A STEP-BY-STEP GUIDE

# PLS-SEM

# DATA ANALYSIS USING SMARTPLS 4

PARTIAL LEAST SQUARES | STRUCTURAL EQUATION MODELING

Mediation Models | Moderation Models
Two-Stage Approach | Multigroup Analysis
Multiple-Order Models | Formative Models

CHUA YAN PIAW

A STEP-BY-STEP GUIDE

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# Brief Contents

# Detailed Contents

# Preface

I had the idea of writing this book while I was conducting data analysis workshops for postgraduates at local universities, at a time when some students stated that there was no step-by-step guide for SmartPLS data analysis book to refer to while they were conducting research. Then I started planning the contents of this book while I was on sabbatical leave at the University of Washington in Seattle, USA in 2014. However, due to the workload, the draft of the book could only be completed while I was on duty as a visiting professor for a year in 2019 at the University of Sussex in Brighton, UK. Now, this book has been successfully published and my dream has come true.

PLS-SEM is a popular quantitative data analysis method in most academic disciplines now; in education, economics and business studies, psychology, medicine, nursing and health, social sciences, natural sciences, applied sciences, etc. This book contains 5 Chapters. It is a step-by-step practical guide that covers many aspects of the PLS-SEM analysis, including the concept, theories, and data analysis.

This book focuses on a step-by-step guide for data analysis using the SmartPLS 4, including *1. Analyzing mediation models, 2. Analyzing moderation models using the two-stage approach, 3. Analyzing moderating effects using the multigroup analysis, 4. Analyzing multiple-order models, and 5. Analyzing formative models*.

The book is a useful teaching and learning tool for research courses at both undergraduate and postgraduate levels. Concepts are explained in detail with *11* step-by-step hands-on *research examples* to enable readers to carry out confidently each stage of the research and in the PLS-SEM data analysis process. Exercises are provided at the end of each chapter to reinforce readers' understanding of the chapter.

In each chapter, complete research datasets with PLS-SEM data analysis steps, detailed interpretation of the analysis results, and research reports will be presented. Readers will understand how to analyze their data using PLS-SEM after reading the chapters.

Some individuals played important roles during my efforts to make this book a reality. I would like to thank Possessor Gillian Hampden-Thompson; The Head of School of Education and Social Work, University of Sussex, the UK as the host of my visit to the university, who has given me the opportunity and encouragement in the process of completing this book. Besides that, special thanks to the staff in the Faculty of Education, University of Malaya, Malaysia, especially those in the Mathematics and Science Education Department, as well as my students, and readers of my books.

I appreciate everything that accompanied me in preparing this book, my laptop, wall fan, room lamps, and my wife who likes to joke and talk all sorts of weird and funny things and news with me while I was stuck with ideas.

Thank you very much. 😆

Chua Yan Piaw

Email: yanpiaw@gmail.com

YouTube channel:
https://www.youtube.com/channel/UCOlj2ylD0uXPPqxOi9ow_xw

# About the Author

*Chua* Yan Piaw is a professor in the Department of Mathematics and Science Education at the University of Malaya. In 2019, he was a visiting professor at the School of Social Work and Education, University of Sussex, Brighton, UK, and in 2014, he was a visiting professor at the Department of Sociology, University of Washington, Seattle, USA. His series of books, *Research Methods and Statistics*, books 1 to 5 with 62 chapters, are among McGraw Hill's Top-10 Bestselling Titles in Malaysia. In addition, his book *Mastering Research Methods, 2nd Edition* was awarded the 2018 Book Publication Award by the University of Malaya. As a result of his contributions to reviewing articles for Elsevier's Web-of-Science journals, especially the Computers in Human Behavior, he received the hand-picked *2016 Excellent Reviewer Award*, and the 2016-2019 *Outstanding in Reviewing* awards from Elsevier. His inventions and innovations have won six gold medals at international invention and innovation expos, as well as five gold medals at the world peace painting and calligraphy exhibitions. He has been an invited speaker for more than a hundred AMOS, SPSS, and SmartPLS workshops. From 2015 to 2017, he was invited by the Institute of Graduate Studies, University of Malaya to conduct 38 data analysis workshops (14 hours each) for postgraduate students at the university to enhance their data analysis skills under the Upskill Program. Between 2015 and 2016, he was invited by the National Sports Institute of Malaysia to conduct 12 data analysis workshops for bio-mechanists, nutritionists, and psychologists of national athletes at the institute to enhance their data analysis skills.

