

# Structural Equation Modeling with Amos

Basic Concepts, Applications, and Programming

THIRD EDITION

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the observed data fit this restricted structure. Because it is highly unlikely that a perfect fit will exist between the observed data and the hypothesized model, there will necessarily be a differential between the two; this differential is termed the *residual*. The model-fitting process can therefore be summarized as follows:

$$\text{Data} = \text{Model} + \text{Residual}$$

where

*Data* represent score measurements related to the observed variables as derived from persons comprising the sample

*Model* represents the hypothesized structure linking the observed variables to the latent variables, and in some models, linking particular latent variables to one another

*Residual* represents the discrepancy between the hypothesized model and the observed data

In summarizing the general strategic framework for testing structural equation models, Jöreskog (1993) distinguished among three scenarios, which he termed *strictly confirmatory* (SC), *alternative models* (AM), and *model generating* (MG). In the strictly confirmatory scenario, the researcher postulates a single model based on theory, collects the appropriate data, and then tests the fit of the hypothesized model to the sample data. From the results of this test, the researcher either rejects or fails to reject the model; no further modifications to the model are made. In the alternative models case, the researcher proposes several alternative (i.e., competing) models, all of which are grounded in theory. Following analysis of a single set of empirical data, he or she selects one model as most appropriate in representing the sample data. Finally, the model generating scenario represents the case where the researcher, having postulated and rejected a theoretically derived model on the basis of its poor fit to the sample data, proceeds in an exploratory (rather than confirmatory) fashion to modify and reestimate the model. The primary focus, in this instance, is to locate the source of misfit in the model and to determine a model that better describes the sample data. Jöreskog (1993) noted that, although respecification may be either theory or data driven, the ultimate objective is to find a model that is both substantively meaningful and statistically well-fitting. He further posited that despite the fact that "a model is tested in each round, the whole approach is model generating, rather than model testing" (Jöreskog, 1993, p. 295).



Of course, even a cursory review of the empirical literature will clearly show the MG situation to be the most common of the three

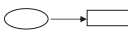
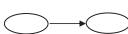


scenarios, and for good reason. Given the many costs associated with the collection of data, it would be a rare researcher indeed who could afford to terminate his or her research on the basis of a rejected hypothesized model! As a consequence, the SC case is not commonly found in practice. Although the AM approach to modeling has also been a relatively uncommon practice, at least two important papers on the topic (e.g., MacCallum, Roznowski, & Necowitz, 1992; MacCallum, Wegener, Uchino, & Fabrigar, 1993) have precipitated more activity with respect to this analytic strategy.

Statistical theory related to these model-fitting processes can be found (a) in texts devoted to the topic of SEM (e.g., Bollen, 1989a; Kline, 2011; Loehlin, 1992; Long, 1983b; Raykov & Marcoulides, 2000; Saris & Stronkhurst, 1984; Schumacker & Lomax, 2004); (b) in edited books devoted to the topic (e.g., Bollen & Long, 1993; Cudeck, du Toit, & Sörbom, 2001; Hoyle, 1995a; Marcoulides & Schumacker, 1996); and (c) in methodologically oriented journals such as *British Journal of Mathematical and Statistical Psychology*, *Journal of Educational and Behavioral Statistics*, *Multivariate Behavioral Research*, *Psychological Assessment*, *Psychological Methods*, *Psychometrika*, *Sociological Methodology*, *Sociological Methods & Research*, and *Structural Equation Modeling*.

## The General Structural Equation Model

### Symbol Notation

Structural equation models are schematically portrayed using particular configurations of four geometric symbols—a circle (or ellipse), a square (or rectangle), a single-headed arrow, and a double-headed arrow. By convention, circles (or ellipses; ) represent unobserved latent factors, squares (or rectangles; ) represent observed variables, single-headed arrows ( $\rightarrow$ ) represent the impact of one variable on another, and double-headed arrows ( $\leftrightarrow$ ) represent covariances or correlations between pairs of variables. In building a model of a particular structure under study, researchers use these symbols within the framework of four basic configurations, each of which represents an important component in the analytic process. These configurations, each accompanied by a brief description, are as follows:

-  Path coefficient for regression of an observed variable onto an unobserved latent variable (or factor)
-  Path coefficient for regression of one factor onto another factor
-  Measurement error associated with an observed variable
-  Residual error in the prediction of an unobserved factor

The Path Diagram

Schematic representations of models are termed *path diagrams* because they provide a visual portrayal of relations that are assumed to hold among the variables under study. Essentially, as you will see later, a path diagram depicting a particular SEM model is actually the graphical equivalent of its mathematical representation whereby a set of equations relates dependent variables to their explanatory variables. As a means of illustrating how the above four symbol configurations may represent a particular causal process, let me now walk you through the simple model shown in Figure 1.1, which was formulated using *Amos Graphics* (Arbuckle, 2015).

