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Conventions of Path Diagrams

Structural equation models are of three sorts: (a) confirmatory factor analysis, (b) path analysis (with observed variables only) and (c) hybrid models, which are path models with latent traits rather than observed variables, that is, it allows us to incorporate factor analysis into our path model. Here is an example of a path diagram for a hybrid model:

1. MSC is one factor (called a latent trait in SEM); it is measured by three observed variables, SDQMSC, APIMSC, SPPCMSC.
2. MATH is the other factor (latent trait); it is measured by two variables, MATHGR and MATHACH.
3. The path model proposes that MSC “causes” MATH (so the MSC is exogenous and MATH is endogenous). This path model can not be assessed by multiple regression because of the latent traits.

Note:
- Rectangles are observed variables; ovals are latent traits.
- Each observed variable in the measurement model has an error associated with it—the variance that is not predicted by the latent trait.
- The dependent variable of the structural model has a residual, often called D for disturbance. It is the variance left unexplained by the model (the difference between the predicted and obtained). It reflects only omitted causes and not measurement error.
- The latent trait is considered to predict its observed variables, hence the direction of the arrows.
- The error terms (error and residual) impact the variables they point to.
- Two-headed errors are covariances (if data are unstandardized) or zero-order correlations (if the data are standardized).
- Be aware that the absence of arrows is a specific prediction. For example, it is hypothesized that E2 and E3 are not correlated.
- There are nonvisible parameters, e.g., variances of the exogenous variables (8 in this case—1 for MSC, 1 for D1 and 5 for the errors). They must be counted.

How SEM does it

SEM solves a series of equations to estimate the parameters you ask it to. The key parameters are (a) regression coefficients and factor loadings, which appear in the model as one-sided arrows, and (b) variances and covariances of exogenous variables (covariances appear on the two-sided arrows).
Constraining parameters.
The number of parameters (unknowns) that can be estimated in SEM is limited. With $v$ observed variables there are $v(v+1)/2$ parameters that can be estimated. If the number of unknowns in a model exceeds that number then the model is unidentified (i.e., underdetermined) and it is necessary to constrain additional parameters (give them a value so they are not estimated). In addition, every latent trait must have its scale constrained.
Using Amos: An Overview

AMOS can be done entirely in path diagrams, by its AMOS Graphics. If one prefers structural equations, one can use AMOS Basic or other SEM programs (EQS or LISREL).

After you open AMOS Graphics (from Start-Program), you see the following:

- The two large buttons in the upper left represent the input diagram and the output diagram. The input diagram (one on left) is currently selected.
- You draw on the large open space to the right. This is in portrait orientation; you can make it landscape by selecting View/Set—Interface Properties—Page Layout.

Attaching the data

DATA can be input as raw data or variance/covariance matrix. AMOS can read SPSS (.sav) files, Excel (.xls) files, text (.txt) files, and several other types of files.

To attach data: File—Data Files...—File Name
The dialog box works just like the one in SPSS.

NOTE: If you have to change your data in any way, you will have to do so in SPSS. When you return to AMOS, you have to repeat the data attaching process (it is attached
to the old data file, not the revised one—that is the disadvantage of buying the cheap version of AMOS).

Likely problems to arise:
• Missing Data (see Appendix C)
• Variable names don't match. For every rectangle in AMOS you must have a variable in SPSS and the variable names must be exactly the same. **NOTE** the variable label you see on the rectangle does not have to be the SPSS Variable Name. You can create an intelligible name for the diagram, then double click and a dialog box pops up in which you can put the SPSS Variable name.
• Specifying the model and drawing your diagram

To create a structural equation model in AMOS GRAPHICS (make sure you open AMOS GRAPHICS and not one of the other choices) you must draw all variables (the observed in rectangles and the latent in ovals), all arrows (single headed are paths, double-headed are correlations/covariances), and all residuals (errors for observed variables and disturbances for endogeneous variables).

You can get to all the drawing tools either through the tools palette that is at the right side or bottom of your screen or through the Menus at the top of the layout.