*This book is dedicated to*

*my wife Bok Kai Wa*

*my three daughters*

*and*

*in the memory of my parents*

# CHAPTER 1

# ANALYZING MEDIATION MODELS

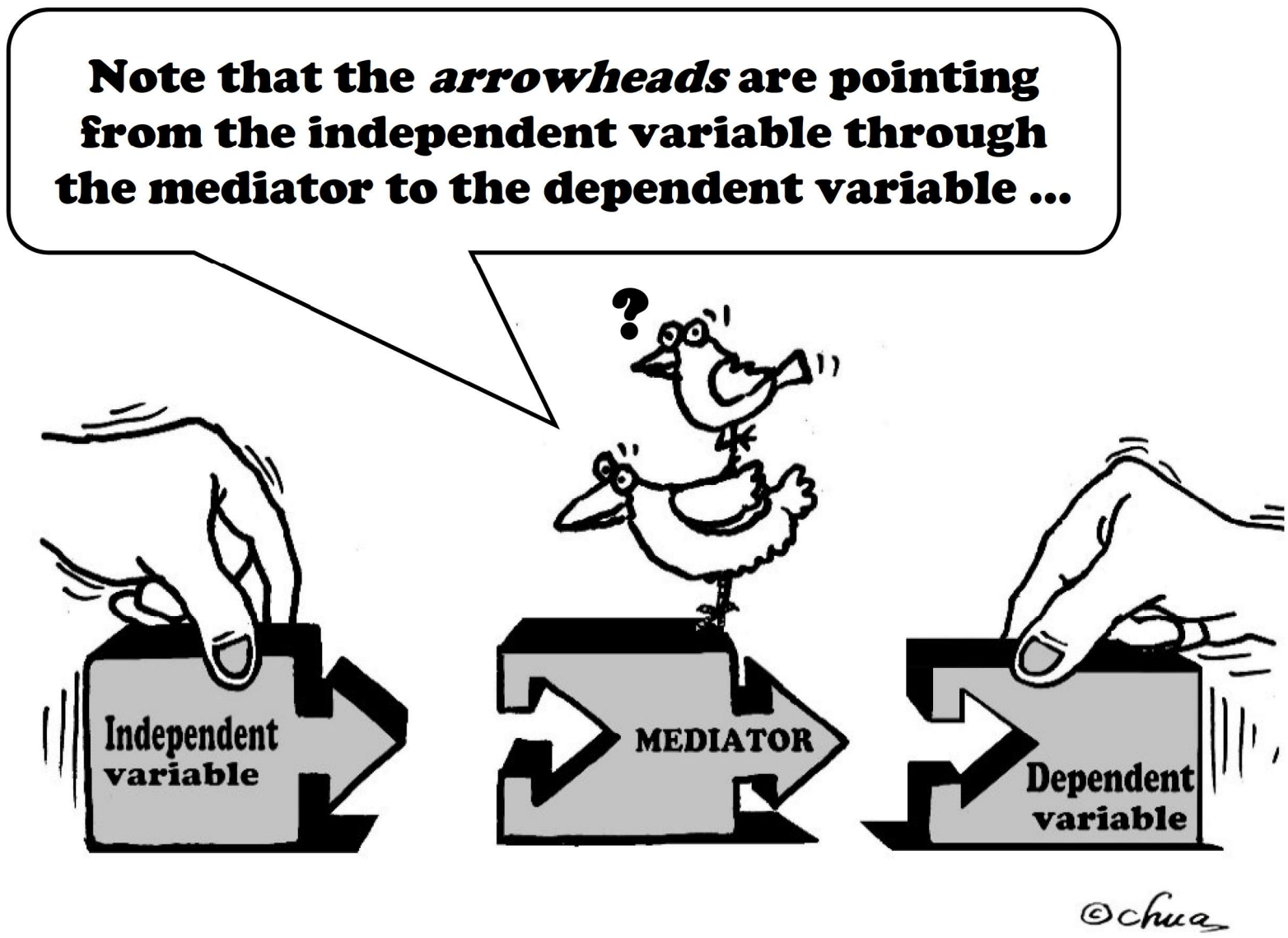



Figure 1.1: The concept of mediation

## THE CONCEPT OF MEDIATION MODELS

The mediator is the third variable that affects the effect of the independent variable on the dependent variable in a mediation model. In the mediation model, the mediator is located between the independent variable and dependent variable in a *recursive model* where it forms an *indirect effect* on the relationship between the independent variable and dependent variable.

In short, mediators are intermediate variables that either increase or decrease the effect of the independent variable on the dependent

variable. The effect of the mediator can be explained using the mediation model in Figure 1.2.

