Structural Equation Modeling Texts: A Primer for the Beginner

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Many multivariate statistical techniques that previously appeared prohibitive to the applied researcher are now becoming increasingly accessible given the advances and user-friendly nature of the graphic interfaces associated with many software applications. Structural equation modeling (SEM) is one such technique that has seen an exponential growth in its development and usage. However, up to a decade ago, most of the texts devoted to SEM were relatively complex, with a sound foundation in matrix algebra necessitated. However, there has been a spate of introductory texts that have inundated the marketplace recently, each with their own emphasis (e.g., type of software) and philosophy. The purpose of this article is to provide a comprehensive review of the various introductory texts, some of which are software specific and some that are more general. Also, for those who have gained more than a cursory familiarity with SEM, a brief review of more advanced text is provided.

Many researchers know that with the advent of user-friendly software even the most complex statistical analysis is made accessible. Whereby many neophytes find the syntax and programming code associated with many of the popular statistical packages (e.g., SPSS, SAS, and so on) to be overwhelming, Windows-based, point-and-click packages have smudged many of these user concerns. Even though a grasp of the syntax or code of any package is still necessary to maximize the full capacity of the statistical package, it is unequivocal that computer analysis is now much more accessible to the casual user. An example of such is SEM.

In a nutshell, SEM “is a statistical methodology that takes a confirmatory (i.e., hypothesis-testing) approach to the multivariate analysis of a structural theory bearing on some phenomenon” (Byrne, 1999). Thus, its roots germinate from the schools of factor analysis, regression analysis, and path analysis (see Bolles, 1989, and Kaplan, 2000, for a brief historical treatment of the development of SEM). A technique that up to a decade ago was still relatively arcane to many researchers has now flourished in its use and applicability in a wide array of fields and disciplines (Hayduk, 1996).

Concomitant with this growth in the use of SEM, in addition to software development, has been the influx of introductory texts. As pointed out in prior SEM text reviews (Glaser, 2000, 2001, 2002), up until 1995 there was a paucity of SEM texts that were readily accessible to the fledgling SEM user. Many of us used Bolles (1989) and Hayduk (1987) as our primary reference points, and they still stand as seminal readings in this domain. However, as texts for the newly applied user, or as part of a multivariate graduate course, those books may initially be a bit imposing. To capitalize on this gap, there has been a spate of introductory texts in the last 7 years, each with their own emphasis and idiosyncrasies. Thus, this review serves to point the reader to an introductory text that may best suit his or her needs. Even though toward the end of this review I offer some references that are more advanced, or specialized, in nature, the assumption is that the reader will be newly exposed to this exciting and rapidly developing analytical domain. Moreover, the reviews are primarily overviews; hence, more detailed (and critical) reviews can be found in the journal solely devoted to SEM: Structural Equation Modeling: A Multidisciplinary Journal. For ease of referencing, each section starts off with the titles to be reviewed.

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The Classics


Even though there are texts that well predicate the emerging popularity of SEM (e.g., Duncan, 1975), two texts were the primary references for introducing SEM, that is, those by Bollen (1989) and Hayduk (1987). Both of these texts still pass the litmus test in regard to their continued relevance and range of subject matter. The treatment of pertinent issues such as model identification and estimation in Bollen’s text is virtually without peer, whereas Hayduk’s text, though more oriented to LISREL users, has an impressive grasp on models that are of much current interest, such as mean structures and multivariate modeling. However, unless the reader has some facility with matrix algebra and is relatively comfortable with intermediate statistics, the texts may be a formidable read. Thus, even though these texts are frequently cited in others’ research endeavors, they may not be the best recommendation for the SEM neophyte. However, it is my opinion that, once the researcher has mastered the introductory rudiments of SEM, both of those texts are worthy collections. It is also recommended that as an extension of Hayduk’s 1987 text, the interested reader pursue Hayduk’s 1996 text titled LISREL: Issues, Debates, and Strategies, a follow-up companion piece that addresses such issues as model equivalence, hoops, stacked models, and modeling strategy.