Appendix A gives examples of common types of SEM diagrams.
Appendix B is a list of most of the icons of the palette and their action, but it is useful only to get an overview. When actually working in AMOS, let its power help you. To figure out what an icon means, right click on it (or just put the mouse over it and wait a second)

**Drawing**

You can draw your variables from the bottom up by these three buttons:

![Variable icons](image)

**TWO-SIDED ARROWS**

Hint: If the arrow curves in the wrong direction, redo it starting at the bottom item.

**NOTE:** Drawing this stuff can get very tiresome. Here are some shortcuts:

**DUPLICATE ICONS**

Once you get an icon (rectangle or oval) the size and shape you want it, it is easier to duplicate it than to draw a new one. Use the copier tool.

![Copy icon](image)

**ERASE ICON**

So you hate what you've drawn. X it out:

![Eraser icon](image)

**MOVING ICONS**

So you don't like where on the “page” an icon is. Get a moving truck:

![Moving icon](image)
**DRAWING ERRORS AND DISTURBANCES WITH THE ERROR ICON**
This is one-stop shopping—it draws circle and arrow at one time in proper configuration.

Sometimes when you draw with the error icon or the indicator icon (shown next), the complexes stick off in wrong directions. Click again.

**DRAWING LATENT TRAITS WITH THEIR OBSERVED VARIABLES**
This is the indicator icon.

First select it, then move to the drawing area and draw an oval. Then (it is still selected) click again and an indicator appears (the rectangle for the observed variable plus its error). If the indicators are in the wrong direction or not smoothly arranged, use the rotate button

**ROTATE**

Activate the rotate button (click on it or move mouse over and right click) and then click on icon you want to move.

**CHECK OUT MORE TOOLS**
There are a number of tools to help you adjust your diagram—Shape Change, Touch-up, Reflect, Move Parameters, Preserve Symmetry, Fit-to-Page, Link, etc. See Appendix B.

If your model is too large for the work space, then you can use the Magnification and Scroll tools to move around the diagram.
Naming the variables

You have to name all your variables. Double click on one (any one) or select Object Properties from the View/Set menu. A dialog box appears. Click on the Text table and enter your variable name. It must be the same name as the SPSS variable name. You can also enter a variable label, which can be longer than eight characters. The variable label will be what appears on the diagram. If you do not enter a variable label, the SPSS variable names will appear in the diagram.

NOTE: When doing variable names, it is easier to leave the Object Properties dialog box open (drag it to the side of your path model) and move from one variable name to the other by mouse clicking on rectangles and ovals sequentially. This trick also works on paths (arrows), which you will also need.

Constraining variables.

SEM requires certain "anchoring" of latent variables to be able to calculate. Understand that this includes not only latent traits (in the factor sense) but also all residuals (error and disturbance terms). This can be done by specifying values for path coefficients or the variances of variables. Double click on either an arrow or a latent variable (oval) and the Object Properties dialog box appears. Choose the parameters tab. If you selected an arrow, you will see a box for regression coefficient in the lower left. If you selected a latent trait, that same box will be labeled variance.

- For confirmatory factor analysis (the measurement model), the path to each error term and one of the paths from the latent variable (oval) to its indicator variables (observed variables in rectangles) must be constrained. In both cases the typical value chosen is unity. If you chose the indicator icon, this will be done for you. If you are choosing among indicator variables (the rectangle), choose the one that you hypothesize to be the best indicator (see Appendix A for an example).

  Note that constraining the error terms to 1 means that we are NOT entering them as unknowns in our model (by definition, the error is unknown). Fixing one path from latent traits to observed measures is a way of specifying the variance of the latent trait; with a path of one, it takes on the variance of the observed measure.

- For the structural model (regression) you must define the scale of the latent variable that represents the residuals. You can do this by fixing either the variance of the residual (1 makes it a z score) or the path coefficient from residual to the dependent variable at some positive value (typically unity). To do the latter you double click on the arrow, not on the residuals oval.

