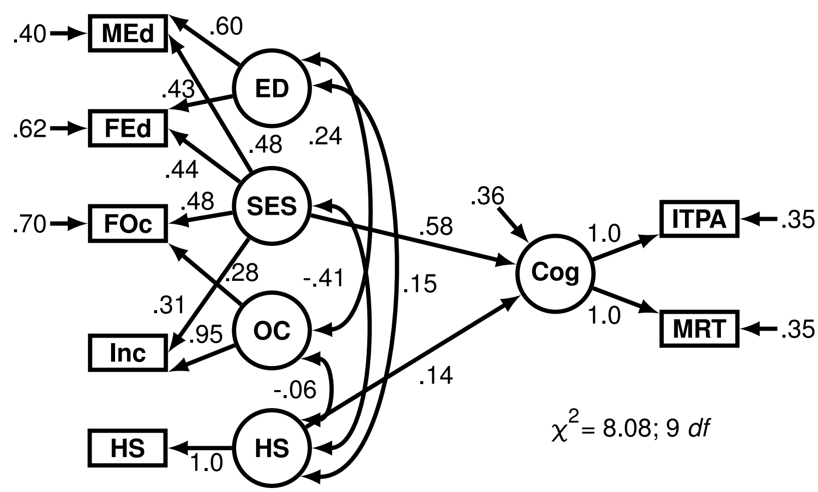


Figure 3.10 Path diagram of Fig. 3.9 with values from solution including Head Start effect.

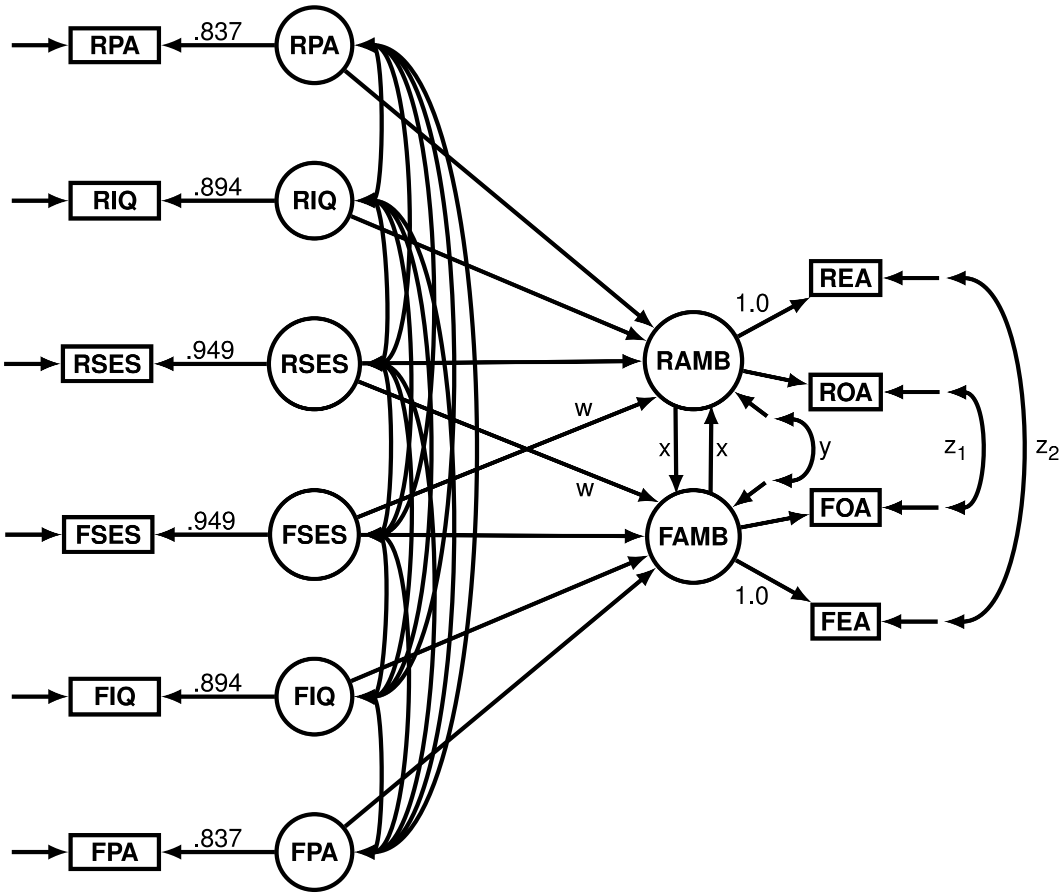


Figure 3.11 Path model for study of career aspirations. R = respondent, F = friend; PA = parental aspirations; IQ = intelligence; SES = socioeconomic status; AMB = ambition; EA = educational aspirations; OA = occupational aspirations; w, x, y, z = paths tested. Path values fixed by assumption are shown.

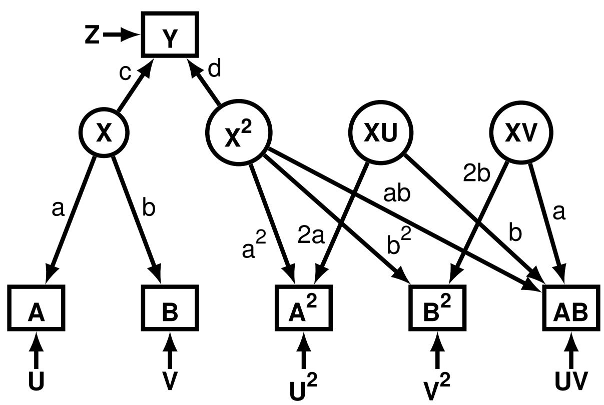


Figure 3.12 Path diagram for nonlinear effect of X on Y.

