STRUCTURAL EQUATION MODELING, 6(1), 127–133

REVIEW SECTION

Multivariate Statistical Methods: A First Course. George A. Marcoulides and Scott L. Hershberger. Mahwah, NJ: Lawrence Erlbaum Associates, Inc., 1997, 322 pages, $89.95 (cloth), $39.95 (paper).

Reviewed by Dale Glaser
Sharp HealthCare and San Diego State University

Given the prevalence of personal computer environments, and especially with the advent of Windows applications, statistical techniques that were once relatively formidable in both their calculations and interpretation have become accessible to the average user. Such techniques include multivariate operations such as multivariate analysis of variance (MANOVA), discriminant analysis, principal components analysis, and factor analysis. There is a big difference between hand-calculating a one-way analysis of variance (ANOVA) as opposed to a MANOVA, the latter requiring some facility with matrix algebra. Thus, one obvious advantage of Windows-based multivariate statistical packages is the dramatic reduction in time spent performing what may be considered the onerous task of matrix inversion, calculations of determinants, and so on. However, one key disadvantage is that given the accessibility and user-friendliness of the recent statistical packages, one can perform any of the optional multivariate techniques with little or no knowledge of the underlying mathematical or conceptual principles. For instance, a repeated measures MANOVA printout can be relatively complex: What does violation of sphericity imply? Should one interpret the multivariate or averaged univariate results? Thus, even though recent texts such as *Reading and Understanding Multivariate Statistics* (Grimm & Yarnold, 1995) do a serviceable job of providing a nontechnical introduction to multivariate techniques, such texts should not be used as stand-alone texts if multivariate analysis will be required of the researcher or student. As instructors of multivariate statistics will attest, there are quite a few multivariate texts in the marketplace, all of varying complexities and biases. Especially within the social sciences, the more mathematically inclined textbooks may be cumbersome; thus, the objective of any multivariate text should be the right blending of concept and math. The new text by Marcoulides and Hershberger does a nice job of accomplishing that goal.

Requests for reprints should be sent to Dale Glaser, Sharp HealthCare, Clinical Outcomes Research, 3131 Berger Avenue, San Diego, CA 92123.

As most purveyors of applied multivariate texts will attest, there is a heavy reliance on computer output. In fact, it is not unusual for some of the texts to present results from two to three separate software applications. However, in Marcoulides and Hershberger's text, as summarized in their introduction, they solely rely on SAS when juxtaposing the technique of interest with the accompanying output. For the most part, and as the authors indicate, the "capabilities and flavors" of these applications are sufficiently similar that only SAS, being a relatively popular package, prevailed as the application of choice for this text. One obvious drawback with this is that many social scientists are SPSS users; thus, the syntax associated with each of the techniques may not prove to be readily accessible.

Chapter 2 provides a basic summary of matrix algebra, which obviously serves as the foundation for the mathematics behind multivariate techniques. Addition, subtraction, inversion, and the calculation of the determinant are all reviewed. For this type of text, it is always a judgment call about how in-depth the review of matrix algebra should be. For the most part, the authors do this subject area justice, with a nice review of eigenvalues and eigenvectors.

Chapter 3 (The Multivariate Normal Distribution and Tests of Significance) commences with a very nice review of the univariate standard normal distribution. This is imperative, as many of the multivariate tests (e.g., MANOVA) include in their printouts univariate tests. A brief review of the t statistic and F distribution, and what I found most appealing, the relations of those statistics and distributions to the χ^2 distribution is covered nicely in this chapter. It is not unusual for graduate education, prior to multivariate statistics, to emphasize the t and F distributions, but then comes a significant gap in a fundamental understanding of the χ^2 distribution. This creates a problem, especially when subjects such as log-linear modeling and structural equation modeling (SEM) come up for discussion. However, there is one section in this chapter that struck me more than any other: a discussion regarding the multivariate normal distribution. Multivariate normality is usually regarded in the context of any attendant bivariate violations, but rarely have I found that the nonmathematically oriented multivariate texts provide a sufficient discussion of this distribution. In this instance, the authors do a very serviceable job of discussing the multivariate distribution and multivariate normality within a MANOVA framework. The treatment of MANOVA itself is relatively brief in this chapter, as the primary focus is on the multivariate distribution.