  Note that setting these paths/variances to 1 (or another specific value), you are NOT turning them from unknowns to knowns. You are setting the scale of the variables. In the solution you will see the "1's" turned into estimates.

Creating a title (figure caption) for the path diagram

This may seem superfluous but it is a good way to keep track of your diagrams and having a goodness of fit statistic appear on the diagram.

Double-click on the Title icon on the Tool Bar.
Enter a label (e.g., Saturated Ordinary Least Squares Model) and then RMSEA = \rmsea

When your calculations are complete the \rmsea will be replaced by the RMSEA.
**Running the analysis**

The next step is to choose how to run the analysis and what output you wish. Select:

Or use menus: **View/Set—Analysis Properties**

Select the Estimation tab and make sure the analysis is the one you want. Maximum likelihood is the default, but you can also do unweighted least squares (multiple regression, principal components factor analysis and principal components analysis) and others.

**NOTE:** If you have missing data, AMOS will require that you check the box called Means and Intercepts. See Appendix C.

Select the Output tab and make your choices. Common choices are minimization history, standardized estimates, squared multiple correlations, residual moments, indirect, direct and total effects (for path models), factor score weights (for factor analysis), tests for normality and outliers, and Modification Indices.

Select the Title tab and write a title (this title appears on your text output; the one you did earlier will appear on your diagram).

Then you are ready to calculate the estimates. Select:

Or by menus: **Model-fit—Calculate estimates**

**Viewing the output**

You have three views:

1. Graphical—from the upper-left corner of the AMOS desktop, click the right view button:

To print this, make sure you select the model in the Print dialog box—it will be “default” if you have only one model.

1. See output in a spreadsheet table.

   The table view allows you to choose the page you want to see in a menu on the left.

3. See output in a text file.
This is the same output as in the table view, but it is formatted as one continuous output. This makes it convenient to print out, but not to find what you need to check.

**Checking Your Run**

There are many things that can go wrong when you ask AMOS to calculate:

- It does not calculate a model. You can tell this because the graphical output icon will not become red and/or because minimization is not reached.
- It reaches a minimum, but reports an inappropriate model. To ascertain this, see the text output or the table output. Make sure "minimization is reached." The message "Model is inadequate" will be displayed on the same page. Other nasty messages you might see are: "Matrix is not positive definite," and "negative variances" (Heywood cases). Check also for correlations > 1.00.
- It displays a dialog box that says it is assuming that some variables are assumed to be noncorrelated and lists those correlations.

Appendix C has suggestions to fix recalcitrant AMOS runs.

Once you have an adequate model, check the text or table output for the following:

- Make sure it is the one on your final model by looking at the beginning of the output.
- If you made a title, it is listed at the beginning.
- Are all your variables listed?
- Are the observed variables listed as observed?
- If you have latent traits, are they listed as unobserved?
- Are all the error terms listed and are they unobserved?
- Are the designations as exogenous and endogenous correct?
- If the above are all correct, then the summary of the number of each kind of variable should be correct. Check it.
- Do you have the correct number of fixed weights in the Summary of Parameters? Fixed weights are parameters you have constrained, i.e., not unknowns.
- There should be no means and intercepts in the Summary of Parameters in a standardized solution.
- The model should be recursive. That means there are no reciprocal paths, i.e., no double arrows (two arrows, one in each direction). (There can be double-ended arrows on exogenous variables.)
- Check the computation of the degrees of freedom.

Then check your output graphic (click on the output icon--the one on the right):

- You should have numbers on all paths (and a few extra).
- The numbers should all be less than 1.
- One or more path coefficients are very high (> .80).

If all this is OK, you can proceed.

**Printing the output**

The first model in a new file is the default model. If you make alternative models, you will name them so you will know what you are printing. We typically choose the standardized output no matter what we used as input (unstandardized output may be better when you are comparing path models for two groups).

Always print the output path diagram and text output.

Printing text output:
• If you want all the textual output, just print the text file.
• If you want only part of it, go to the table view and select which tables you want to print.