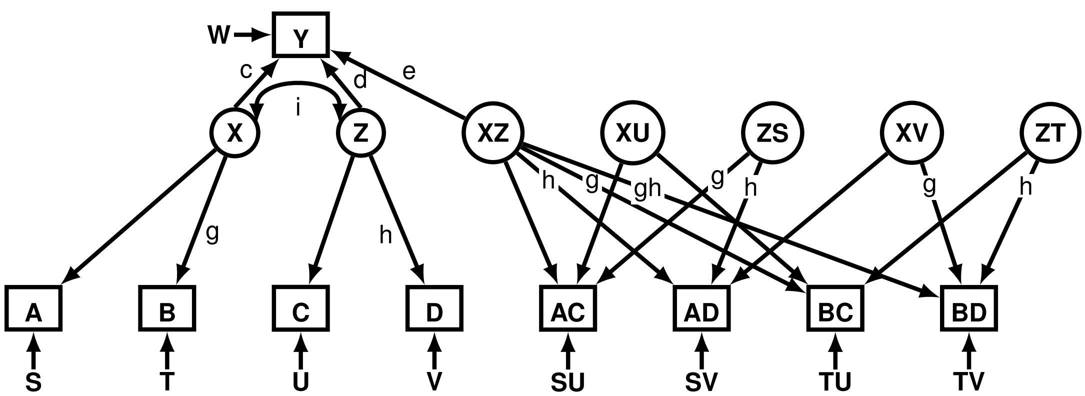


Figure 3.13 Path diagram for interactive effect of X and Z on Y. Unlabeled paths set to 1.0.

Chapter 4:
Fitting Models Involving Repeated Measures, Multiple Groups, or Means

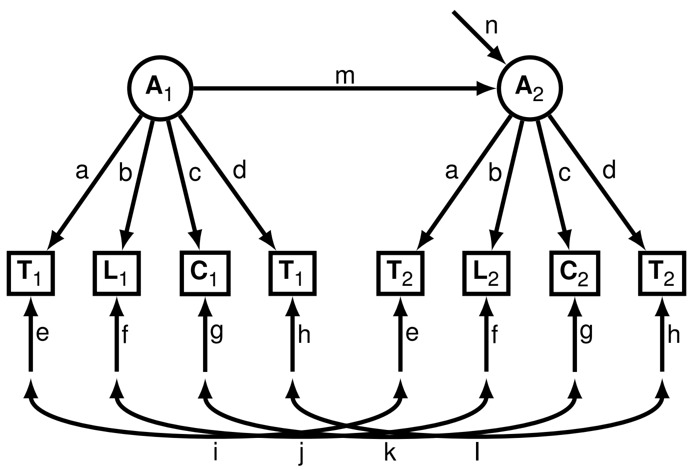


Figure 4.1 A model for the "love" data (Table 4-1). A = general attraction; T, L, C, D = four measures of specific attitudes and behavior (see text); 1, 2 = two occasions.

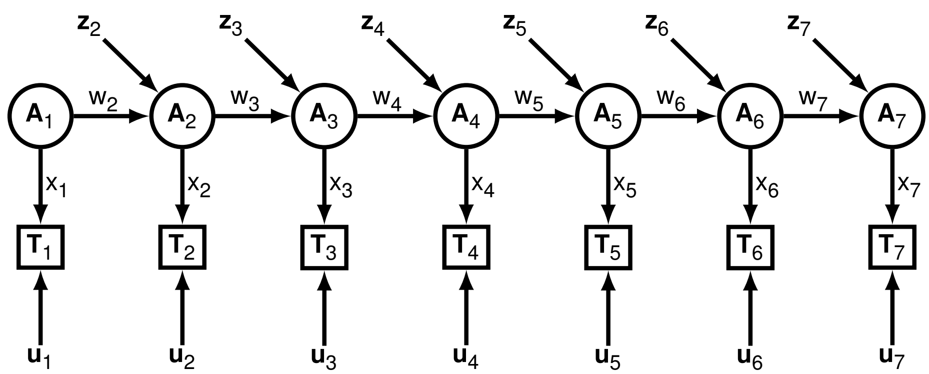


Figure 4.2 Path model of growth over time. A = academic achievement; T = test score; 1–7 = grades.

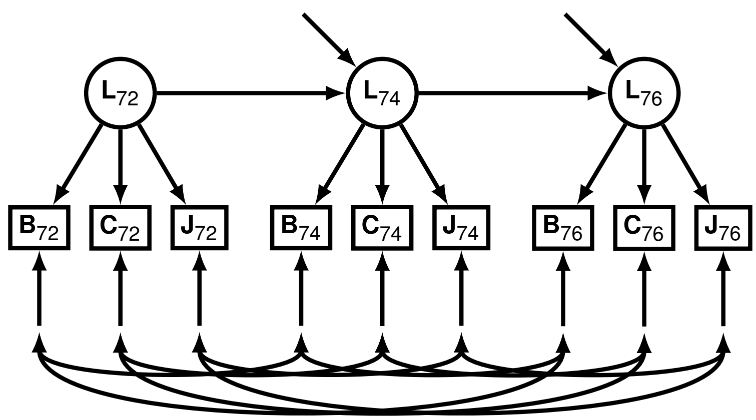


Figure 4.3 Path model for attitudes measured in 1972, 1974, and 1976. L = general factor; B, C, J = specific attitudes; 72, 74, 76 = years.

