BOOK COMMENTARY

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 less than 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 texts is provided.

Many researchers know that with the advent of user-friendly software even the most complex statistical analysis is made accessible. Whereas 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 ameliorated many of those 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 complex 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, 1998). Thus, its roots germinate from the schools of factor analysis, regression analysis, and path analysis (see Bollen, 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 Bollen (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.

The Classics

Bollen, K. (1989). *Structural equations with latent variables.*

Hayduk, L. A. (1987). *Structural equation modeling with LISREL: Essentials and advances.*

Hayduk, L. A. (1996). *LISREL: Issues, debates, and strategies.*

Even though there are texts that well predate 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 multisample 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 peruse Hayduk's 1996 text titled *LISREL: Issues, Debates, and Strategies*, a follow-up companion piece that addresses such issues as model equivalence, loops, stacked models, and modeling strategy.

Introductory Texts:
Non-Software Specific

Kline, R. B. (1998). *Principles and practice of structural equation modeling.*

Loehlin, J. C. (1998). *Latent variable models.*

Maruyama, G. M. (1997). *Basics of structural equation modeling.*

Raykov, T., & Marcoulides, G. A. (2000). *A first course in structural equation modeling.*

Schumacker, R. E., & Lomax, R. G. (1996). *A beginner's guide to structural equation modeling.*

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 closely the logic of 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, thus, if used in a graduate class, it may be beneficial to segment the chapters accordingly. At the time of writing, the various matrices that capture the mathematics in SEM were based on LISREL (with its 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 indexes 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 a 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.

Schumacher 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 appropriate for the neophyte. It is simple in its prose, clearly written, and very much a nontechnical 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 matrices (e.g., θ, ψ, β). However, an accompanying language was created for this program called SIMPLIS, which in lieu of code such as "Free: LX (1,2)" could be replaced with the actual names of the variables: "Jobsat = Jobperf." Thus, both of these languages are covered in the examples that are liberally 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 multisampling SEM, are fairly routine nowadays. More-

over, quite a few new fit indexes 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 thus 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 (Glaser, 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 requisite assumptions. If the reader is already versed in assumptions associated with regression and multivariate analysis, this will serve as a pithy review.

There is a substantive treatment on path analysis and, what I thought, initially, a too-prolonged treatment on nonrecursive models (i.e., $x \rightarrow y$ and $y \rightarrow x$). 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 do'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 measurement error correlations without substantive reason); data (e.g., fail to examine distributional characteristics, assume that all relations are linear without checking); analysis and respecification (e.g., respecify 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 but worthwhile chapter for the introductory student, and 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 judicious 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 can 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 has 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 Nonexperimental Data?" is intriguing, but as most modelers are aware of, ascribing 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/nonrandom error, each afforded an 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 matrices, though without the algebraic derivations. 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 access 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 Variable SEM to Examine Plausibility 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 delves into assessing model fit, which can prove to be a rather formidable task for the fledgling user, given there are well over 30 indexes at this point of SEM development. The different clusters of fit indexes are compared (absolute vs. relative vs. adjusted) and interpreted.

The final chapters cover variations of the basic latent variable model and then a final summation of various points that may be germane to the modeling process but were not covered in this text (e.g., types of estimators, non-continuous variables, nonlinear models). There is much to recommend for Maruyama's (1997) text, though various subjects are given short thrift (nonconventional models, type of estimators) that do yield some import in the modeling enterprise, whereas others are given more attention than warranted in an introductory text (e.g., collinearity).

Raykov and Marcoulides' *A First Course in Structural Equation Modeling* (2000), which is extensively reviewed in Glaser (2001), is probably one of the briefer 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 generalities to be applicable to any software user or introductory reader. Some of the more technical details (e.g., the nonconventional 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 a bit terse, and some nonexistent (e.g., nonrecursive 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 final chapter to special trends and 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 would be within the context of a multivariate 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

Byrne, B. (1994). *Structural equation modeling with EQS and EQS/Windows.*

Byrne, B. (1998). *Structural equation modeling with LISREL, PRELIS, and SIMPLIS.*

Byrne, B. (2001). *Structural equation modeling with AMOS.*

Diamantopoulos, A., & Siguaw, J. (2000). *Introducing LISREL.*

Kelloway, E. K. (1998). *Using LISREL for structural equation modeling.*

Barbara Byrne has furnished texts on the three leading softwares (EQS [1994], LISREL [1998], and AMOS [2001]) that literally take the researcher, step by step, through the model-testing process. The texts do seem to reflect the development of the software environment, insofar as the first text emphasizes the use of syntax (i.e., program code unique to EQS) in model testing, with a cursory treatment of the Windows environment in the final three chapters. Conversely, the most recent text covering AMOS illustrates the dramatic progress made in testing models in a graphic/Windows environment. In addition, the texts mirror the extensive research (and Monte Carlo studies) that has gone into examining the myriad of fit indexes that have rapidly multiplied in the last 15 years.