Printing the output path diagram
• It should have numbers on paths. If not, you have printed out input diagram. Make sure you have picked OK Default model in print dialog box.
• You have the standardized coefficients, if that is what you want. The output diagram with standardized coefficients has no numbers on error terms (neither on the arrow or near the circles). If your output diagram does, you have printed out the unstandardized form. The option for standardized/unstandardized is at the left of the screen and at the bottom of the PRINT dialog box.

Understanding the Outputs

Understanding the Path Diagram
Here are the location and meaning of the numbers. You can get the same information in your text outputs, if you asked for it (sometimes you need to check the text output, because the numbers are not always clearly placed in the path diagram).

<table>
<thead>
<tr>
<th>Location</th>
<th>Unstandardized Estimates</th>
<th>Standardized Estimates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Near Single-Headed Arrows</td>
<td>Regression weights</td>
<td>Standardized regression weights</td>
</tr>
<tr>
<td>Near Double-Headed Arrows</td>
<td>Covariances</td>
<td>Correlations</td>
</tr>
<tr>
<td>Near Endogenous Variables</td>
<td>Intercepts(^1)</td>
<td>Squared multiple correlations</td>
</tr>
<tr>
<td>Near Exogenous Variables</td>
<td>Means(^1) and variances</td>
<td></td>
</tr>
</tbody>
</table>

\(^1\)Only when mean structures are analyzed.

Understanding the Text Output

Regression Weights
• These are true regression weights whether you have used maximum likelihood or ordinary least squares solution.
• The results marked Regression weights are unstandardized. The standardized weights are labeled standardized.
• The estimates are the partial regression weights; the S.E. is standard error.
• The C.R. is the critical ratio, which equals the estimate/S.E. If distributional assumptions are met, and C.R. \(>2.00\) is significant at .05 level. If don’t meet distributional requirements, the CR\(^2\) is the amount the chi-square would increase if that parameter were fixed to 0.
• SE and CR not available with standardized regression weights, correlations, ULS or SLS.
Squared Multiple Correlations

- There will be one for every endogenous variable. Notice that in the case of latent traits, the squared multiple correlation represents the extent to which the latent trait predicts the latent variable.

Residuals Matrix (covariance, standardized covariance*, correlation)

- The standardized residuals are preferable, because the unstandardized residuals are dependent on the unit of measurement of the observed variables. To produce the standardized residual covariances, each entry is divided by an estimate of what its standard deviation would be with large n (see Joreskog & Sorbom, the LISREL manual, 1988). Thus they are analogous to z scores and most should have a value under 2.00 (AMOS manual) or 2.58 (Byrne, 2001, p. 89).
- Look for relatively large residuals for places to fix in the model.
- The residuals should average to zero.

Modification Indexes

- Get one for each fixed parameter specified; AMOS includes the ones you made equal to another one and ones you left out (which have parameters fixed to 0). It does not include 0-weighted paths that change variables from exogenous to endogenous or recursive to nonrecursive (reciprocal).
- There is a chi-square for each path, with df=1 (critical chi-square with df=1 is 3.84, for \( p < .05 \)).
- MI represents the decrease in chi-square expected if this parameter were added to the model (i.e., becomes an unknown, which is done by creating an arrow for it); doing so reduces your degrees of freedom by 1.
- The actual decrease may be greater than the MI.
- Column called Par Change represented the expected predicted change (EPC)
- Do not make changes based on MI and EPC unless they make theoretical sense.
- The default threshold for MI is 4; that means no MI<4.00 are printed. Making the threshold smaller results in lots of paper.