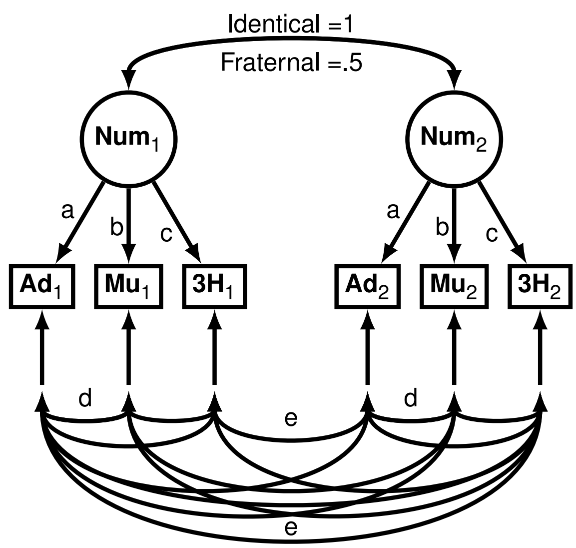


Figure 4.4 Twin correlations on three subscales of numerical ability. Num = genetic component of numerical ability; Ad, Mu, 3H = subscales; 1, 2 = first and second twin of a pair.

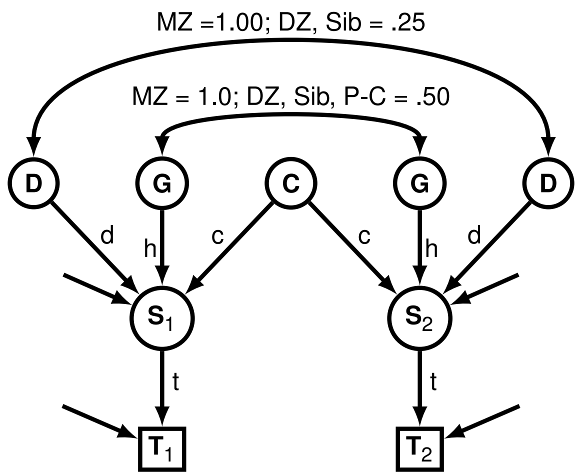


Figure 4.5 Path model of genetic and environmental sources of correlation between two individuals. G = additive genes; D = non-additive genetic effect; C = shared environment; S = sociability; T = test score; 1, 2 = two individuals.

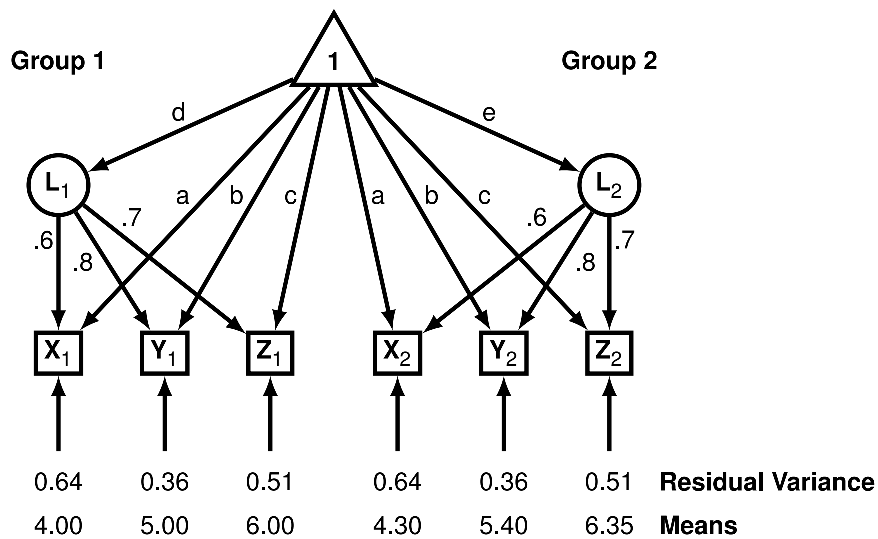


Figure 4.6 A two-group path model incorporating means.

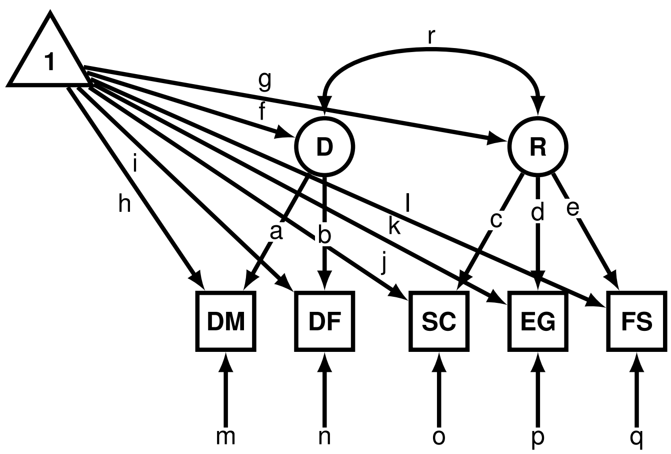


Figure 4.7 Path diagram for the high-stressor group, initial testing. (The diagram for the low-stressor group is the same, except that the paths *f* and *g* from the constant to D and R are fixed to zero.) Latent variables: D = Depression and R = Resources. Observed variables: DM = depressed mood, DF = depressive features, SC = self-confidence, EG = easygoingness, FS = family support.

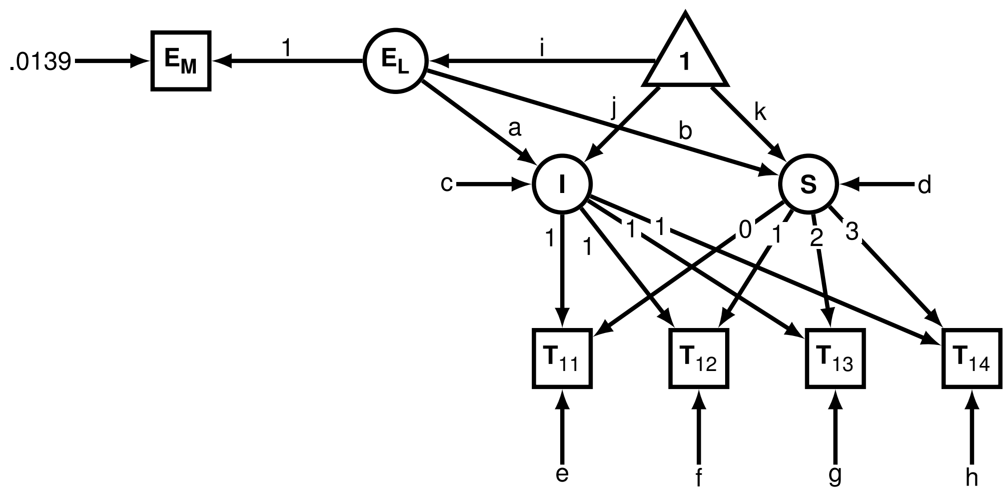


Figure 4.8 Path model of change in tolerance for deviant behaviors.