All of the texts follow essentially the same format. Rudimentary aspects of SEM are briefly reviewed, with a more focused discussion on the mathematical model that is unique to each software (e.g., Bentler–Weeks model for EQS, LISREL model by Jöreskog & Sörbom). The following chapter then specifically zeroes in on the software itself. Readers will notice a more concentrated emphasis on the syntax for EQS and LISREL, whereas though AMOS has a programming interface (i.e., AMOS Basic), the primary overview is associated with AMOS Graphics (which many modelers find extremely user friendly). Both EQS and LISREL texts have a similar structure for the section titled Single-Group Analyses, with the chapters detailing first- and second-order confirmatory factor models, testing for construct validity (i.e., multitrait–multimethod model) and a chapter titled "Testing the Validity of a Causal Structure." The AMOS text slightly deviates with the omission of the construct validity chapter. Chapter 3 ("Testing for the Factorial Validity of a Theoretical Construct"), in each of the texts, provides a very accessible overview of how to assess model fit. Whereas older versions of LISREL consisted of just a handful of indexes to examine model fit (e.g., Goodness-of-Fit Index, Adjusted Goodness-of-Fit Index, χ^2), there are probably more than 30 indexes to select from in current versions of the SEM software packages. Hence, given what may seem to be a bewildering choice of fit indexes for the fledgling SEM researcher, readers may find Boomsma (2000b) and Hoyle and Panter (1995) to be most helpful references in determining (and reporting) model fit. Byrne allo-

cates a relatively brief, but sufficiently comprehensive, treatment of the different types and classes of indexes (e.g., absolute fit indexes, incremental fit indexes, information-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 multiple group analyses. Whereas multiple group analyses may have seemed formidable 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 who 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 structures 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 one of the first SEM applications that used 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 Kline (1998) or Raykov 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 *Introducing LISREL* (Diamantopoulos & Siguaw, 2000) and *Using LISREL for Structural Equation Modeling* (Kelloway, 1998). Whereas Diamantopoulos and Siguaw focus on the more accessible SIMPLIS language, Kelloway tests model fit via the more complex LISREL language, which uses Greek notation liberally. Even though these two texts provide a preliminary introduction to LISREL that may suffice in the initial stages of learning SEM, they are relatively undernourished compared to the other texts.

More Advanced Texts and Special Topics

Bollen, K. A., & Long, J. S. (1993). (Eds.). *Testing structural equation models.*

Collins, L. M., & Horn, J. L. (Eds.). (1991). *Best methods for the analysis of change.*

Collins, L. M., & Sayer, A. (Eds.). (2001). *New methods for the analysis of change.*

Duncan, T., Duncan, S. C., Strycker, L. A., Li, F., & Alpert, A. (1999). *An introduction to latent variable growth curve modeling.*

Hoyle, R. H. (1995). (Ed.). *Structural equation modeling: Concepts, issues, and applications.*

Kaplan, D. (2000). *Structural equation modeling: Foundations and extensions.*

Marcoulides, G. A., & Schumacker, R. E. (Eds.). (1996). *Advanced structural equation modeling: Issues and techniques.*

Marcoulides, G. A., & Schumacker, R. E. (Eds.). (2001). *New developments and techniques in structural equation modeling.*

Moskowitz, D. S., & Hershberger, S. L. (Eds.). (2002). *Modeling intraindividual variability with repeated measures data.*

Schumacker, R. E., & Marcoulides, G. A. (Eds.). (1998). *Interaction and nonlinear effects in structural equation modeling.*

The burgeoning interest, and use, of SEM is made manifest not just by the spate of introductory texts but also issues of journals and texts 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 nontechnical 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 reference them. However, as a more advanced companion piece, 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 those, hitherto, arcane domains. For instance, 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 Hershberger (2002). Moreover, longitudinal modeling has seen

such an upsurge 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 now is virtually absorbed in the mainstream, as illustrated by a text that focuses exclusively on interaction and nonlinear SEM (Schumacker & Marcoulides, 1998). Kaplan (2000) also authored an excellent introductory test on SEM that takes an econometric perspective (see Glaser, 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 opining 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 Marcoulides and Moustaki 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 error, semiparametric models, and confidence regions in SEM models.

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