Summary of models

- The default model is the first one you made in a file.
- The saturated model is the model with all the possible paths included (with 0 df, which means it will have no chi-square and several others).
- The independence model is the model with zero correlations between all pairs of variables.
- CMIN is the chi-square. Notice that this has already been given for the default model.
- The output has a long list of goodness-of-fit statistics.
- AMOS allows you to add models, so you can compare among models, as is recommended. Then you will have a default and a new model, which you named.
- If you have more than one model, the last entry is the comparison between them—the difference in chi-square (and others)

**Assessing the Fit of the Model**

Once Amos acknowledges that you have an adequate model that reaches minimization, you are ready to assess its fit.
Goodness-of-fit Statistics
The chi-square (called CMIN) is given to you right up with the error messages, so it is easy to get a general idea about your model. Remember that with small sample size chi-square will hardly ever be significant and with large sample sizes it will almost always be significant. Remember also that the larger the degrees of freedom the larger the critical chi-square (the tabled value). Some researchers create a ratio by dividing chi-square by df; 5.00 or below is considered good fit (Wheaton, Muthen, Alwin, & Summers, 1977).

You will notice several other goodness-of-fit criteria discussed in Kline. Kline recommends you use more than one and rest easy only if disparate measures come out the same way.

Standard Errors
Standard errors that are excessively large or excessively small indicate poor model fit. In either case, the test statistic for its related parameter can not be defined.

Critical Ratios (c.r.)
Nonsignificant c.r.s mean the parameters can be deleted from the model--if the sample has sufficient power.

Model as a Whole
The RMSEA, which addresses parsimony and population issues, and which provides confidence intervals, is the goodness-of-fit index of choice. We will follow Kline’s suggestion, however, and supplement it with one or two other indices.

Model Misspecification
Check the residuals--large residuals indicate the model is not predicting the value of the variables involved (see above for details). For unstandardized residuals a large value is .10; for standardized residuals a large value is 2.00 or 2.58, depending on the expert. Check the Modification Indices. Large values indicate that the model might fit better if that path or variable were added to the model.

Compare Models
Just because a structural equation model passes muster by the above tests does not mean it is "correct." Other models might also past muster. Therefore, it is incumbent on researchers to always check their model against alternative, plausible models. The ideal is to have nested designs, so that one can see if chi-square difference is significant. Nonetheless, a nonnested alternative model is better than none.

Confirmatory vs. Exploratory SEM
If your model needs revising, based on the above indicators, you might choose to leave confirmatory mode and enter exploratory mode. That is, you can add and delete
parameters and/or variables and rerun the SEM. Exploratory models then require cross validation.
Appendix A Examples of Input Diagrams

EXAMPLE 1 Confirmatory Factor Analysis
EXAMPLE 2 Causal Model (Path Analysis) with Latent Traits

```
Latent Trait 1
  Obs1Tr1  <- E1
  Obs2Tr1  <- E2
  Obs3Tr1  <- E3

Latent Trait 2
  Obs1Tr2  <- Latent Trait 1
  Obs2Tr2  <- E4
  Obs3Tr2  <- E5

D1
```

[Diagram of the causal model with latent traits and observed variables]
Appendix B AMOS Icons

Below are listed many of the icons available in AMOS. It has a good in-context help system. Simply move the mouse over the icon slowly and its label will pop up. Right click and you can choose two types of information. There is also a separate graphics manual, which is a .PDF file and is available from the Windows START menu.