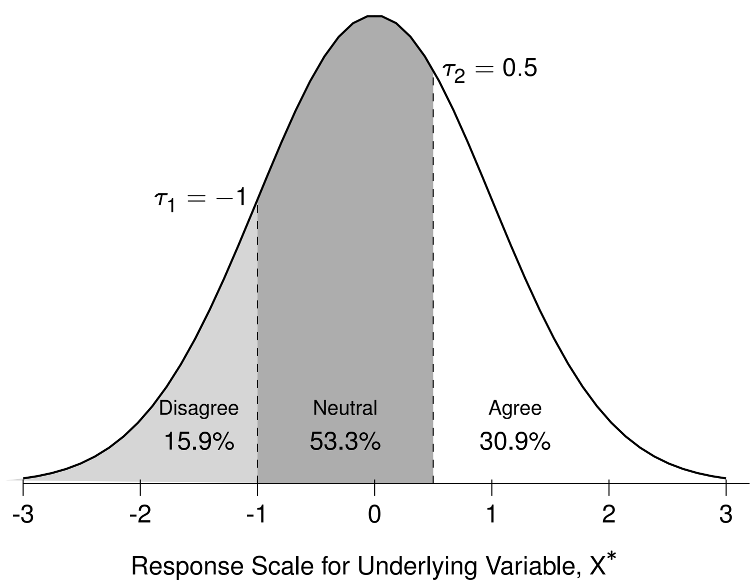


Figure 4.9 Underlying variable response distribution. The τ values mark the thresholds between observed responses.

Chapter 5:
Exploratory Factor Analysis—Basics

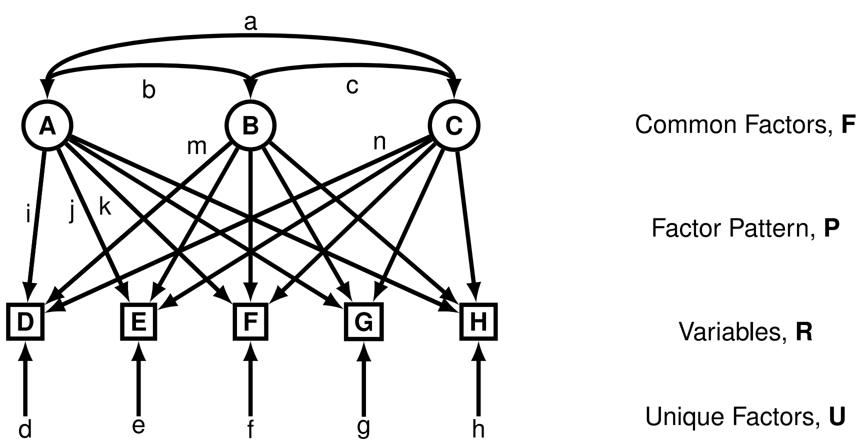
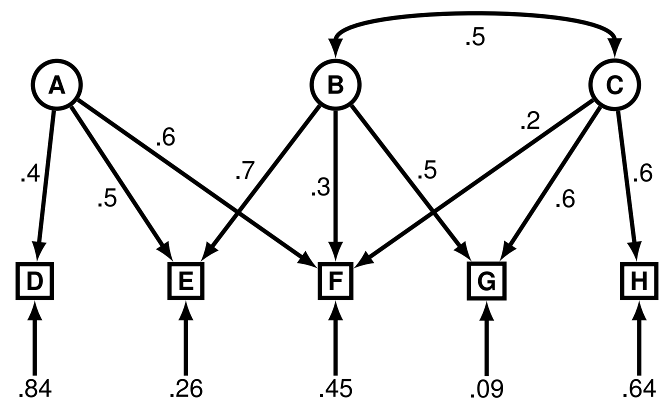
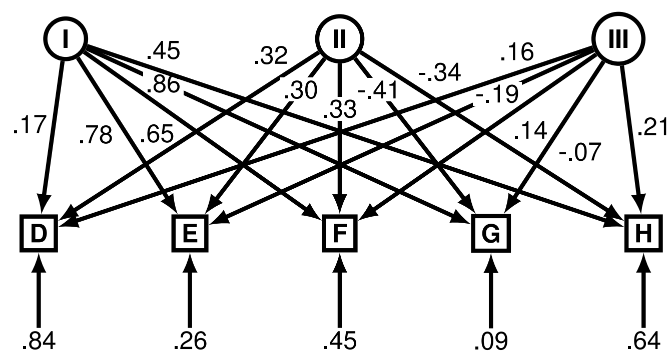


Figure 5.1 Example of a factor analysis model. A, B, C = factors; D, E, F, G, H = observed variables; a, b, c = factor correlations; d, e, f, g, h = specifics; i, j, k, m, n, etc. = factor pattern coefficients.



(a)



(b)

Figure 5.2 Path models for Table 5-1. (a) Model used to generate correlations. (b) Model representing initial principal factor solution.