Introductory Texts: Non-Software Specific


The texts reviewed in this section, though providing examples of software code (e.g., LISREL, EQS), are not wholly devoted, nor inclined, to the use of a particular type of software. One of the forerunners was John C. Loehlin’s Latent Variable Models: An Introduction to Factor, Path and Structural Analysis. Now in its third edition (1998; the first edition was published in 1987 and the second edition in 1992), this text was unique in its characterization of path models and active use of path diagrams. Thus, for the graphically inclined (i.e., those who can follow the flowcharts and the attendant notation), Loehlin appears most accessible. However, for some readers, this same approach may seem off-putting. There are only seven chapters in the text, though, so if you can make the commitment, it may be beneficial to segment the chapters accordingly. At the time of writing, the various manaces that capture the mathematics of SEM were based on LISREL (with the attendant eight matrices); however, Loehlin uses the more economical McArdle-McDonald equation, which is essentially reduced to three matrices. Many examples of uses of SEM in the literature are summarized in this text, with the various fit measures and ten-dexes reviewed. One other facet of this book that is most appealing is the Notes section appended at the end of each chapter. Not only are references provided, but this section also serves as a glossary of sorts, defining various terms and techniques. This text basically covers variations on path and structural models and includes two full chapters on exploratory factor analysis (EFA) and a final chapter with assorted odd and ends (e.g., multivariate path models, nonlinear modeling, and so on). Thus, if the reader is already versed in EFA, the amount of attention paid to this topic may seem’s bit disproportionate. However, given the seminal importance of EFA as a latent variable technique, and the parallels that can be drawn between EFA and SEM, the reader may have much to gain by these two chapters. Schumacker and Lomax’s 1996 text A Beginner’s Guide to Structural Equation Modeling was the first text in the marketplace devoted to SEM that was indeed aptly titled for the neophyte. It is simple in its prose, clearly written, and very much a non-technical treatment for a relatively complex mathematical endeavor. Because it is truly aimed at an introductory audience, certain subjects are treated in an all too terse fashion (e.g., missing data, statistical assumptions); thus, this book serves as a springboard for more advanced texts that are more comprehensive in the coverage of those various topics. This text relies on two software packages for the bulk of examples: LISREL and EQS. Just prior to the text, LISREL syntax was relatively formidable, requiring a fundamental understanding of the various manaces (e.g., θ, δ, β). However, an accompanying language was created for this program called SIMPLS, which in line of code such as “Free: LX (1,2)” could be replaced with the actual names of the variables: “JobSat = JobPer.” Thus, both of these languages are covered in the examples that are literally provided in this text. Interestingly, and what shows the development of SEM in the years since, some of the topics covered in the “advanced” chapter such as multivariate SEM, are fairly routine nowadays. More-
over, quite a few new fit indices have come up since the publication of this text; thus an updated edition is definitely warranted. I have used this text as part of a multivariate class, of which I had approximately 4 weeks devoted to SEM. I found this text to be easily consumed within that relatively constrained time period. As mentioned earlier, though, I opine that certain key topics are given too economical of a treatment, overall the introductory reader will find much to gain by this text.

Rex Kline’s 1998 text Principles and Practice of Structural Equation Modeling is one of the few texts that are truly agnostic in its presentation of SEM; that is, not based on any specific software application. In fact, in his introductory chapter, Kline assures the reader that advanced quantitative skills will not be needed for this text, even though a background in elementary statistics (e.g., correlation) will be fruitful. An egalitarian approach is employed in the notation and just does not favor any one particular software (e.g., Greek subscripts for LISREL). A very rudimentary treatment of statistics is covered in the chapter titled “Basic Statistical Concepts,” including correlation, regression parameters, and so on. As reviewed in a more detailed summary (Chase, 2000), the reader will especially find much to gain from the chapter on “Data Preparation and Screening,” which includes sections on missing data, data screening, multivariate normality, and other required assumptions. The reader is already versed in assumptions associated with regression and multivariate analysis, this will serve as a pitly review.

There is a substantive treatment of path analysis and, what I think, initially, a too-prolonged treatment on nonrecursive models (i.e., y → y and y → y). My initial reasoning was that given the known problems of model identification with nonrecursive paths (nonrecursive models are those that include paths in which, in the simplest case, two variables serve as both “cause” and “effect” on each other), there is a paucity of these models tested in the scientific literature. However, on a second perusal of this text, issues that are brought up in this chapter, such as order and rank conditions, identification, and so on, are not unique only to nonrecursive models.

Chapter 9 (“How to Fool Yourself With SEM”) provides for the introductory student a much relied-on checklist of pitfalls, cautions, and so’s and don’ts. This set of guidelines is demarcated by four major topics: specification (e.g., fail to have sufficient numbers of indicators of latent variables, add disturbance, or measure error correlations without substantive reason); data (e.g., fail to examine distributional characteristics, assume that all relations are linear without checking); analysis and specification (e.g., respect a model based entirely on statistical criteria, estimate a very complex model with a small sample); and interpretation (e.g., interpret good fit as meaning that the model is proved, fail to consider [nonequivalent] alternative models). This is a brief not worthwhile chapter for the introductory student, though Kline provides many modeling guidelines throughout the text, as with many principles in statistics, there are also many shades of gray in the assessment and testing of model fit. Overall, the text is sufficiently comprehensive in that it could serve as the primary text for a semester course, and, at the same time, if the presentation of SEM is part of a multivariate course, the instructors instructor could select excerpts that provide a suitable foundation. Furthermore, even without the benefit of an academic environment, the book is written clearly enough that the interested reader could readily absorb the material on his or her own initiative.