Many of the Amos Icons

- **Rectangle Icon**: Draw observed (measured) variables
- **Oval Icon**: Draw unobserved (latent, unmeasured) variables
- **Indicator Icon**: Draw a latent variable and add one or more indicator variables
- **Path Icon**: Draw regression path
- **Covariance Icon**: Draw covariance
- **Error Icon**: Add error/uniqueness variable to an existing observed variable
- **Title Icon**: Add figure caption to path diagram
- **Variable List (I) Icon**: List variables in the model
- **Variable List (II) Icon**: List variables in the data set
- **Single Selection Icon**: Select one object at a time
- **Multiple Selection Icon**: Select all objects
- **Multiple Deselection Icon**: Deselect all objects
- **Duplicate Icon**: Make multiple copies of selected object(s)
- **Move Icon**: Move selected object(s) to an alternate location
- **Erase Icon**: Delete selected object(s)
- **Shape Change Icon**: Alter shape of selected object(s)
- **Rotate Icon**: Changes orientation of indicator variables
- **Reflect Icon**: Reverses direction of indicator variables
- **Move Parameters Icon**: Move parameter values to alternate location
- **Scroll Icon**: Reposition path diagram on the screen
- **Touch-up Icon**: Enables rearrangement of arrows in path diagram
Data File Icon: Select and read data file(s)
Analysis Properties Icon: Requests additional calculations
Calculate Estimates Icon: Calculates default and/or requested estimates
Clipboard Icon: Copies path diagram to Windows clipboard
Text Output Icon: View output in textual format
Table Output Icon: View output in spreadsheet format
Object Properties Icon: Define properties of variables
Drag Properties Icon: Transfer selected properties of an object to one or more target objects
Preserve Symmetry Icon: Maintain proper spacing among selected group of objects
Zoom Select Icon: Magnify selected portion of a path diagram
Zoom-In Icon: Magnify image of path diagram
Zoom-Out Icon: Reduce size of path diagram
Zoom Page Icon: Resize path diagram to fit within AMOS window
Fit-to-Page Icon: Resize path diagram to fit within page boundary
Loupe Icon: Magnify path diagram with a loupe (magnifying glass)
Degrees of Freedom Icon: Display degrees of freedom for a selected model
Link Icon: Link selected objects
Print Icon: Print selected path diagram
Undo (I) Icon: Undo previous change
Undo (II) Icon: Undo previous undo
Redraw Icon: Redraw path diagram on the screen
Appendix C When AMOS Won't Run

Missing Data
Missing data is a problem for all statistical analyses (see the Screening Data manual), but in most it will not prevent you from doing the job. In AMOS missing data has more serious consequences.

You might get a peculiar error message such as nonpositive definite, singular matrix, matrix determinant of zero, negative eigenvalues, or negative variances if you leave data missing or you chose pairwise deletion in SPSS.

The only way AMOS can directly deal with missing data is to run a maximum likelihood model with estimates of Means and Intercepts. The biggest problem with this option is that it is more difficult to get an adequate model. In other words, the model you wish to run might yield an adequate model if you had used an indirect method (listwise deletion or mean substitution). A secondary problem is that you can not use Modification Indices, which is a very valuable tool.

If you want to avoid the problems of dealing with missing data, then return to SPSS and eliminate the missing data by listwise deletion (if your sample is large enough) or mean substitution (if your sample is too small for listwise deletion).

How to:

Listwise deletion. Choose Select Cases (from Data menu). Choose If . . . and specify acceptable values of the variable with missing cases (if there are more than one variables with missing values, you will have to do this again and again). Click continue and in the Select Cases dialog box click the "Unselected cases are deleted" choice. Then select SAVE AS and make a new name for your truncated file. This new file will have to be attached to AMOS.

Mean Substitution. First, know which variables have missing values (a Descriptives will do this). Then choose Replace Missing (from Transformations menu). Select the variables that have missing data. Warning: the variable names will change and you will have to change your variable names in AMOS. Be sure to save your new data file and to attach it again in AMOS (otherwise you will be running your old file with missing data).

Warning: if your missing data are not randomly missing (e.g., respondents who did not live with their fathers when they were teens will have missing data for all questions about when they lived with their fathers. One way to handle this kind of missing data is to run analyses with and without the missing data and examine differences in results.

Problems with creating a model
The most common problems:
• A dialog box appears that says it is assuming that some variables are assumed to be noncorrelated and lists those correlations.
• Not identified
• Solution does not converge
• Negative variances (Heywood cases)
• The input or implied (predicted) variance/covariance matrix is not positive definite.

Dialog box message about uncorrelated variables. This message usually appears because you have not drawn double-ended arrows between exogenous variables. If you know your exogenous variables are not correlated, you can ignore this message. If your
exogenous variables might be correlated, you either want to add these as unknowns (draw the double-ended arrows) or specify their value (draw the double-ended arrows and enter the known correlations as constraints).

**The other messages.** Potential causes/solutions for the other messages (not identified, etc.) are listed below. Although some of the solutions are listed under specific messages, this is a starting point. If none of those solutions work, try some listed under another error message.