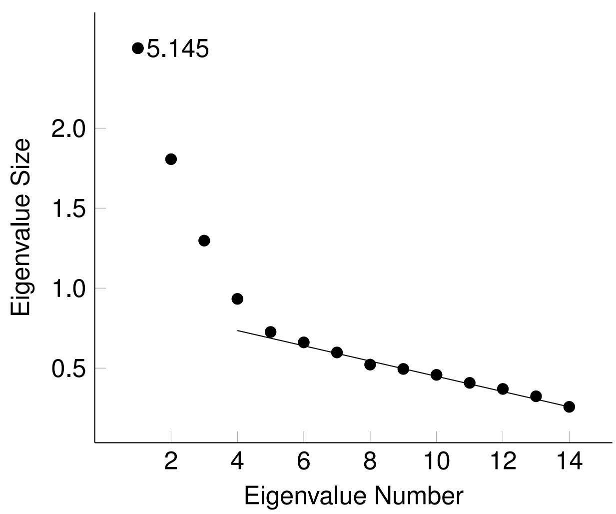


Figure 5.3 Scree test for Holzinger–Swineford data of Table 5-5.

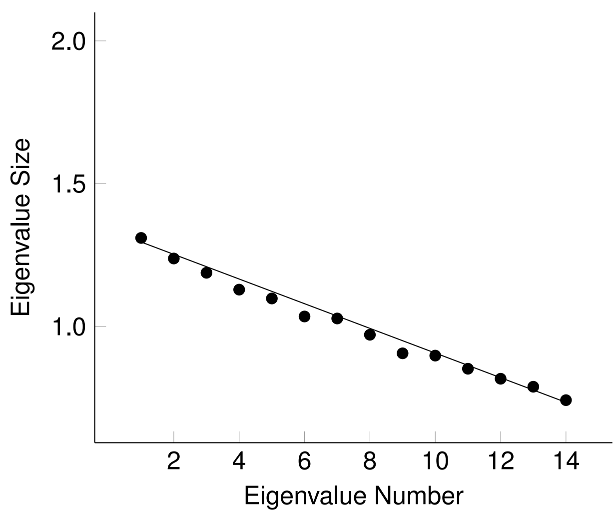


Figure 5.4 Scree test for random data of Table 5-5.

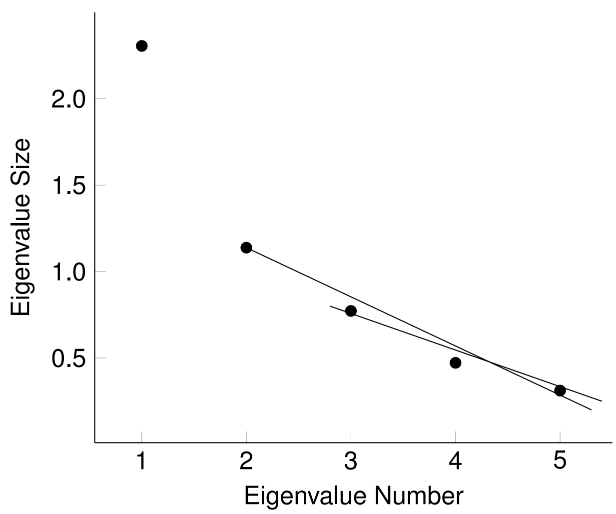


Figure 5.5 Scree test for data of sample problem of Table 5-1.

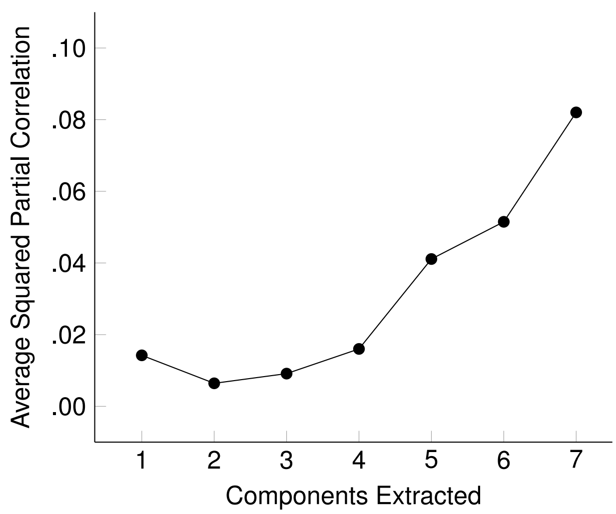


Figure 5.6 Average squared partial correlation values for Holzinger–Swineford data.

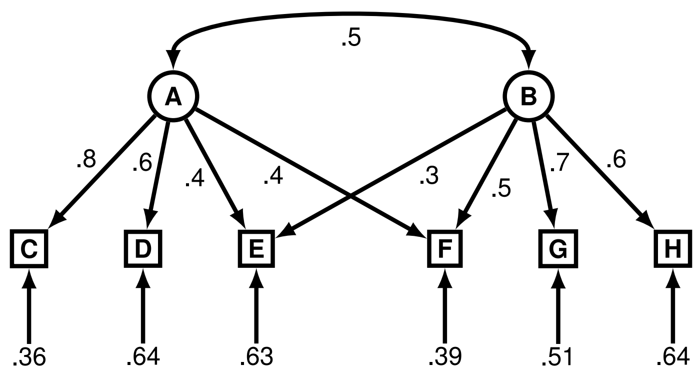


Figure 5.7 Two-factor example to illustrate rotation.