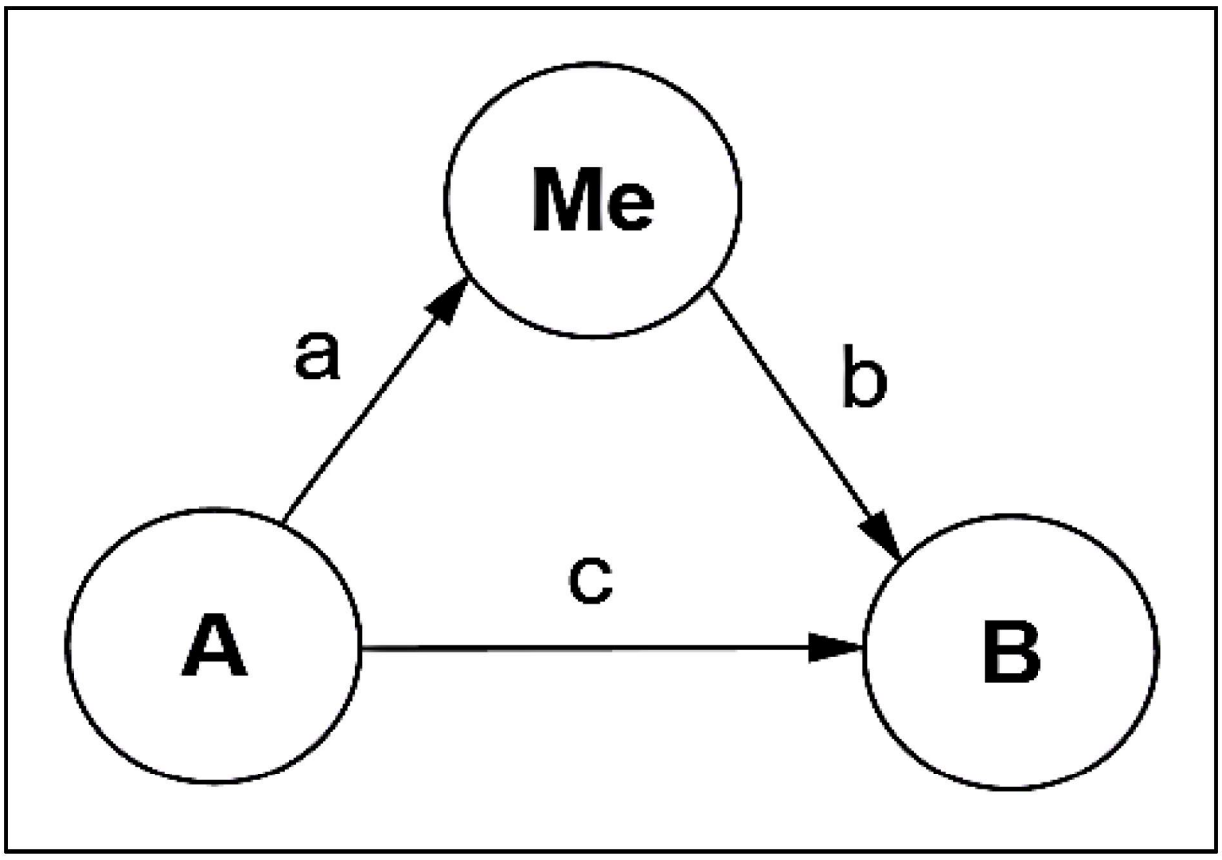



Figure 1.2: An example of a mediation model

In Figure 1.2, A is the independent variable and B is the dependent variable. The causal relationship between A and B is represented by the path coefficient c, which is the *direct effect* of A on B. In the mediation model, the causal relationship between A and B is mediated by the mediator (Me). The mediating effect of Me on the causal relationship between A and B equals the path coefficient of A→Me multiplies the path coefficient of Me→B. This means the mediating effect of the mediator Me is a x b.

The total of the *direct effect* c and the *indirect effect* a x b is the total effect of the causal relationship between A and B. The total effect equals a + b x c. The effects are summarized as follows:

Direct effect = c
Indirect effect = a x b
Total effect = Direct effect + Indirect effect = c + a x b

## FULL MEDIATING EFFECT AND PARTIAL MEDIATING EFFECT

Mediating effects can be classified into full effect and partial effect. A mediating effect exists if there is a relationship between the

independent variable (A) and the mediator (Me), and the relationship between the mediator and the dependent variable (B). Simply put, it occurs when the path of A→Me→B is significant. The conditions of the full and partial mediating effects are as follows:

### 1. Full mediating effect

A full mediating effect occurs when the direct effect (coefficient c) is insignificant, and the indirect effect (a x b) is significant. If a x b is positive, the full mediating effect is positive while if a x b is negative, the full mediating effect is negative (see Figure 1.3).