For all error messages, check the following:
- Do you have missing values? If so, you can not use ordinary least squares (OLS) solution. You can have missing data with a maximum likelihood solution that estimates means and intercepts, but you can't get Modification Indices and adequate models are harder to get. To get rid of missing data, go back into SPSS and assign means to missing data (use Replace Missing Values).
- Each downstream variable (observed and latent) must have a residual (circle with path).
- Each residual must have either variance or path coefficient fixed. We most often solve this problem by setting either path (click on line) or variance (click on circle) to 1. Using the “Add a unique variable” button does this automatically.
- Each latent variable should have at least three observed variables (arrows go from latent to observed) and one of the paths to the observed variables must be set to 1 (usually the one of greatest reliability). Double click on the path and set the coefficient to 1. If you have two observed variables, be aware that you may be in trouble. If you have just one observed variable, you can still run the SEM, but you will probably have to set the variance of the latent trait to 0. This will lead to a "positive definite matrix" error, but you can proceed so long as the solution reaches minimization. If you have one or two observed measures and are still have trouble, you can combine the two measures into one and eliminate the latent variable.
- Make your model recursive—eliminate any reciprocal paths—because nonrecursive models (with reciprocal paths) are difficult to get identified.
- Make sure you have some degrees of freedom (reduce number of parameters by setting paths to zero, or by making two paths equal to each other).
- SEM likes to have at least 100 subjects. If fewer, you may have trouble with latent variables that have only three indicators.
- If your model fails to converge, try OLS or Generalized least squares (GLS) instead of ML, which is more treacherous. If you have decidedly violated multivariate normality, you can try asymptotically distribution-free (ADF) solution, but you need very large samples (200-500 for even simple models).

If you get the "not positive definite" error message:
- If your input matrix is not positive definite, check that the program has read in your data correctly. An empty covariance matrix is always not positive definite.
- If your implied matrix (the predicted values) is not positive definite, try specifying starting values (i.e., make a guess of the predicted values on every path).
- If you have negative variances, try fixing them to 0 (Gerbin & Anderson, 1987). The text (or table) output tells you which variables have the negative variances.
- If there is a lot of missing data, the correlation or covariance matrix may not be positive definite. Eliminate missing data by replacing listwise or replacing missing values. Do not use delete pairwise.
- Check for multicollinearity.

If your model runs, but the solution is inadequate:
Check your assumptions. If your data are not multivariately normal or have nonlinearities, or are multicollinear (or linearly dependent, such as part and whole, or proportion correct and proportion errors), take the standard measures.

Examine your standard errors. Very large or very small standard errors may prevent the program from determining the parameter. Unfortunately, large or small is a moving target; it depends on the units of measurement and the magnitude of the parameter estimate.

If still having trouble with identification:
- You can tell Amos to continue with unidentified. If you do this, be sure to:
- Compare runs with different sets of initialization values. To set initial values, set the parameter coefficients of all the paths.

If you have Heywood cases (negative variances):
- First try constraining the variables AMOS lists in parentheses with the message.
- Set the variances of the variables in question to some reasonable value (such as the variance of one of the observed variables, or 1, which makes it a z score).
- Change the model--different number of factors, rescaling variables to linearize relationships, eliminating the offending variable, etc.
- Check your fit indices, such as the Modification Index, the residuals, the standard errors (either too large or too small).
- Researchers can make a ridge adjustment to the covariance or correlation matrix. This involves adding some quantity to the diagonal elements of the matrix. This addition has the effect of attenuating the estimated relations between variables. A large enough addition is sure to result in a matrix with a positive determinant. The price of this adjustment, however, is bias in the parameter estimates, standard errors, and fit indices.

Peculiarities in the output diagram

You have path coefficients that exceed 1. First, make sure that you have asked for standardized regression coefficients (highlight the Standardized Regression Coefficients in the left column). If that doesn't solve the problem, read on.