The subsequent chapter covers factorial MANOVA. As a prelude to MANOVA, the authors briefly review the univariate two-way ANOVA and the attendant interpretation. Even though the next section, Fixed, Random, and Mixed Factorial Designs, is necessarily brief, the mention of random effects ANOVA is absolutely crucial, especially in light of analyzing the data with the correct F ratio. The following section reviews the Two-Way MANOVA inclusive of interpretation of the determinants that make up Wilks's lambda. The bulk of this chapter re-

volves around an example of M
printout. Whereas SAS users will
find some of the printout to be fore
MANOVA procedure is included
the printout that varies. The auth
glimpse into MANOVA.

The following chapter revie
multivariate techniques, DA is o
niques to instruct, especially wh
levels (I have seen transparencies
tionally, DA is typified as fulfill
thors commence their discussion
the selection and maximizing of
various configurations of coeffic
other texts, the structure coefficie
ally advised as forming the basis
ficients are useful in determin
"agnostic view," encouraging the
pose". This would be parallel to
tion) express on some of the stati
matrices and then base a determ
interpretation of a SAS printout
within a DA framework, the se
viewed. Having some exposure
for comprehending this section,
matics. The four possible types
ear/equal and linear/unequal p
prior probability rules. For mos
section may prove to be relativ
helpful, and will be for applied r
It is not uncommon to have une
the authors do an exemplary job
sizes and strategies that can be
the evaluation of the classificat

The next chapter, Canonica
describing relations that exist b
most of the applied research jo
ploy canonical correlational m
be somewhat deemphasized i
provide a worthwhile compar
tion and regression and a sub
regression. A fundamental fou

volves around an example of MANOVA and the interpretation of the SAS printout. Whereas SAS users will find this to be familiar territory, SPSS users may find some of the printout to be foreign. Even though most of the content in the SAS MANOVA procedure is included in SPSS, it is mainly the format and structure of the printout that varies. The authors do a nice job of providing an introductory glimpse into MANOVA.

The following chapter reviews discriminant analysis (DA). Of all the multivariate techniques, DA is one of the more difficult (i.e., nonintuitive) techniques to instruct, especially when the grouping variable contains three or more levels (I have seen transparencies of territorial mapping cross a few eyes!). Traditionally, DA is typified as fulfilling descriptive and predictive purposes; the authors commence their discussion of DA with a brief algebraic summary detailing the selection and maximizing of the discriminant criterion. Interpretations of the various configurations of coefficient matrices are discussed, and in symmetry with other texts, the structure coefficients (the function/variable correlation) are generally advised as forming the basis for interpretation, whereas the standardized coefficients are useful in determining redundancy. The authors wisely adopt an "agnostic view," encouraging the reader to base their interpretation on "one's purpose". This would be parallel to what other users of DA (and canonical correlation) express on some of the statistic Internet groups: Assess each of the coefficient matrices and then base a determination on all the information. After providing an interpretation of a SAS printout, including a discussion of statistical significance within a DA framework, the second goal of DA (predictive/classification) is reviewed. Having some exposure to Bayesian statistics will definitely be of service for comprehending this section, as classification is a function of probability mathematics. The four possible types of classification rules are then defined: (a) linear/equal and linear/unequal probability rules and (b) quadratic equal/unequal prior probability rules. For most students just being introduced to this subject, this section may prove to be relatively overwhelming. The section that is especially helpful, and will be for applied researchers, is Evaluating Classification Accuracy. It is not uncommon to have unequal sample sizes in the grouping variable, hence the authors do an exemplary job of discussing the implications of disparate sample sizes and strategies that can be employed in determining how this will influence the evaluation of the classification results.

