

Visualizing Moderating Effects in Path Models with Latent Variables

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ABSTRACT

Path models with and without latent variables are extensively used in e-collaboration research. Both direct and moderating relationships can be included in such path models. Moderating relationships involve three latent variables, the moderating variable and a pair of variables that are connected through a direct link. This paper discusses the visualization of moderating relationships through two-dimensional and three-dimensional graphs. The software WarpPLS version 5.0 is used in this discussion, since it provides an extensive set of graphs that can be used to visualize moderating effects.

Keywords: E-Collaboration, Partial Least Squares, Path Analysis, Statistical Moderation, Structural Equation Modeling, WarpPLS

INTRODUCTION

Path models with and without latent variables are extensively used in e-collaboration research (Kock, 2011; 2014a). Such models can be analyzed through the method of path analysis (Wright, 1934; 1960), which itself provides the foundation for structural equation modeling (Kock & Mayfield, 2015; Kock & Verville, 2012). In these analyses, latent variables have been traditionally approximated via composites, employing partial least squares algorithms (Kock & Mayfield, 2015). A recent related development is the estimation of the true latent variables through factor-based algorithms (Kock, 2015a).

Both direct and moderating relationships can be included in path models (Kock, 2014a). Moderating relationships involve three latent variables, the moderating variable and a pair of variables that are connected through a direct link. In this paper we discuss the visualization of moderating relationships through two-dimensional and three-dimensional graphs. The software WarpPLS version 5.0 (Kock, 2015b) is used in this discussion, as it provides an extensive set of graphs that can be used to visualize moderating effects.

DOI: 10.4018/IJeC.2016010101

DATA USED IN THE ANALYSES

Departing from a “true” model, which is a model for which we know the nature of the relationships among variables and their respective magnitudes, we created 300 rows of data for several latent variables and indicators based on a Monte Carlo simulation (Robert & Casella, 2005; Paxton et al., 2001). These are equivalent to 300 returned questionnaires.

The true model was based on an actual study of the effects of e-collaboration technology use on team-based project success, previously used by Kock & Lynn (2012) to illustrate the phenomena of vertical and lateral collinearity. At the time of this writing, the data we created was publicly available as a sample dataset from the WarpPLS web site: warpls.com.

The following variables were included in the illustrative analyses discussed here: e-collaboration technology use (ECollab), project management (Projmgt), job satisfaction (JSat), and project success (Success). More details about these variables are provided below.

E-Collaboration Technology Use (ECollab)

This is the main technology-related latent variable in the model. It measures, through three indicators, the extent to which a team that is tasked with the development of a new product (e.g., a new toothpaste or airplane part) uses an e-collaboration technology that integrates several synchronous and asynchronous features (e.g., e-mail, text-based chat, video-conferencing, discussion board).

Project Management (Projmgt)

This latent variable measures, through three indicators, the degree to which the team uses project management techniques that allow team members to monitor and control the progress of their work.

Job Satisfaction (JSat)

This latent variable measures, through three indicators, the degree to which team members are satisfied with their current jobs.

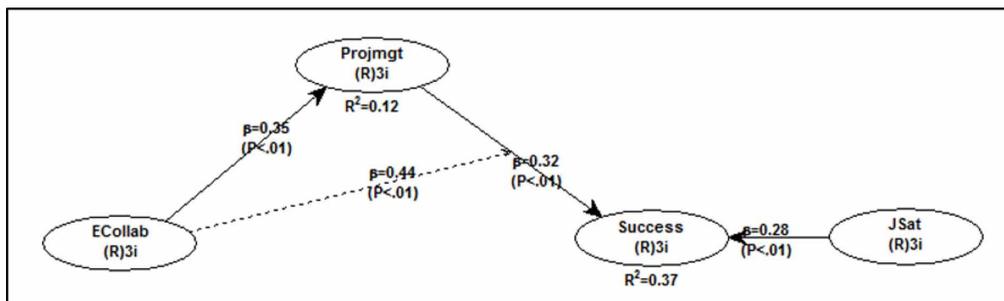
Project Success (Success)

This latent variable measures, through three indicators, the degree to which the new product developed by the team is successful in the marketplace (i.e., has a high volume of sales, with a good profit margin).

In our true model, e-collaboration technology use (ECollab) directly influences project management (Projmgt). Job satisfaction (JSat) also directly influences project success (Success). Finally, e-collaboration technology use (ECollab) moderates the relationship between project management (Projmgt) and project success (Success). Figure 1 shows the results of our analysis.