### 2. Partial mediating effect

This effect occurs when both the direct effect (coefficient c) and the indirect effect (a x b) are significant (Figure 1.3). A positive partial mediating effect occurs when a x b is positive. When a x b is negative, a negative partial mediating effect occurs.

### 3. No mediating effect

Mediating effect does not occur when at least one of the paths connected to the mediator (Me) is insignificant. This means when a or b is insignificant, mediating effect does not occur. This is because a x b = 0 when a or b = 0.

**Full mediating effect**
The direct effect is insignificant, and the indirect effect is significant

**Partial mediating effect**
The direct effect and indirect effect are significant

**No mediating effect**
When a or b in the mediation model is insignificant

Figure 1.3 presents examples of mediating effects in mediation models.

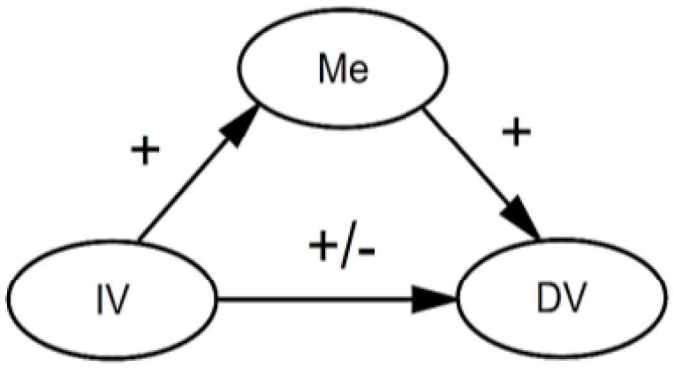
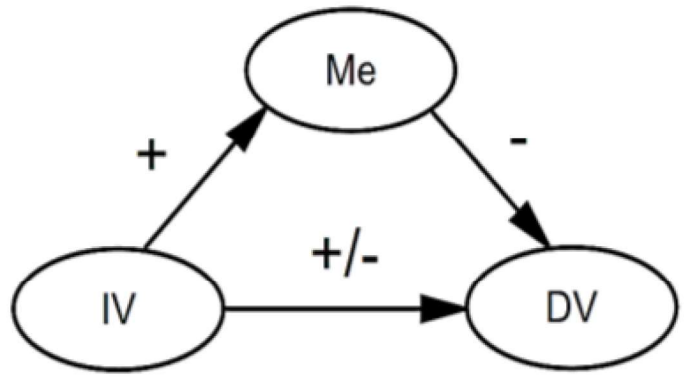
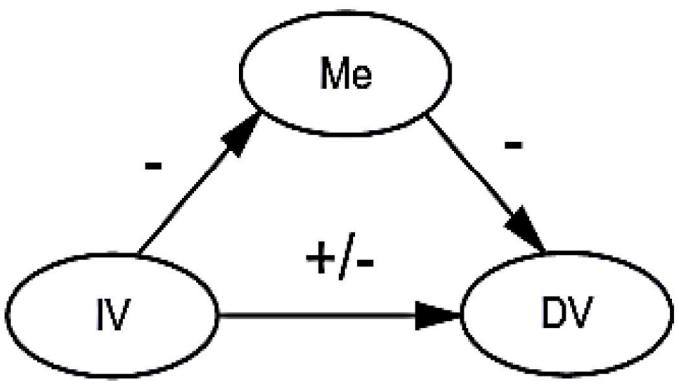
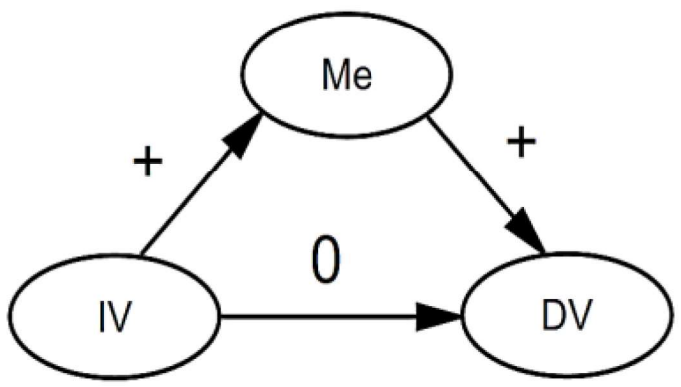
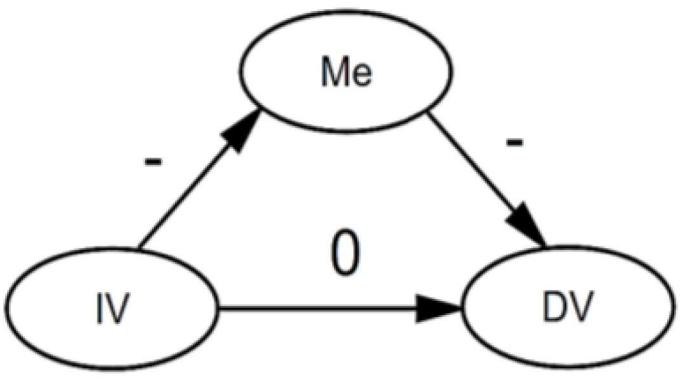
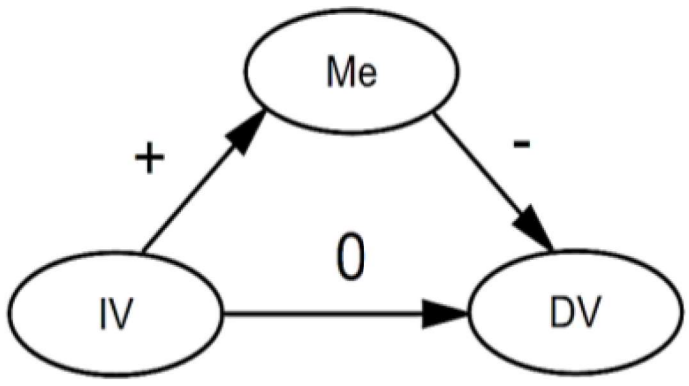
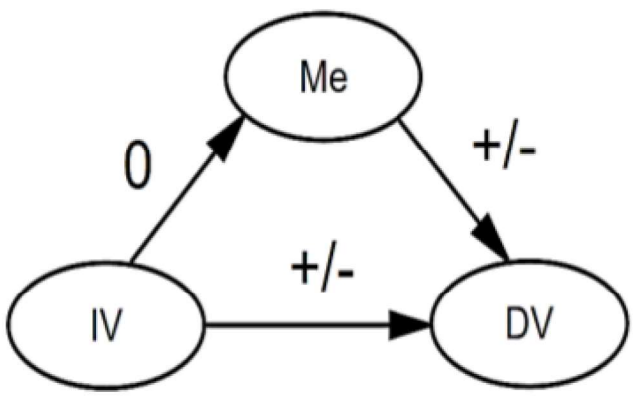
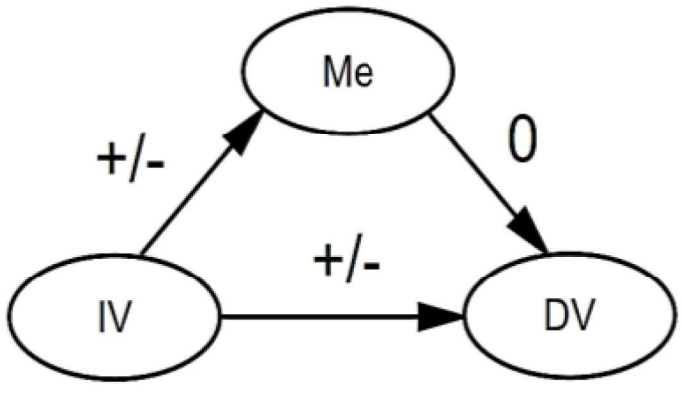
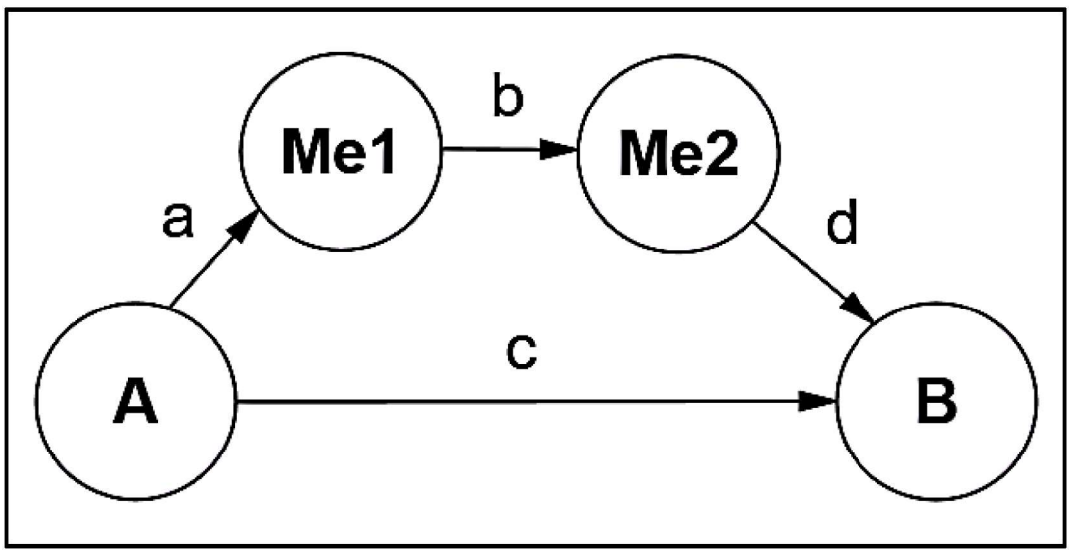
| Positive partial mediating effect | Negative partial mediating effect |
|---|---|
|  |  |
| **Positive partial mediating effect** | **Positive full mediating effect** |
|  |  |
| **Positive full mediating effect** | **Negative full mediating effect** |
|  |  |
| **No mediating effect** | **No mediating effect** |
|  |  |