The next chapter, Canonical Correlation, describes a technique that serves in describing relations that exist between two sets of variables. A cursory review of most of the applied research journals will result in a paucity of studies that employ canonical correlational methods. Further, given that this technique seems to be somewhat deemphasized in most graduate studies curriculums, the authors provide a worthwhile comparison of canonical correlation to multiple correlation and regression and a subsequent juxtaposition of discriminant analysis and regression. A fundamental foundation in discriminant analysis definitely renders

the technique of canonical correlation more intelligible given the distinct parallels in interpreting the coefficients (e.g., function in DA, variates in canonical correlation). An example characterizing the relation of organizational characteristic variables and worker psychological characteristic variables is provided with a brief interpretation of the SAS printout. If this text is being used in parallel with SPSS instead of SAS, the MANOVA printout, which is the general command structure to derive the canonical output, can be relatively difficult to interpret. Hence, my experience is that if the students are sufficiently facile, accessing the Cancorr.sps syntax file from SPSS renders the canonical printout to be much more user-friendly than the canonical option in MANOVA. The authors keep this chapter relatively brief, which probably closely parallels the class time generally devoted to this technique.

The subsequent chapter covers two related techniques: Principal Components Analysis (PCA) and Factor Analysis (FA). However, the authors make it clear that a distinction needs to be made between the two techniques: The overarching objective of PCA is to maximize the variance, whereas FA is geared toward explaining common variance. Even though PCA is the extraction procedure by default for some of the popular software applications, the authors emphasize that the decision to employ PCA versus FA should be driven by the researcher's goals.

An appropriately detailed explanation of PCA and its functionality in maximizing the variance is provided; even though the mathematical discussion of PCA can be rather dense for most readers, the authors do a nice job of supplementing the brief matrix algebra with graphical displays of PCA employing the Cartesian coordinate system. The section on principal component loadings is very similar to the section on eigenvectors and eigenvalues in chapter 2, and thus may be somewhat redundant for the more mathematically inclined readers. However, this section is absolutely crucial in grasping the PCA procedure. Given that PCA and FA are part science and part art, the brief discussion regarding retention of components cautions the reader that there is no set algorithm in component retention (e.g., Kaiser vs. scree test). An example of PCA using SAS is then reviewed.

A summary of FA and its distinction from PCA (i.e., discussion of common variance/factors and error variance) is provided. Some texts, even though acknowledging the crucial mathematical differences between PCA and FA, nevertheless admit that generally the resultant interpretation of the two techniques is strikingly similar. However, in this section on FA, the authors point out again the distinct goals associated with each of the techniques. Experienced users of SEM and the attendant use of path models will find the discussion of FA particularly familiar, as this is the approach the authors employ in describing FA. Methods of estimation and then component retention within a FA context are reviewed (i.e., Kaiser, scree test). Once again, users of SEM will find the discussion on the large sample χ^2 test and the ratio of chi-square to degrees of freedom ratio (χ^2/df ratio; keeping in mind that there has been some discussion on SEMNET about the ultimate usefulness of the χ^2/df rati
tion within an FA framework is
under "Loose Ends" (i.e., in the
eates the inappropriateness of r
ample of FA and the accompany
on PCA and FA to be most illun
ers rethinking their reliance on
tion). The only hesitation I hav
with SEM, some of the discuss
may seem a bit arcane.

It is not surprising that the fi
and Structural Equation Modeli
would be expected, given that
does a nice job of summarizing
tory of CFA is illustrated by
equalities, Kelly's pentad criter
section was most edifying, but m

A description of SEM, its rel
to depict CFA and SEM mode
reader. I am especially pleased t
causal analysis, given that "one
tions to reality" (p. 212). This i
mathematical treatment of SEM
of the rationale for this emphasis
eters for the Bentler–Weeks mo
Keesling–Wiley–Jöreskog mod
sufficiently exhaustive review o
summary of the LISREL notatio
ing SAS CALIS.

The CFA section continues w
(EFA) and CFA, delineated via
Problem of Identification" dra
underidentified models in a very
sociated with model identificatio
perplex the introductory reader,
the importance of this issue. A n
PROC CALIS is provided; how
junction with LISREL (or other
be necessary.