In reviewing the model shown in Figure 1.1, we see that there are two unobserved latent factors—math self-concept (MSC) and math achievement (MATH)—and five observed variables—three of which are considered to measure MSC (SDQMSC; APIMSC; SPPCMSC), and two to measure MATH (MATHGR; MATHACH). These five observed variables function as indicators of their respective underlying latent factors.

Associated with each observed variable is an error term (err1–err5), and with the factor being predicted (MATH), a residual term (resid1)<sup>2</sup>; there is an important distinction between the two. Error associated with observed variables represents *measurement error*, which reflects on their adequacy in measuring the related underlying factors (MSC; MATH). Measurement error derives from two sources: random measurement error (in the psychometric sense) and error uniqueness, a term used to describe error variance arising from some characteristic that is considered to be specific (or unique) to a particular indicator variable. Such error often represents *nonrandom* (or *systematic*) measurement error. *Residual* terms represent error in the prediction of endogenous factors from exogenous factors. For example, the residual term shown in Figure 1.1 represents error in the prediction of MATH (the endogenous factor) from MSC (the exogenous factor).

It is worth noting that both measurement and residual error terms, in essence, represent unobserved variables. Thus, it seems perfectly reasonable

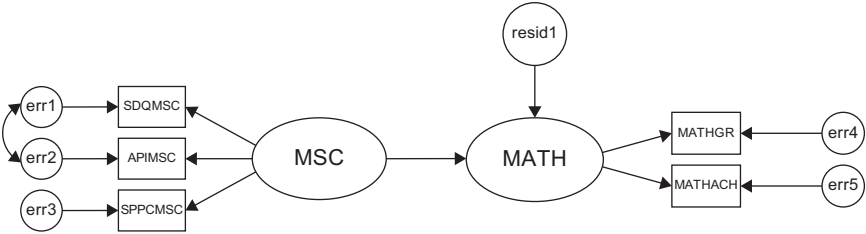


Figure 1.1 A general structural equation model.

that, consistent with the representation of factors, they too should be enclosed in circles. For this reason, then, Amos path diagrams, unlike those associated with most other SEM programs, model these error variables as circled enclosures by default.<sup>3</sup>

In addition to symbols that represent variables, certain others are used in path diagrams to denote hypothesized processes involving the entire system of variables. In particular, one-way arrows represent structural regression coefficients and thus indicate the impact of one variable on another. In Figure 1.1, for example, the unidirectional arrow pointing toward the endogenous factor, MATH, implies that the exogenous factor MSC (math self-concept) “causes” math achievement (MATH).<sup>4</sup> Likewise, the three unidirectional arrows leading from MSC to each of the three observed variables (SDQMSC, APIMSC, SPPCMSC), and those leading from MATH to each of its indicators, MATHGR and MATHACH, suggest that these score values are each influenced by their respective underlying factors. As such, these path coefficients represent the magnitude of expected change in the observed variables for every change in the related latent variable (or factor). It is important to note that these observed variables typically represent subscale scores (see, e.g., Chapter 8), item scores (see, e.g., Chapter 4), item pairs (see, e.g., Chapter 3), and/or carefully formulated item parcels (see, e.g., Chapter 6).

The one-way arrows pointing from the enclosed error terms (err1–err5) indicate the impact of measurement error (random and unique) on the observed variables, and that from the residual (resid1) indicates the impact of error in the prediction of MATH. Finally, as noted earlier, curved two-way arrows represent covariances or correlations between pairs of variables. Thus, the bidirectional arrow linking err1 and err2, as shown in Figure 1.1, implies that measurement error associated with SDQMSC is correlated with that associated with APIMSC.