Figure 1.3: Examples of mediating effects

## SEQUENTIAL AND PARALLEL MEDIATING EFFECTS

A mediation model can have more than a mediator. There are two types of mediators in a mediation model that has more than a single mediator: *Sequential mediators* and *Parallel mediators*. Figure 1.4 presents the two types of mediators.

(a) Sequential mediators




(b) Parallel mediators

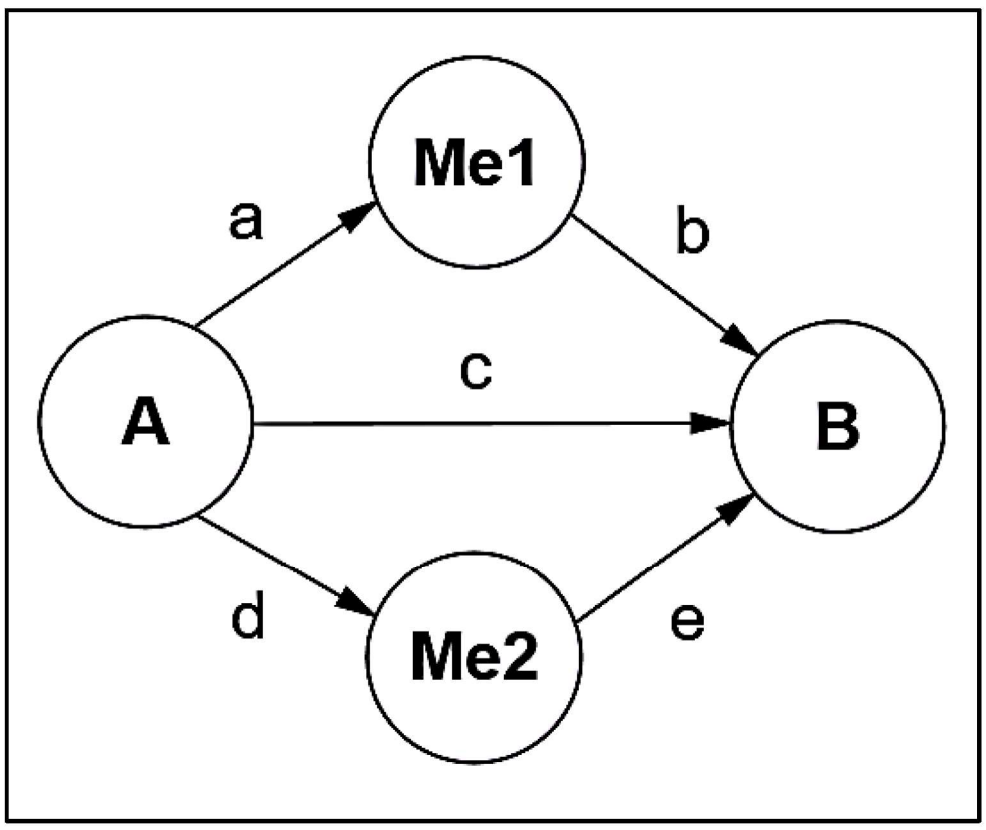



Figure 1.4: Sequential mediators and parallel mediators

### 1. Sequential mediating effects

Figure 1.4(a) presents the sequential mediating effect of Me1 and Me2 on the causal relationship between A and B. For the sequential mediation model, the mediating effect is calculated by multiplying the three mediation paths A→Me1, Me1→Me2, and Me2→B. This means

the mediating effect in Figure 1.4(a) is a x b x d. Thus, the total effect c' equals c + a x b x d.