There are currently a bewilde
it would be interesting to count h
have been created, probably nur

elligible given the distinct paral-
on in DA, variates in canonical
tion of organizational character-
eristic variables is provided with
is text is being used in parallel
tout, which is the general com-
n be relatively difficult to inter-
tudents are sufficiently facile,
S renders the canonical printout
l option in MANOVA. The au-
bably closely parallels the class

hniques: Principal Components
er, the authors make it clear that
hniques: The overarching objec-
FA is geared toward explaining
action procedure by default for
ors emphasize that the decision
e researcher's goals.
nd its functionality in maximiz-
ematical discussion of PCA can
nice job of supplementing the
employing the Cartesian coor-
t loadings is very similar to the
r 2, and thus may be somewhat
aders. However, this section is
Given that PCA and FA are part
retention of components cau-
nponent retention (e.g., Kaiser
ien reviewed.
A (i.e., discussion of common
Some texts, even though ac-
between PCA and FA, never-
ation of the two techniques is
the authors point out again the
es. Experienced users of SEM
scussion of FA particularly fa-
describing FA. Methods of es-
A context are reviewed (i.e.,
nd the discussion on the large
s of freedom ratio (χ^2/df ratio;
n on SEMNET about the ulti-

mate usefulness of the χ^2/df ratio) to be relatively familiar. The discussion on rotation within an FA framework is particularly edifying, especially given the teaser under "Loose Ends" (i.e., in the previously discussed PCA section), which delineates the inappropriateness of rotation under the PCA extraction strategy. An example of FA and the accompanying SAS printout is provided. I found this chapter on PCA and FA to be most illuminating, and it will have even experienced modelers rethinking their reliance on the generic defaults (i.e., PCA with varimax rotation). The only hesitation I have with this chapter is that for students unfamiliar with SEM, some of the discussion (e.g., Heywood cases, maximum likelihood) may seem a bit arcane.

It is not surprising that the final chapter, Confirmatory Factor Analysis (CFA) and Structural Equation Modeling (SEM), is the lengthiest of all the chapters. As would be expected, given that the authors are seasoned SEM users, this chapter does a nice job of summarizing the primary tenets of CFA and SEM. A brief history of CFA is illustrated by Spearman's well-documented efforts with tetrad equalities, Kelly's pentad criterion, and Jöreskog's seminal contributions. This section was most edifying, but may be a bit complex for the introductory student.

A description of SEM, its relation to path analysis, and the graphical tools used to depict CFA and SEM models provide a nice template for the introductory reader. I am especially pleased the authors forewarned the audience about the term *causal analysis,* given that "one must regard all structural models as approximations to reality" (p. 212). This is a point that cannot be emphasized enough. The mathematical treatment of SEM is conducted via the Bentler–Weeks model. Part of the rationale for this emphasis may be the economy of explanation: four parameters for the Bentler–Weeks model as opposed to nine different parameters for the Keesling–Wiley–Jöreskog model. Because space limitations would preclude a sufficiently exhaustive review of both of the models, the authors provide a general summary of the LISREL notation in Appendix B with a LISREL model output using SAS CALIS.

The CFA section continues with a contrast between exploratory factor analysis (EFA) and CFA, delineated via matrix notation. An exemplary treatment of "The Problem of Identification" draws out the differences between just-, over-, and underidentified models in a very concise and cogent fashion. The complexities associated with model identification are summarized in sufficient depth so as not to perplex the introductory reader, but covers enough material that amply evidences the importance of this issue. A numerical CFA example, with interpretation using PROC CALIS is provided; however, if the multivariate class is instructed in conjunction with LISREL (or other SEM software) alternative texts will most likely be necessary.

There are currently a bewildering number of indexes to assess model fit (in fact, it would be interesting to count how many indexes across all software applications have been created, probably numbering more than 40 by now), so it is to the au-

thors' credit that they give just the right amount of information about tests of significance, descriptive indexes, and information indexes without unduly saturating the reader. I found the discussion of model modification appropriate for the audience, but the authors could have been even more emphatic about basing modification on substantive empirical and theoretical grounding. For the fledgling modeler, it is very seductive to reestimate the model based on data-driven decisions; this point can never be overemphasized.