In our analysis we employed “PLS Regression” as the outer model (a.k.a. measurement model) analysis algorithm, “Stable3” as the “resampling” method used in the analysis, and “Linear” as the default inner model analysis algorithm (Kock, 2015b). The Stable3 is referred to as a “resampling” method for simplicity; it does not actually generate resamples, and yields more reliable estimates of standard errors (Kock, 2014a). All paths were modeled employing the default inner model analysis algorithm, as linear paths.

Figure 1. Results of the analysis



TWO-DIMENSIONAL GRAPHS

After an analysis is conducted with WarpPLS, choosing the menu option “View/plot linear and nonlinear relationships among latent variables” causes the software to show a table with the types of relationships, warped or linear, between latent variables that are linked in the model. The term “warped” is used for relationships that are clearly nonlinear. The term “linear” is used for linear or quasi-linear relationships; the latter are slightly nonlinear relationships that appear to be linear upon visual inspection.

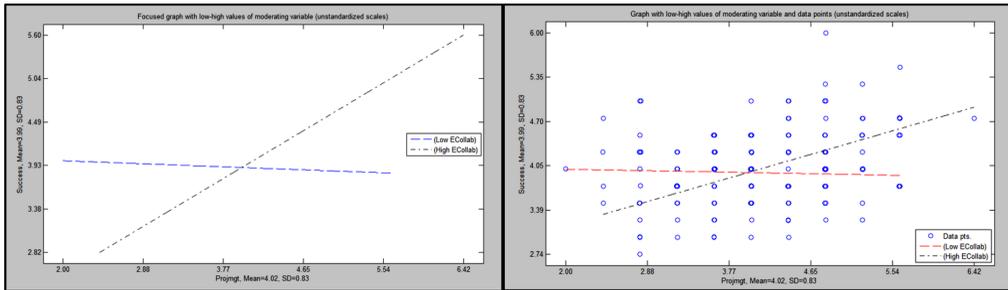
In the table with the types of relationships, each cell may refer to a direct or moderating effect. As with direct effects, several graphs (a.k.a. plots) for moderating effects can be viewed by clicking on a cell containing a relationship type description. These cells are the same as those that contain path coefficients, in the path coefficients table that was shown earlier. Their column labels are displayed on the table as product latent variables (e.g., ECollab*Projmgt). In this example, namely ECollab*Projmgt, the latent variable ECollab is hypothesized to moderate the relationship between Projmgt and another latent variable, where Projmgt points at the third latent variable. The third latent variable is listed in the corresponding row label. Among the options available are two-dimensional and three-dimensional graphs.

As noted earlier, moderating relationships involve three latent variables, the moderating variable itself and a pair of variables that are connected through a direct link. The sign and strength of a path coefficient for a moderating relationship refer to the effect of the moderating variable on the sign and strength of the path for the direct relationship that it moderates. For example, if the path for the direct relationship has its sign going from negative to positive and becomes significantly stronger in that direction as one moves from the low to the high range of the moderating variable, then the sign of the path coefficient for the corresponding moderating relationship will be positive and the path coefficient will be relatively high; possibly high enough to yield a statistically significant effect.

The “View moderating relationship in one focused graph” options allow users to view two-dimensional moderating effect graphs that focus on the best-fitting lines or curves for high and low values of the moderating variable, and that exclude data points to provide the effect of zooming in on the area comprising the best-fitting lines or curves (see Figure 2, left graph). The options available are: “View focused graph with low-high values of moderating variable (standardized scales)”, and “View focused graph with low-high values of moderating variable (unstandardized scales)”.

Through the “Settings” menu option the user can also set the following two-dimensional moderating effect graph options: the graph title, the labels associated with high and low values

Figure 2. Two-dimensional graphs of moderating effect



of the moderating variable, and the location of the legend box containing these labels. These options allow users to create more informative two-dimensional moderating relationship graphs. For example, instead of “Low Exp” and “High Exp”, more informative labels such as “Novices” and “Veterans” could be used. Setting the location of the legend box (e.g., from “East” to “Northwest”) allows users to move the legend box from more to less crowded areas of the graph, giving the graph a more balanced and “cleaner” appearance.