### *Structural Equations*

As noted in the initial paragraph of this chapter, in addition to lending themselves to pictorial description via a schematic presentation of the causal processes under study, structural equation models can also be represented by a series of regression (i.e., structural) equations. Because (a) regression equations represent the influence of one or more variables on another, and (b) this influence, conventionally in SEM, is symbolized by a single-headed arrow pointing from the variable of influence to the variable of interest, we can think of each equation as summarizing the impact of all relevant variables in the model (observed and unobserved) on one specific variable (observed or unobserved). Thus, one relatively simple approach to formulating these equations is to note each variable

that has one or more arrows pointing toward it, and then record the summation of all such influences for each of these dependent variables.

To illustrate this translation of regression processes into structural equations, let's turn again to Figure 1.1. We can see that there are six variables with arrows pointing toward them; five represent observed variables (SDQMSC–SPPCMSC; MATHGR, MATHACH), and one represents an unobserved variable (or factor; MATH). Thus, we know that the regression functions symbolized in the model shown in Figure 1.1 can be summarized in terms of six separate equation-like representations of linear dependencies as follows:

$$\text{MATH} = \text{MSC} + \text{resid1}$$

$$\text{SDQMSC} = \text{MSC} + \text{err1}$$

$$\text{APIMSC} = \text{MSC} + \text{err2}$$

$$\text{SPPCMSC} = \text{MSC} + \text{err3}$$

$$\text{MATHGR} = \text{MATH} + \text{err4}$$

$$\text{MATHACH} = \text{MATH} + \text{err5}$$

### *Nonvisible Components of a Model*

Although, in principle, there is a one-to-one correspondence between the schematic presentation of a model and its translation into a set of structural equations, it is important to note that neither of these model representations tells the whole story; some parameters critical to the estimation of the model are not explicitly shown and thus may not be obvious to the novice structural equation modeler. For example, in both the path diagram and the equations just shown, there is no indication that the variances of the exogenous variables are parameters in the model; indeed, such parameters are essential to all structural equation models. Although researchers must be mindful of this inadequacy of path diagrams in building model input files related to other SEM programs, Amos facilitates the specification process by automatically incorporating the estimation of variances by default for all independent factors.

Likewise, it is equally important to draw your attention to the specified nonexistence of certain parameters in a model. For example, in Figure 1.1, we detect no curved arrow between err4 and err5, which suggests the lack of covariance between the error terms associated with the observed variables MATHGR and MATHACH. Similarly, there is no hypothesized

covariance between MSC and resid1; absence of this path addresses the common, and most often necessary, assumption that the predictor (or exogenous) variable is in no way associated with any error arising from the prediction of the criterion (or endogenous) variable. In the case of both examples cited here, Amos, once again, makes it easy for the novice structural equation modeler by automatically assuming these specifications to be nonexistent. (These important default assumptions will be addressed in Chapter 2, where I review the specification of Amos models and input files in detail.)

### *Basic Composition*

The general SEM model can be decomposed into two submodels: a measurement model and a structural model. The *measurement model* defines relations between the observed and unobserved variables. In other words, it provides the link between scores on a measuring instrument (i.e., the observed indicator variables) and the underlying constructs they are designed to measure (i.e., the unobserved latent variables). The measurement model, then, represents the CFA model described earlier in that it specifies the pattern by which each measure loads on a particular factor. In contrast, the *structural model* defines relations among the unobserved variables. Accordingly, it specifies the manner by which particular latent variables directly or indirectly influence (i.e., “cause”) changes in the values of certain other latent variables in the model.

For didactic purposes in clarifying this important aspect of SEM composition, let’s now examine Figure 1.2, in which the same model presented in Figure 1.1 has been demarcated into measurement and structural components.

Considered separately, the elements modeled within each rectangle in Figure 1.2 represent two CFA models. The enclosure of the two factors within the ellipse represents a full latent variable model and thus would not be of interest in CFA research. The CFA model to the left of the diagram represents a one-factor model (MSC) measured by three observed variables (SDQMSC–SPPCMSC), whereas the CFA model on the right represents a one-factor model (MATH) measured by two observed variables (MATHGR, MATHACH). In both cases, the regression of the observed variables on each factor and the variances of both the factor and the errors of measurement are of primary interest; the error covariance would be of interest only in analyses related to the CFA model bearing on MSC.

It is perhaps important to note that, although both CFA models described in Figure 1.2 represent first-order factor models, second- and higher-order CFA models can also be analyzed using Amos. Such hierarchical CFA models, however, are less commonly found in the literature