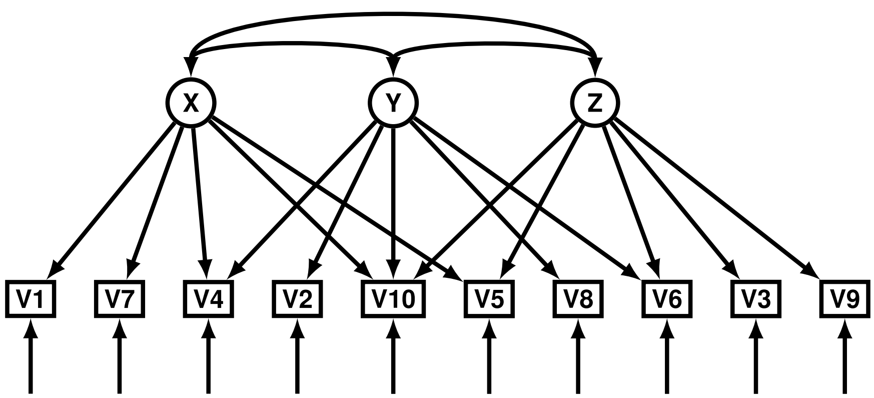


Figure 5.8 Path diagram of Thurstone box problem.

Chapter 6:
Exploratory Factor Analysis—Elaborations

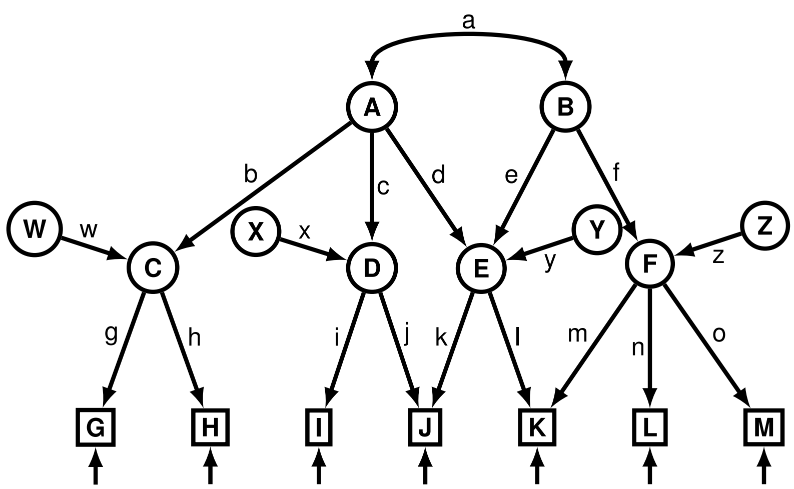


Figure 6.1 Path diagram representing a higher-order factor analysis. C, D, E, F = first-order factors; A, B = second-order factors; G, H, I, J, K, L, M = observed variables; W, X, Y, Z = residuals from second-order analysis.

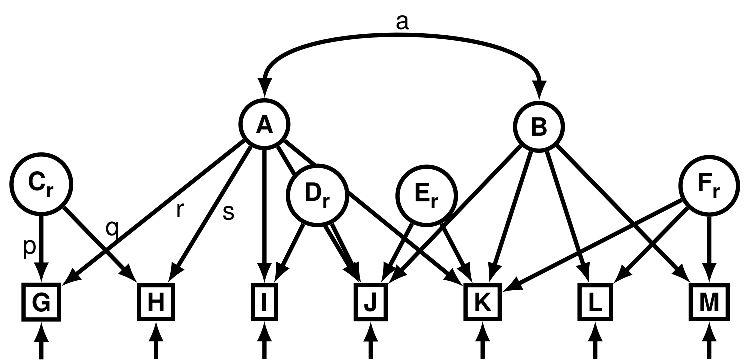


Figure 6.2 Path diagram of higher-order factor analysis with first-order factors residualized. A, B = second-order factors of original analysis; C_r, D_r, E_r, F_r = residualized first-order factors of original analysis; G to M = measured variables.

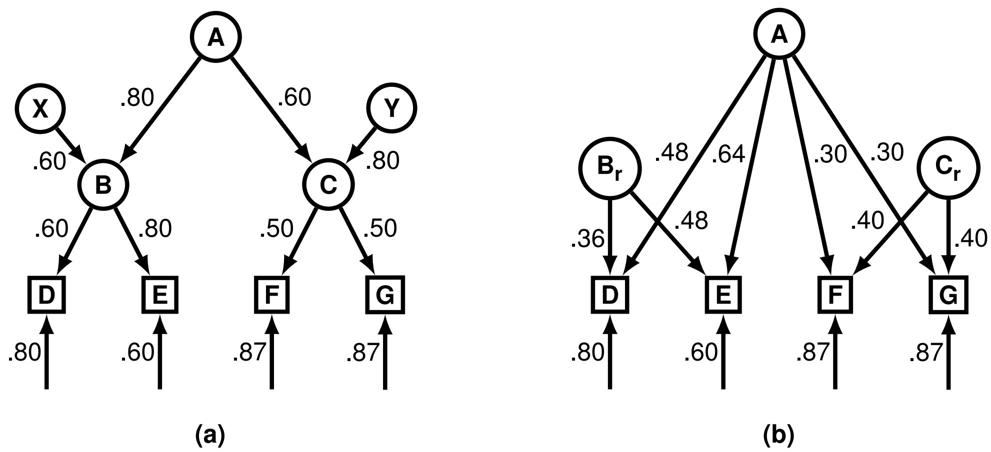


Figure 6.3 Simple second-order factor model in original form (a), and after a Schmid–Leiman transformation (b). B_r and C_r are residualized versions of B and C.

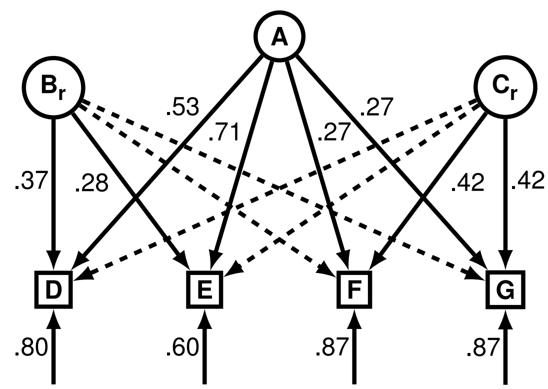


Figure 6.4 Results from direct bi-factor rotation using correlations in Table 6-9. Values for dashed lines (- -) are functionally zero.

