

# Introduction

It is both a pleasure and honor to introduce the fifth edition of this book. Like the previous editions, structural equation modeling (SEM) is presented in an accessible way for readers without strong quantitative backgrounds. Included in this edition are many new examples of SEM applications in disciplines that include health, political science, international studies, cognitive neuroscience, developmental psychology, sport and exercise, and psychology, among others. Some examples were selected due to technical problems in the analysis, but such examples provide a context for discussing how to deal with challenges that can and do occur in SEM, especially in samples that are not large. So not all applications of SEM described in this book are trouble free, but neither are actual research problems.

## WHAT'S NEW

The many changes in this edition are intended to enhance the pedagogical presentation and cover recent developments. The biggest changes are summarized next:

1. The fourth edition of this book was one of the first introductory works to incorporate Judea Pearl's nonparametric approach to SEM, also called the struc-

tural causal model (SCM), into the larger SEM family that dates to the development of path analysis by Sewall Wright in the 1920s–1930s and to the publication of LISREL III in 1976 as the first widely available computer program for covariance structure analysis, also called covariance-based SEM. In the same tradition, this fifth edition includes composite SEM, also referred to as partial least squares path modeling or variance-based SEM, as the third full member of the SEM family. Composite SEM has developed from a set of methods seen in the 1980s–1990s as more suitable for exploratory research that emphasized prediction over explanation to a suite of full-fledged modeling techniques for exploratory or confirmatory analyses, including theory testing. Both the SCM and composite SEM offer unique perspectives on causal modeling that can benefit researchers more familiar with traditional, covariance-based SEM. This means that researchers acquainted with all three members of the SEM family can test a wider range of hypotheses about measurement and causation. I try to make good on this promise throughout the fifth edition.

2. Traditional SEM and composite SEM are described within Edward Rigdon's concept proxy framework that links data with theoretical concepts through proxies, which approximate concepts based on

correspondence rules—also called auxiliary theory—about presumed causal directionality between concepts and data. This point refers to the distinction between reflective measurement, where proxies for latent variables are common factors, and formative measurement, where proxies for emergent variables are composites of observed variables. The choice between the two measurement models just mentioned should be based on theory, not by default due to the researcher's lack of awareness about SEM techniques for analyzing composites.

3. There are additional new chapters on SEM analyses in small samples and recent developments in mediation analysis. Surveyed works about mediation analysis concern research designs and definitions of mediated effects, including natural direct and indirect effects and interventional direct and indirect effects estimated in clinical trials, among other topics. There is also coverage of new reporting standards for SEM studies by the American Psychological Association (APA) and the technique of piecewise SEM, which is based on concepts from Pearl's SCM. There are also extended tutorials on modern techniques for dealing with missing data, including multiple imputation and full information maximum likelihood (FIML), and also about instrumental variable methods as a way to deal with the confounding of target causal effects.

4. The topics of specification and identification versus analysis were described in separate chapters in the fourth edition. They are now combined into individual chapters for each technique described in the fifth edition. I believe this more closely integrated presentation helps readers to more quickly and easily develop a sense of mastery for a particular kind of SEM technique.

5. There is greater emphasis on freely available software for SEM analyses in this new edition. For example, the R package `lavaan` package was used in most analyses described in this book. It is a full-featured computer program for both basic and advanced SEM analyses. It has the capability to analyze both common factors and composites as proxies for theoretical concepts. The syntax in `lavaan` is both straightforward and used in some other R packages, including `cSEM` for composite SEM, to specify structural equation models, so it has application beyond `lavaan`.

Other R packages used for detailed examples in the fifth edition include `semTools`, `piecewiseSEM`, `MBESS`, `MIIvsem`, `psych`, `WebPower`, `systemfit`, `sem`, `bmem`,

`CauseAndCorrelation`, `dagitty`, and `ggm`. Together with the `lavaan` package, a wide variety of analyses for non-parametric, parametric, and composite models in SEM is demonstrated, all with no-cost software. Commercial software for SEM is still described, including `Mplus`, which can feature state-of-the-art analyses before they appear in other computer tools, but free SEM software is now nearly as capable as commercial products. Also, I would guess that free software could be used in the large majority of published SEM studies.