In this model, if one of the path coefficients of a, b, or d is negative, the mediating effect is negative. However, if two of them are negative, the effect is positive. If the three path coefficients are negative, then the mediating effect is negative.

## 2. Parallel mediating effects

Figure 1.4(b) presents the parallel mediating effect of Me1 and Me2 on the causal relationship between A and B. For the parallel mediation model, the mediating effect for the relationship between A and B is the total mediating effect of the first mediator (Me1) and the second mediator (Me2). This means the mediating effect in Figure 1.4(b) equals a x b + d x e. The total effect c' equals c + a x b + d x e.

When one of the mediating effects of Me1 and Me2 is negative, *effect competition* between the two mediators takes place. For example, if the mediating effect of Me1 (a x b) = 0.30 and the mediating effect of Me2 (d x e) = -0.20, then the mediating effect is positive with the effect size 0.10 (calculated from 0.30 + (-0.20) = 0.10). On the other hand, if the mediating effect of Me1 (a x b) is -0.45 and the mediating effect of Me2 (d x e) = 0.20, then the mediator effect is negative with an effect size of -0.25 (calculated from -0.45 + 0.20 = -0.25).

When the value of c (direct effect) is negative, the total effect c' is positive (c + a x b + d x e) when the total mediating effect (a x b + d x e) is positive and greater than c. In this case, the mediator changes the effect of A→B from negative to positive. If the total mediating effect is positive, the *reduction effect* occurs where the mediating effect reduces the negative effect of A→B. For example, if the direct effect c = -0.65 and the total mediating effect (a x b + d x e) = 0.40, then the mediating effect reduces the effect of A→B from -0.65 to -0.25 (calculated from -0.65 +0.40 = -0.25).

Another condition of the parallel mediating effect is when the two mediating effects Me1 and Me2 are equal and one of them is negative, then the total mediating effect = 0. For example, if the mediating effects of Me1 = 0.20 and Me2 = -0.20, the total mediating effect is 0.20 + (-0.20) = 0.

## MEDIATING EFFECT SIZES

To interpret the effect size, Kenny (2021) refers to the path coefficient (β). He stated that the *mediating effect sizes* are 0.01 for a small effect, 0.09 for a medium effect, and 0.25 for a large effect.

However, if the independent variable is in the *dichotomy scale* (a nominal data with two scales, for example, 1= Low and 2 = High, or 1 = No and 2 = Yes), then the β values for mediating effects would be 0.02 for a small effect, 0.15 for a medium effect and 0.40 for a large effect.

The following sections present three examples of mediating effects' analysis with the PLS-SEM using the SmartPLS in a *single mediation model* (Example 1.1), a *sequential mediation model* (Example 1.2), and a *parallel mediation model* (Example 1.3).