Another text that is not software-specific is Basics of Structural Equation Modeling (1998) by Geoffrey M. Maruyama. For a more in-depth review of this text, see Boomsma (2000a). As a summary, I agree with Boomsma’s synopsis that this text would be of limited utility if the reader already had some exposure to SEM. However, as a starting point, keeping in mind that this text is devoid of the technical issues that are the heart and soul of SEM, this book may suffice. The title of the leading chapter “What Does It Mean to Model Hypothesized Causal Processes With Non-experimental Data?” is intriguing, but as modelers are aware of, assigning causation, even with the most sophisticated statistical techniques, is problematic. A nice historical review of the precursors to SEM is offered with a very generous rendering of path analysis following.

Where this book deviates from many of the other SEM texts is the coverage of collinearity and random/nonnormal error, each afforded as individual chapter. Though this text intentionally minimizes the statistical details of SEM, I am also not convinced that the attention allocated to subjects such as ridge regression (which is used to stabilize the regression solution when predictors are highly related, generally by adding a constant), are wholly necessary. After a relatively lengthy treatment of recursive and longitudinal models and factor analysis, latent variable SEM is brought to the fore in chapter 8. It is in this chapter that the reader is introduced to the LISREL notation and the accompanying matrix, though without the algebraic derivation. The author differentiates the measurement model (i.e., relation of manifest indicators with latent constructs) from the structural model (i.e., relation of the exogenous and endogenous constructs), although it might benefit the reader to accept a special issue of Structural Equation Modeling: A Multidisciplinary Journal, 2000, volume 7, issue 1) that primarily focuses on the multistep process of model testing and assessment.

Real-life examples of various models comprise the next chapter titled “Using Latent Variables SEM to Examine Pianalysis of Models,” including a longitudinal
model with multiple indicators. The reader may find this chapter helpful not only in its detailed orientation toward application, but also the appendix that provides the syntax for LISREL, AMOS, and EQS for model testing. The next chapter is devoted to the analysis of change fit, which can prove to be a rather formidable task for the fledgling user, given there are over 50 indices at the SEM statistician's disposal. The different clusters of fit indices are compared (absolute vs. relative vs. adjusted) and interpreted.

The final chapters cover variations of the basic linear structural model and their useful summation of various points that may be germane to the modeling process but not covered in this text (e.g., types of estimators, non-continuous variables, nonlinear models). There is no need to recommend for Maruyama's (1997) text, though various authors are given short (no-conventional models, type of estimator) that do yield some import in the modeling enterprise, whereas others are given more attention than warranted in an introductory text (e.g., collinearity).

Rayment and Marcusfield's A First Course in Structural Equation Modeling (2000), which is extensively reviewed in Gleser (2001), is probably one of the briefest and more concise of the SEM introductory texts. Even though each of the chapters provides examples of LISREL and EQS syntax and output (which, according to the authors, are the more widely circulated software), the text still covers topics in sufficient generality to be applicable to any software user or introductory reader. Some of the more technical details (e.g., the non-emotional reliance on the all-y model) may perplex some of the fledgling readers, but for the most part the text is aimed at the reader desiring a concise and relatively nontechnical primer. Generous examples of path analysis, confirmatory factor analysis, and structural models are provided. However, even though some of the sections are bit terse, and some nonexistent (e.g., recursive models), some readers may view as excessive the fact that one fourth of the length of the text is devoted to latent change analysis. Even though this type of analysis is becoming increasingly more popular (this is briefly touched on in the "Special Topics section"). the authors could probably have devoted a full chapter to special topics and included latent change analysis as an ancillary topic. As I commented in my more detailed review, the most likely usage of this text will be within the context of a multimedia course, where 2 to 3 weeks are dedicated to SEM. The relative brevity of this book would render it appropriate for such a course.

Introductory Texts: Software Specific

cates a relatively brief, but sufficiently comprehensive, treatment of the different types and classes of indexes (e.g., absolute fit indexes, incremental fit indexes, inflation-theoretic indexes, and so on) that are unique to each program (though there is tremendous overlap).