6. Extended presentations on regression fundamentals, significance testing, and measurement and psychometrics beloved by readers of the fourth edition are freely available in updated form as primers on the book's website. This change was necessary to include the new material in the fifth edition. The topics just mentioned are still covered in the new edition but in a more concise way. New to the fifth edition in the main text is a self-test of knowledge about background concepts in statistics and measurement. There is a scoring key, too, so readers can check their understanding of fundamentals. Readers with higher scores could directly proceed to substantive chapters on SEM analyses, and readers with lower scores can consult any of the primers on the website for more information and exercises.

## BOOK WEBSITE

The address for the book's website is <https://www.guilford.com/kline-materials>. From the site, you can freely access the computer files—data, syntax, and output files—for all detailed examples in this book. The website promotes a learning-by-doing approach. The availability of both syntax and data files means that readers can reproduce the analyses in this book by using the corresponding R packages. Even without doing so, readers can still open the output file on their own computers for a particular analysis and view the results. This is because all computer files are simple text files that can be opened with any basic text editor, such as Notepad (Windows), Emacs (Linux/UNIX), or TextEdit (macOS), among others. Syntax files are annotated with extensive comments. Even if readers use a different computer tool, such as LISREL, it is still worthwhile to review the files on the website generated in the R environment. This is because it can be helpful to view the same analysis from somewhat different perspectives. Some of the

exercises for this book involve extensions of the analyses for these examples, so there are plenty of opportunities for practice with real data sets.

## PEDAGOGICAL APPROACH

Something that has not changed in the fifth edition is pedagogical style: I still speak to readers (through my author's voice) as one researcher to another, not as statistician to the quantitatively naïve. For example, the instructional language of statisticians is matrix algebra, which conveys a lot of information in a short amount of space, but readers must already be versed in linear algebra to understand the message. There are other, more advanced works about SEM that emphasize matrix presentations (Bollen, 1989; Kaplan, 2009; Mulaik, 2009b), and these works can be consulted when you are ready. Instead, fundamental concepts about SEM are presented here in the language of applied researchers: words, tabular summaries, and data graphics, not matrix equations. I will not shelter you from some of the more technical aspects of SEM, but I aim to cover fundamental concepts in accessible ways that promote continued learning.

## PRINCIPLES > SOFTWARE

You may be relieved to know that you are not at a disadvantage at present if you have no experience using an SEM computer tool. This is because the coverage of topics in this book is not based on the symbolism, syntax, or user interface associated with a particular software package. In contrast, there are many books linked to specific SEM computer programs. They can be invaluable for users of a particular program, but perhaps less so for others. Instead, key principles of SEM that users of *any* computer tool must understand are emphasized here. In this way, this book is more like a guide to writing style than a handbook about how to use a particular word processor. Besides, becoming proficient with a particular software package is just a matter of practice. But without strong conceptual knowledge, the output from a computer tool for statistical analyses—including SEM—may be meaningless or, even worse, misleading.

## SYMBOLS AND NOTATION

Advanced works on SEM often rely on the symbols and notation associated with the original matrix-based syntax for LISREL, which features a profusion of doubly subscripted lowercase Greek letters for individual model parameters, uppercase Greek letters for matrices of parameters for the whole model, and two-letter acronyms in syntax for matrices. For example, the symbols

$$\lambda_{12}^{(x)}, \Lambda_x, \text{ and } LX$$

refer in LISREL notation to, respectively, a specific loading on an exogenous (explanatory) factor, the parameter matrix of loadings for all such factors, and LISREL syntax that designates the matrix (Lambda-X). Although I use here and there some symbols from LISREL notation, I do not oblige readers to memorize LISREL notation to get something out of the book. This is appropriate because LISREL symbolism can be confusing unless one has learned the whole system by rote.

## ENJOY THE RIDE

Learning a new set of statistical techniques is not everyone's idea of fun. (If doing so is fun for you, that's okay, I understand and agree.) But I hope the combination of accessible language that respects your intelligence, examples of SEM analyses in various disciplines, free access to background tutorials (i.e., the primers) and computer files for detailed examples, and the occasional bit of sage advice offered in this book will help to make the experience a little easier, perhaps even enjoyable. It might also help to think of this book as a kind of travel guide about language and customs, what to know and pitfalls to avoid, and what lies just over the horizon in SEM land.