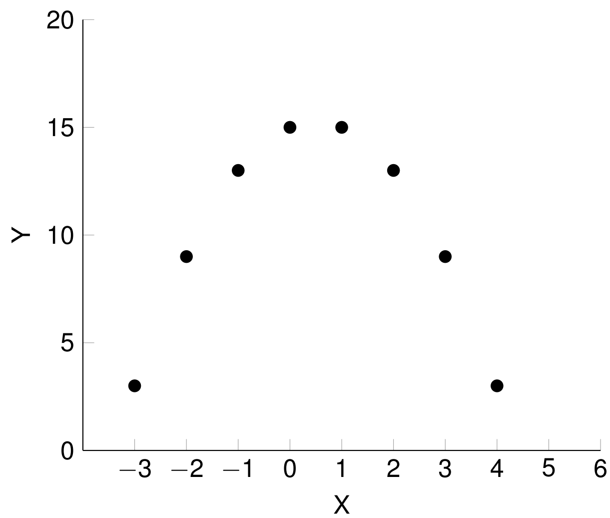


Figure 6.5 Graph of curvilinear relationship ($a = 1$, $b = -1$, $c = 15$).

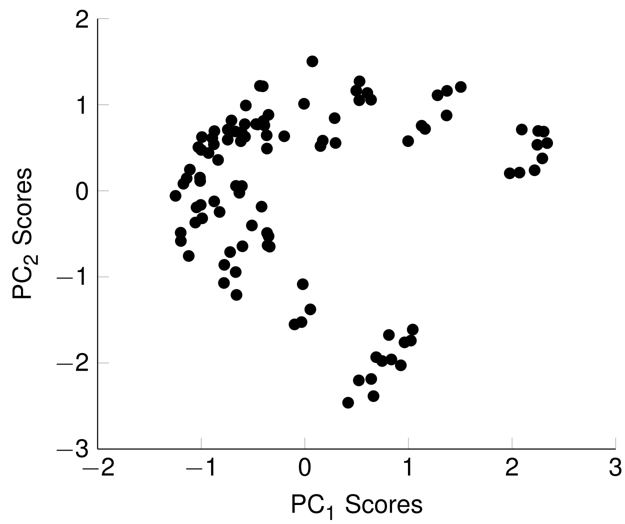


Figure 6.6 Scatterplot of first two principal component scores from factor analysis of Table 6-11.

Chapter 7:
Issues in the Application of Latent Variable Models

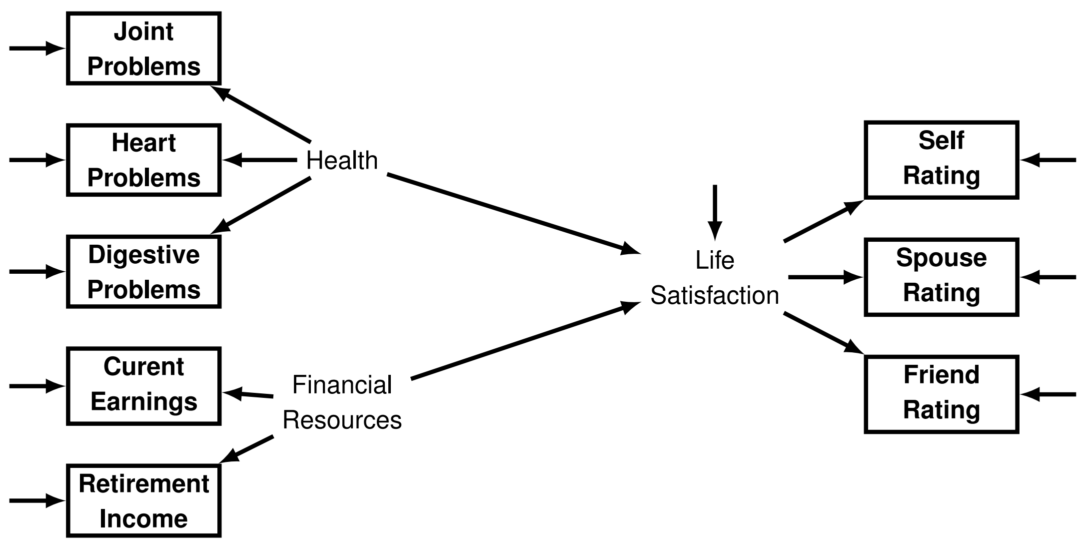


Figure 7.1 A hypothetical study of life satisfaction: conventional (reflective) measurement model.