The following section in each of the texts covers multivariate group analyses. Whereas multiple group analyses may have several derivations in the initial stages of SEM, it is now a frequently used analysis, especially when testing the invariance of factorial structures across groups. This holds tremendous application to the researcher may be interested in assessing the invariance of an assessment tool across populations of interest (e.g., does the factorial structure of a child depression inventory remain consistent across boys and girls?). The chapter on testing latent mean structure further indicates the level of complexity the researcher can pursue in model testing. For a comprehensive summary of the developments in the invariance domain, the reader is encouraged to peruse Vandenberg and Lance (2000).

Each of the texts finishes off with topics that, though germane to any SEM user, have specific applicability to the software at hand. For instance, the AMOS text has chapters on bootstrapping and dealing with incomplete data. There have been tremendous strides made in the employment of missing data techniques, and AMOS was the first of the SEM software packages to use maximum likelihood approaches to missing data (though the most recent version of LISREL [8.50] now incorporates a likelihood approach to missing data). For a nice primer on maximum likelihood approaches to missing data, see Enders (2001). Overall, the Byrne texts are very accessible and serve as excellent supplements to the manual provided with each of the software. However, readers will notice that certain topics are omitted, such as latent change analysis and nonrecursive modeling, thus they will need to refer to Little (1998) or Ragin and Marcoulides (2000) for a more accelerated treatment of those topical areas.

Two other brief texts solely devoted to LISREL that the reader may be interested in are Introduction to LISREL (Diamantopoulos & Sigauw, 2000) and Using LISREL for Structural Equation Modeling (Kelloway, 1998). Whereas Diamantopoulos and Sigauw focus on the more accessible SIMPLIS language, Kelloway text model fit via the more complex LISREL language, which uses Greek notation liberally. Even though these two texts provide a preliminary introduction to LISREL, they are limited to the initial stages of learning SEM, they are relatively underemphasized compared to the other texts.

More Advanced Texts and Special Topics


The burgeoning interest, and use, of SEM is made manifest not just by the spate of introductory texts but also issues of journals and tests devoted to more advanced topics in SEM. Two earlier edited texts by Hoyle (1995) and Bollen and Long (1993) covered topics as wide ranging as nonnormality, statistical power, categorical variables, and evaluating model fit. However, though they deal with topics in more detail than the introductory texts, they are relatively non-technical and thus readily accessible to users who have absorbed the rudimentary concepts of SEM. Even though there have been major strides in many of the domains covered in these texts since the date of publication, many SEM authors still refer to them. However, as more advanced companion pieces, the reader may want to delve into the two edited texts by Marcoulides and Schumacker: Advanced Structural Equation Modeling: Issues and Techniques (1996) and New Developments and Techniques in Structural Equation Modeling (2001). Topics ranging from structural time series, multilevel models, mixture modeling, and specification searches are reviewed, with the mathematical detail not particularly overwhelming.

Interestingly, what were advanced topics in 1996 are now so sufficiently accessible that entire books are devoted to these topics. Hierarchical, and extreme (e.g., from the initial stages of hierarchical linear modeling (see Bryk & Raudenbush, 1992) multilevel modeling has been incorporated in SEM packages. For recent examples, see Moskowitz and Hersberger (2000). Moreover, longitudinal modeling has seen

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such an upwurge of interest (probably based in part on the software access) that an entire text has covered SEM approaches to latent variable growth curve modeling (Duncan, Duncan, Strycker, Li, & Alpert, 1999). There are also two excellent texts from the American Psychological Association that cover, in more advanced detail, analysis of change (Collins & Horn, 1991; Collins & Sayer, 2001), though not exclusively employing SEM techniques.

What may have seemed intractable more than a decade ago is now virtually absorbed in the mainstream, as illustrated by a text that focuses exclusively on interaction and nonlinear SEM (Schumacker & Maccoulides, 1998), Kaplan (2000) also authored an excellent introductory text on SEM that takes an econometric perspective (see Glasser, 2002, for a detailed review). However, this book is more akin to Bollen’s 1989 text and thus may be arduous reading for the neophyte modeler.

With some optimism that SEM literally subsumes the widest swath of statistical models (i.e., the broadest general linear model), the developments and progress that are made in this area almost seem limitless. As I was writing this review, I was furnished a new text to review edited by Maccoulides and Mountakai titled Latent Variable and Latent Structure Models (2002), which again indicates the stunning strides made in this field and includes chapters on multilevel factor analysis, modeling measurement errors, semiparametric models, and confidence regions in SEM models.

References


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