## PLAN OF THE BOOK

Part I introduces fundamental concepts, reporting standards, preparation of the data, and computer tools. Chapter 1 lays out both the promise of SEM and widespread problems in its application. Concepts in regression, significance testing, and psychometrics that are especially relevant for SEM are reviewed in Chapter 2, which also include the self-test in these areas. Basic

steps in SEM and reporting standards are introduced in Chapter 3 along with an example from a recent empirical study. How to prepare the data for analysis in SEM and options for dealing with common problems, including missing data, are covered in Chapter 4, and computer tools for SEM, both commercial and free, are described in Chapter 5.

Part II deals with the fundamentals of hypothesis testing in SEM for classical path models, which in the analysis phase feature a single observed measure for each theoretical variable, also called single-indicator measurement. It begins in Chapter 6, which introduces nonparametric SEM as described by Judea Pearl (i.e., the SCM). The SCM is graphical in nature; specifically, causal hypotheses are represented as directed graphs where theoretical variables are depicted with no commitment to any distributional assumptions or specific operational definitions for any variable. Graphs in nonparametric SEM can be analyzed by special computer tools *without* data. This capability allows researchers to test their *ideas* before collecting the data. For example, the analysis of a directed graph may indicate that a particular causal effect cannot be estimated unless additional variables are measured. After the data are collected, it is a parametric model that is typically analyzed, and such models and their assumptions are described in Chapter 7. The technique of piecewise SEM, which connects the two perspectives, nonparametric and parametric, through novel techniques for analyzing path models, is covered in Chapter 8.

Chapters 9–12 are perhaps the most important ones in the book. They concern how to test hypotheses and evaluate models in complete and transparent ways that respect both reporting standards for SEM and best practices. These presentations are intended as counterexamples to widespread dubious practices that plague many, if not most, published SEM studies. That is, the state of SEM practice is generally poor, and one of my goals is to help readers distinguish their work above this din of mediocrity. Accordingly, Chapter 9 outlines methods for simultaneous estimation of parameters in structural equations models and explains how to analyze means along with covariances. Chapter 10 deals with the critical issue of how to properly assess model fit after estimates of its parameters are in hand. A critical point is that model fit should be routinely adjudged from at least two perspectives: global or overall fit, and local fit at the level of residuals, which in SEM concerns differences between sample and predicted asso-

ciations for each pair of measured variables. Chapters 11–12 extend these ideas to, respectively, the comparison of alternative models all fit to the same data and the simultaneous analysis of a model over data from multiple groups, also called multiple-group SEM.

Part III deals with the analysis of models where at least some theoretical concepts are approximated with multiple observed variables, or multiple-indicator measurement. Such models are often referred to as “latent variable models,” but for reasons explained in Chapter 13, our models include only proxies for latent variables, not latent variables themselves. These proxies are of two general types: common factors based on reflective measurement models and composites based on formative measurement models. The analysis of pure reflective measurement models in the technique of confirmatory factor analysis (CFA) is described in Chapter 14, and Chapter 15 deals with the analysis of structural regression (SR) models—also called latent variable path models—where causal effects between observed variables or common factors are estimated. Chapter 16 is about composite SEM, which analyzes causal models with multiple-indicator measurement based on formative, not reflective, measurement and where proxies for conceptual variables are composites, not common factors. Application of the technique of confirmatory composite analysis (CCA), the composite analog to CFA, is demonstrated.

Part IV is about advanced techniques. How to deal with SEM analyses in small samples is addressed in Chapter 17, and Chapter 18 concerns the analysis of categorical data in CFA. Chapter 19 explains how to analyze nonrecursive models with causal loops that involve two or more endogenous (outcome) variables assumed to influence each other, and Chapter 20 surveys recent developments that enhance, improve, and extend ways to assess hypotheses of causal mediation, or indirect causal effects that involve at least one intervening variable. The state of mediation analysis in the literature is problematic, but some of the newer approaches and methods described in this chapter seem promising. The analysis of latent growth models for longitudinal data is the subject of Chapter 21, and the application of multiple-group CFA to test hypotheses of measurement invariance is dealt with in Chapter 22. The capstone of the book is the summary of best practices in SEM in Chapter 23. Also mentioned in this chapter are common mistakes with the aim of helping you to avoid them.