One or more path coefficients are very high (> .80). Check that you have error terms wherever needed--look first at the variable that is at the end of the arrow with the too-high partial regression coefficient.
### Appendix D Glossary

**CMIN**
the chi-square that acts as the discrepancy function in AMOS. That is, it is the number that reaches minimization, that connotes the smallest discrepancy between predicted (implied) and obtained.

**Confirmatory factor analysis.**
One or more latent traits and their observed measures. The observed measures all have errors attached with them and the latent trait must have an error if it is endogenous. It is the same sort of analysis as exploratory factor analysis, but it is used when the researcher can predict the structure (the relations between observed variables and measures). It is called the measurement model if it is part of a larger structural equation model.

**Default model**
the model you build (the first one you make in a file).

**Degrees of freedom.**
in SEM is the difference between the number of independent observed values--(m(m+1)/2)--and the number of unknowns to be solved.

**Determined**
Another term for identification--a model can be underdetermined (unidentified), overdetermined (1 or more df), or just determined (0 df, a saturated model).

**Discrepancy function**
another term for goodness-of-fit criteria used to determine if the fit of SEM solutions is at a minimum. There are four criteria--ordinary least squares, maximum likelihood, generalized least square, and Browne's asymptotically distribution-free criterion (ADF, called generally weighted least squares in LISREL and arbitrary distribution generalized least squares in EQS).

**Disturbance term**
The residual of prediction, i.e., the error in predicting to an endogenous variable.

**Downstream variables**
All variables at the end of an arrow, that is, in which some other variable is predicting to them. They are also called endogenous variables.

**Endogenous variables**
All variables at the end of an arrow, that is, in which some other variable is predicting to them. They are also called downstream variables.

**Error**
The residual associated with observed variables that are indicators of latent trait. As such these terms represent measurement error, the sum of random measurement error and variance specific to the observed variable.

**Exogenous variables**
All variables that have NO arrow pointing toward them. That is, nothing in the path diagram predicts to them, although in the larger world they may have causes. These are the most distal causes in the particular model.

**Identified.**
Another term for determined--a model can be unidentified (underdetermined), overidentified (1 or more df), or just identified (0 df, a saturated model). An SEM model will not run if unidentified, it will not produce a chi-square if just identified. Note that there is empirical identification as well; the model won't run even if there are many df.
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Implied</td>
<td>AMOS's term for predicted.</td>
</tr>
<tr>
<td>Independence model</td>
<td>the model with zero correlations between all pairs of variables.</td>
</tr>
<tr>
<td>Measurement model</td>
<td>The confirmatory factor analysis part of a path diagram, consisting of one or more latent traits and their observed measures. The observed measures all have errors attached with them and the latent trait must have an error if it is endogenous.</td>
</tr>
<tr>
<td>Parameters</td>
<td>These are the unknowns in the SEM. Parameter in general is a population variable; the same number in samples is called a statistic (e.g., $\mu$ vs $\bar{X}$). In SEM we are estimating population parameters in all the paths (partial regression coefficients) and variances we hypothesize to be not zero.</td>
</tr>
<tr>
<td>Positive Definite matrix</td>
<td>A symmetric matrix $A$ is positive semidefinite if $c'Ac \geq 0$, for all vectors $c$. If, in addition, $c'Ac=0$ is true only for the trivial vector $c=0$, then $A$ is said to be positive definite.</td>
</tr>
<tr>
<td>Reciprocal model</td>
<td>A model in which at least one pair of endogenous variables predict to each other. These are notoriously hard to reach identification.</td>
</tr>
<tr>
<td>Recursive model</td>
<td>A model in which there are no reciprocal relationships in endogenous variables, that is, all endogenous variables have either one or no arrow between them and every other variable</td>
</tr>
<tr>
<td>Residuals</td>
<td>the difference between what was predicted and the observed values, that is, the error</td>
</tr>
<tr>
<td>Saturated model</td>
<td>the model with all the possible paths included (with 0 df, which means it will have no chi-square). This is what you get with exploratory factor analysis and path analysis done via multiple regression.</td>
</tr>
<tr>
<td>Structural model</td>
<td>The part of a path diagram that predicts causal relationships.</td>
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