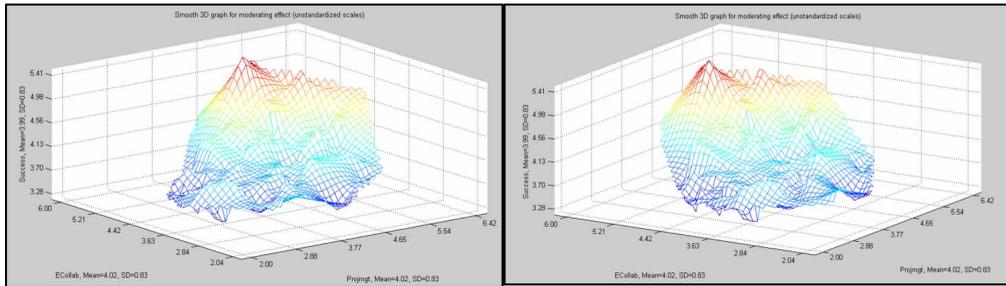
The “View moderating relationship in one graph with data points” options allow users to view two-dimensional moderating effect graphs with the best-fitting lines or curves for high and low values of the moderating variable, and the data points used to produce the best-fitting lines or curves (see Figure 2, right graph). These options show all the data points, and thus do not provide the effect of zooming in on the area comprising the best-fitting lines or curves. The options available are: “View graph with low-high values of moderating variable and data points (standardized scales)”, and “View graph with low-high values of moderating variable and data points (unstandardized scales)”.

The “View moderating relationship in two graphs with data points” options allow users to view two-dimensional moderating effect graphs with the best-fitting lines or curves for high and low values of the moderating variable, and the data points used to produce the best-fitting lines or curves, in two graphs shown side-by-side. These options show all the data points, and thus do not provide the effect of zooming in on the areas comprising the best-fitting lines or curves. The options available are: “View two graphs with low-high values of moderating variable and data points (standardized scales)”, and “View two graphs with low-high values of moderating variable and data points (unstandardized scales)”.

THREE-DIMENSIONAL GRAPHS

After an analysis is conducted with WarpPLS where moderating links are included, the “View moderating relationship in one smooth 3D graph with data points” options allow users to view three-dimensional graphs where the surfaces are generated through Delaunay triangulations (Chew, 1989; Lee & Schachter, 1980) with smoothing (see Figure 3). Because the surfaces are generated *with* smoothing, they sometimes resemble more somewhat rumpled bed sheets than rocky mountain formations. Surfaces can be viewed with data points excluded or included. The options to view surfaces with data points excluded are: “View smooth 3D graph for moderating effect (standardized scales)” and “View smooth 3D graph for moderating effect (unstandardized scales)”. The options to view surfaces with data points included are: “View smooth 3D graph

Figure 3. Three-dimensional graphs of moderating effect



for moderating effect with data points (standardized scales)”, and “View smooth 3D graph for moderating effect with data points (unstandardized scales)”.

The “Rotate” menu option allows the user to rotate a three-dimensional graph up, down, left, and right. (See Figure 3; the right graph is a right-rotated version of graph on the left.) Through the “Settings” menu option the user can set the following three-dimensional graph options: the graph title, the moderating variable (M) axis label, the X axis label, and the Y axis label. The graph title is the text shown at the top of the graph. The M axis label is the text shown next to the moderating variable axis. The X axis label is the text shown next to the X axis, or the predictor variable axis. The Y axis label is the text shown next to the Y axis, or the criterion variable axis.

The “View moderating relationship in one rocky 3D graph” options allow users to view three-dimensional graphs where the surfaces are generated through Delaunay triangulations (Chew, 1989; Lee & Schachter, 1980) without smoothing. Surfaces can be viewed with data points excluded or included. The displays with data points excluded are analogous to those used in the focused two-dimensional graphs (discussed later). The options to view surfaces with data points excluded are: “View rocky 3D graph for moderating effect (standardized scales)” and “View rocky 3D graph for moderating effect (unstandardized scales)”. The options to view surfaces with data points included are: “View rocky 3D graph for moderating effect with data points (standardized scales)”, and “View rocky 3D graph for moderating effect with data points (unstandardized scales)”.

DISCUSSION AND CONCLUSION

The graphs of relationships between pairs of latent variables, and between latent variables and links (moderating relationships), provide a much more nuanced view of how latent variables are related than coefficients of association and related values (e.g., P values). However, caution must be taken in the interpretation of these graphs, especially when the distribution of data points is very uneven. Outliers can strongly influence the shape of a two-dimensional or three dimensional graph. In cases such as this, the researcher must decide whether the outliers are “good” data that should be allowed to shape the relationships, or “bad” data resulting from a data collection error.