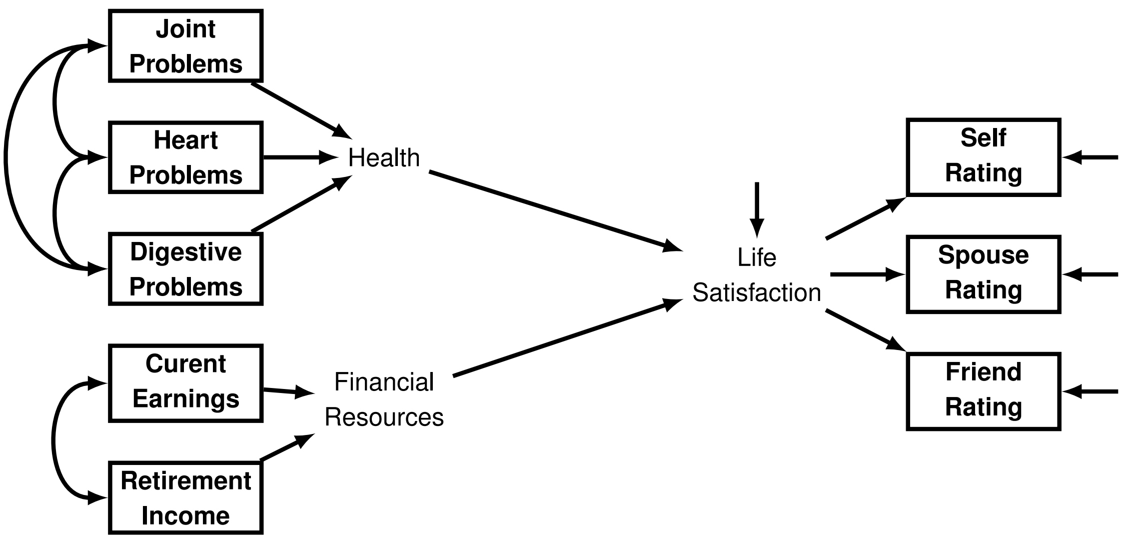


Figure 7.2 A hypothetical study of life satisfaction: indicators causing latent variables (formative model).

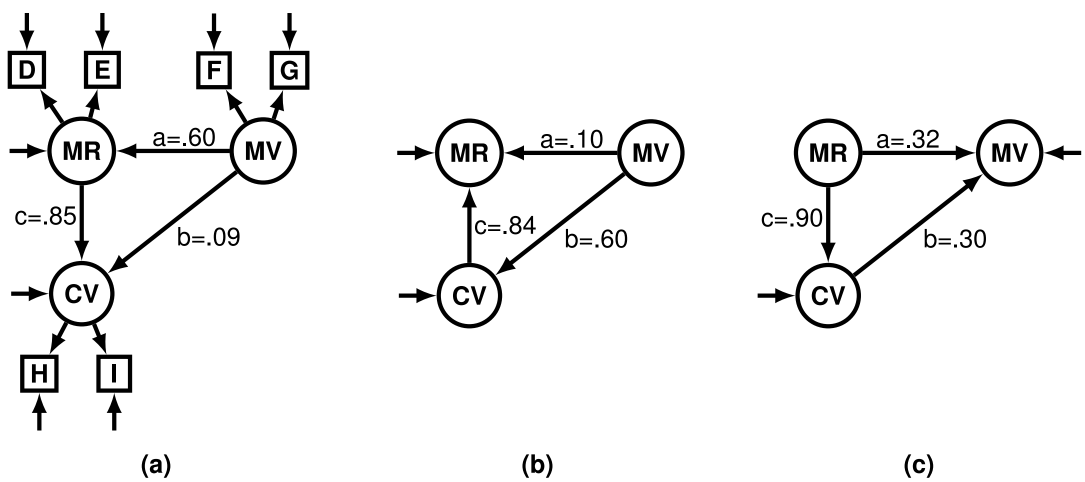


Figure 7.3 Three alternative models of relations among mother's verbal aptitude (MV), child's verbal aptitude (CV), and mother's reading to child (MR). (Same measurement model throughout.)

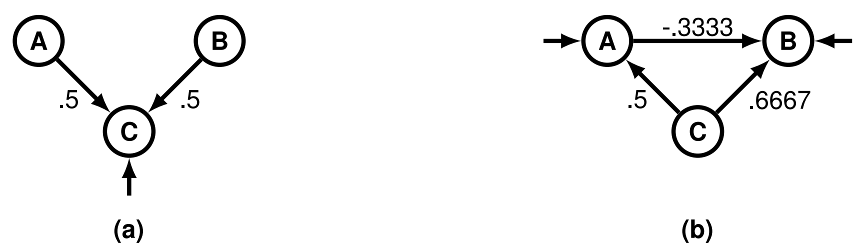


Figure 7.4 Two alternative causal patterns implying the same correlations.

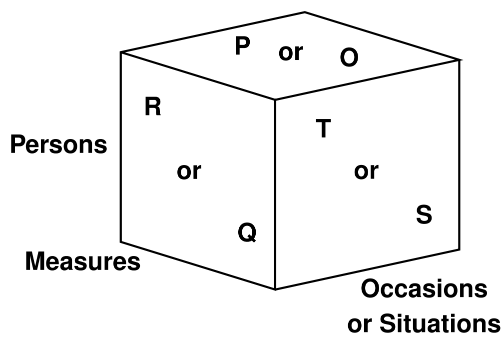


Figure 7.5 A three-dimensional data matrix.

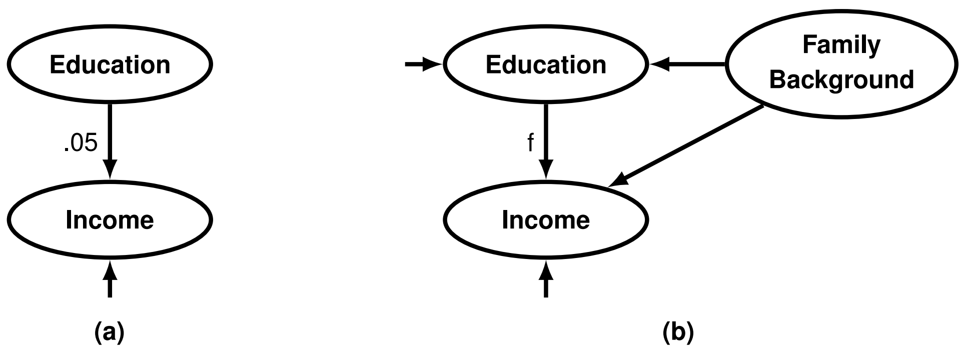


Figure 7.6 Two models of the relationship between education and income.