It is my opinion that Marcoulides and Hershberger have expertly summarized the complexities associated with multivariate statistics in a fashion that will be readily coherent to the introductory graduate student (obvious caveat: solid grounding in General Linear Model would be advantageous). They provide the right amount of mathematics so as not to overwhelm the introductory student, but just enough to whet their appetite. Even though the intended audience of this text is "advanced undergraduate and graduate business students," there is nothing that would preclude this text being required for other disciplines, especially psychology. However, most of the examples are management oriented; hence, it will be incumbent that the instructor tailor the examples to be commensurate with the audience.

If this were indeed geared for an advanced undergraduate audience, then as a stand-alone text this book will suffice. At the graduate level, contingent on the research orientation of the discipline, it may need to be supplemented by other texts such as those by Tabachnick and Fidell (1996) or Stevens (1996). (To some extent the authors may have prognosticated this as indicated in the subtitle of their text: "A First Course.") Both of those texts somewhat parallel the structure of Marcoulides and Hershberger, but with more detail, which will ultimately be necessary for the active researcher. Further, chapters on repeated measures, analysis of covariance, logistic regression, and log-linear modeling (the latter being somewhat problematic to fit in within a one-semester course) in the aforementioned texts will provide the full breadth of multivariate statistics. For the more mathematically oriented multivariate courses, Johnson and Wichern's (1988) text could serve as a supplement to Marcoulides and Hershberger, even though admittedly it would be very rough going for most of the students. If the instructor plans to provide hands-on experience with SEM, the recent introductory text by Schumacker and Lomax (1996) would serve as an excellent companion piece. By contrast, if the instructor plans to have nary a mention of SEM or CFA in their course, then other introductory texts (e.g., Grimm & Yarnold) or non-SEM multivariate texts (e.g., Stevens) may be more appropriate.

Again, I found this text to be well-organized and coherent in its treatment of such complex techniques as PCA, DA, and canonical correlation. Especially for a multivariate class that plans to have some emphasis on model development, the FA section and the CFA and SEM chapter will provide an excellent foundation for the introductory student.

Grimm, L. G., & Yarnold, P. R. (1995). *R*
DC: American Psychological Associ
Johnson, N., & Wichern, D. (1988). *Ap*
Prentice Hall.
Schumacker, R. E., & Lomax, R. G. (
Mahwah, NJ: Lawrence Erlbaum As
Stevens, J. (1996). *Applied multivariate*
rence Erlbaum Associates, Inc.
Tabachnick, B. G., & Fidell, L. S. (
HarperCollins.

nt of information about tests of sig-
i indexes without unduly saturating
dification appropriate for the audi-
e emphatic about basing modifica-
ounding. For the fledgling modeler,
ised on data-driven decisions; this

iberger have expertly summarized
statistics in a fashion that will be
student (obvious caveat: solid
advantageous). They provide the
rwhelm the introductory student,
ugh the intended audience of this
usiness students," there is noth-
l for other disciplines, especially
management oriented; hence, it
examples to be commensurate

ndergraduate audience, then as a
duate level, contingent on the re-
be supplemented by other texts
Stevens (1996). (To some extent
ated in the subtitle of their text:
what parallel the structure of
il, which will ultimately be nec-
on repeated measures, analysis
nodeling (the latter being some-
course) in the aforementioned
statistics. For the more mathe-
nd Wichern's (1988) text could
rger, even though admittedly it
s. If the instructor plans to pro-
troductory text by Schumacker
mpanion piece. By contrast, if
M or CFA in their course, then
or non-SEM multivariate texts

id coherent in its treatment of
al correlation. Especially for a
is on model development, the
de an excellent foundation for

REFERENCES

Grimm, L. G., & Yarnold, P. R. (1995). *Reading and understanding multivariate statistics.* Washington, DC: American Psychological Association.

Johnson, N., & Wichern, D. (1988). *Applied multivariate statistical analysis.* Englewood Cliffs, NJ: Prentice Hall.

Schumacker, R. E., & Lomax, R. G. (1996). *A beginner's guide to structural equation modeling.* Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Stevens, J. (1996). *Applied multivariate statistics for the social sciences* (3rd ed.). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Tabachnick, B. G., & Fidell, L. S. (1996). *Using multivariate statistics* (3rd ed.). New York: HarperCollins.