If the outliers are found to be “bad” data, they can be removed from the analysis, even as they remain in the dataset, by a simple procedure. The user should first add one or more latent variable scores to the set of standardized indicators used in a structural equation modeling analysis, using the appropriate menu option under the option “Modify”, from the main software window, after Step 5 is completed. The user can then remove the outliers by restricting the values assumed by the latent variable, using the appropriate selections under the “Settings” options,

to a range that excludes the outliers. This allows for the exclusion of outliers without the user having to modify and re-read a dataset.

Outliers that are found to be “bad” data can also be removed from the dataset, and thus from the analysis, by a more time-consuming procedure. The user should first save the latent variable scores into a file, using the appropriate “Save” menu option in the results window, after Step 5 is completed. Then the user should add those scores to the original dataset; the rows will be in the same order. Next the user should open the modified dataset with a spreadsheet software tool (e.g., Excel). The outliers should be easy to identify on the dataset (e.g., a value greater than 4), and should be eliminated. Then the user should re-read this modified file as if it was the original data file, and run all of the structural equation modeling analysis steps again.

It is important to note that none of the moderating relationship graphs discussed above accurately represents the true nature of a moderating relationship. Therefore various graphs are provided by WarpPLS so that users can choose the one that in their view best illustrates the relationship. An accurate representation of a moderating relationship would be that of a multivariate distortion in the surface representing the relationship.

The distortion refers to a “twisting” of the surface around the moderating variable axis, with a multivariate adjustment, and with corresponding changes in the overall inclinations of the sections of the surface representing the direct effect being moderated. The mathematical underpinnings of such representation were still under development at the time of this writing, and may be available for implementation in future versions of the software WarpPLS.

ACKNOWLEDGMENT

The author is the developer of the software WarpPLS, which is extensively used in e-collaboration research. WarpPLS has over 7,000 users in more than 33 different countries at the time of this writing. The author is also the moderator of the PLS-SEM e-mail distribution list. He is grateful to those users, and to the members of the PLS-SEM e-mail distribution list, for questions, comments, and discussions on topics related to structural equation modeling and to the use of WarpPLS.

REFERENCES

- Chew, L. P. (1989). Constrained Delaunay triangulations. *Algorithmica*, 4(1-4), 97–108. doi:10.1007/BF01553881
- Kock, N. (2011). Using WarpPLS in e-collaboration studies: Mediating effects, control and second order variables, and algorithm choices. *International Journal of e-Collaboration*, 7(3), 1–13. doi:10.4018/jec.2011070101
- Kock, N. (2014a). Using data labels to discover moderating effects in PLS-based structural equation modeling. *International Journal of e-Collaboration*, 10(4), 1–14. doi:10.4018/jec.2014100101
- Kock, N. (2014b). *Stable P value calculation methods in PLS-SEM*. Laredo, TX: ScriptWarp Systems.
- Kock, N. (2015a). A note on how to conduct a factor-based PLS-SEM analysis. *International Journal of e-Collaboration*, 11(3), 1–9. doi:10.4018/jec.2015070101
- Kock, N. (2015b). *WarpPLS 5.0 User Manual*. Laredo, TX: ScriptWarp Systems.
- Kock, N., & Lynn, G. S. (2012). Lateral collinearity and misleading results in variance-based SEM: An illustration and recommendations. *Journal of the Association for Information Systems*, 13(7), 546–580.

Kock, N., & Mayfield, M. (2015). PLS-based SEM algorithms: The good neighbor assumption, collinearity, and nonlinearity. *Information Management and Business Review*, 7(2), 113–130.

Kock, N., & Verville, J. (2012). Exploring free questionnaire data with anchor variables: An illustration based on a study of IT in healthcare. *International Journal of Healthcare Information Systems and Informatics*, 7(1), 46–63. doi:10.4018/jhisi.2012010104

Lee, D. T., & Schachter, B. J. (1980). Two algorithms for constructing a Delaunay triangulation. *International Journal of Computer & Information Sciences*, 9(3), 219–242. doi:10.1007/BF00977785

Paxton, P., Curran, P. J., Bollen, K. A., Kirby, J., & Chen, F. (2001). Monte Carlo experiments: Design and implementation. *Structural Equation Modeling*, 8(2), 287–312. doi:10.1207/S15328007SEM0802_7

Robert, C. P., & Casella, G. (2005). *Monte Carlo statistical methods*. New York, NY: Springer.

Wright, S. (1934). The method of path coefficients. *Annals of Mathematical Statistics*, 5(3), 161–215. doi:10.1214/aoms/1177732676

Wright, S. (1960). Path coefficients and path regressions: Alternative or complementary concepts? *Biometrics*, 16(2), 189–202. doi:10.2307/2527551

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