# EXAMPLE 1.1

## ANALYZING THE EFFECTS IN A MEDIATION MODEL

### THE MEDIATING EFFECT OF HELPING BEHAVIOR ON THE RELATIONSHIP BETWEEN TEAMWORK AND WORK STRESS

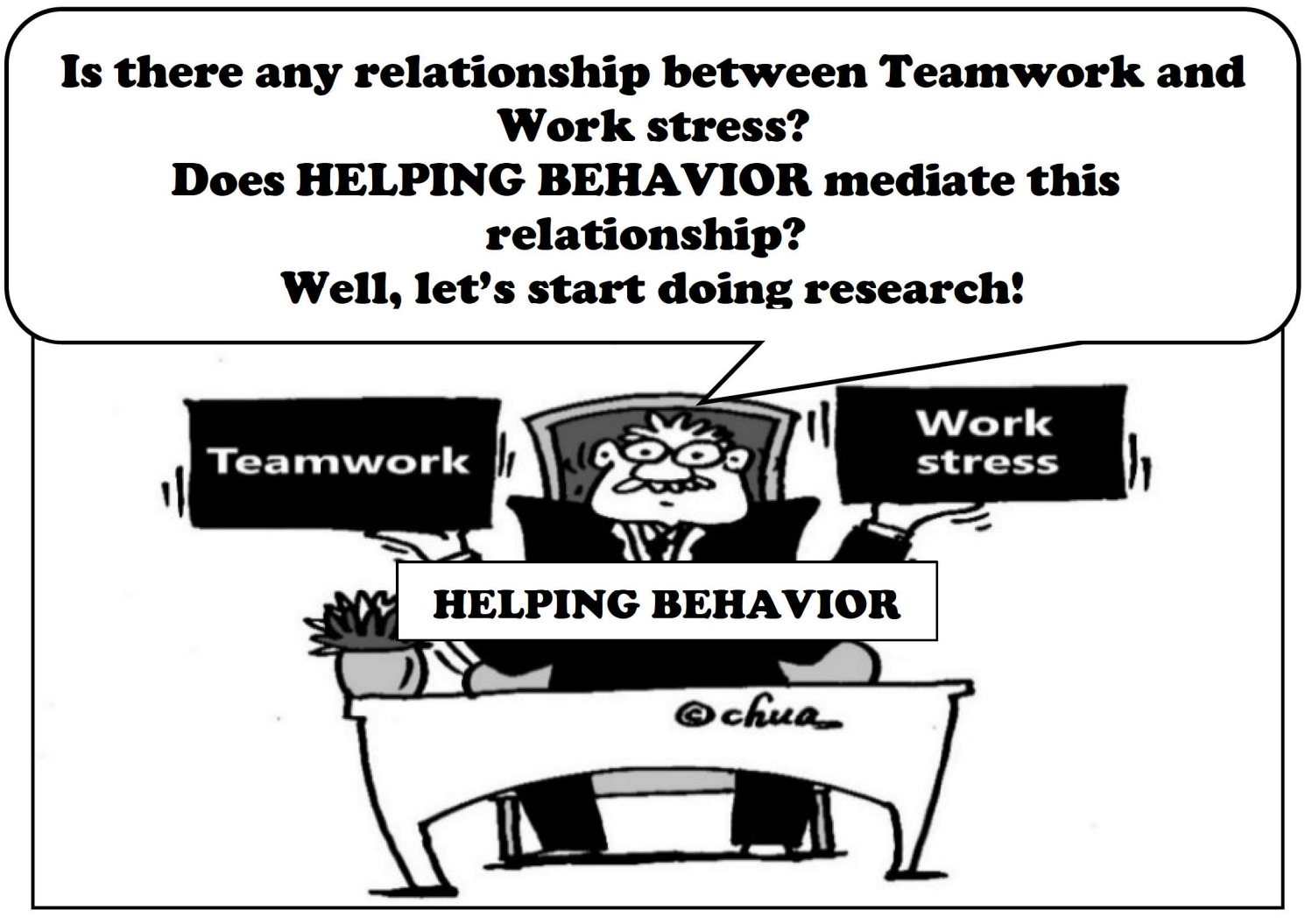



Figure 1.5: The mediating effect of helping behavior

A researcher reviews the literature and speculates that *Helping behavior* may be a mediator for the causal relationship between *Teamwork* and *Work stress*. He conducts a study to examine the causal relationship between Teamwork and Work stress, and to what extent Helping behavior mediates the relationship.

The research objectives of his study are to examine:

1. The direct effect of Teamwork on Work stress.
2. The direct effect of Teamwork on Helping behavior.
3. The direct effect of Helping behavior on Work stress.
4. The mediating effect of Helping behavior on the causal relationship between Teamwork and Work stress.

The hypothesized model of his study is presented in Figure 1.6.

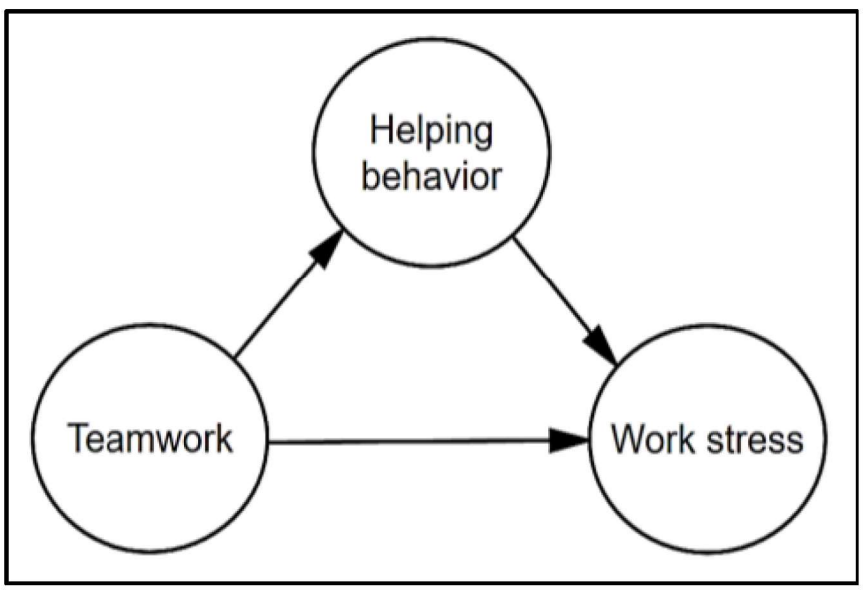


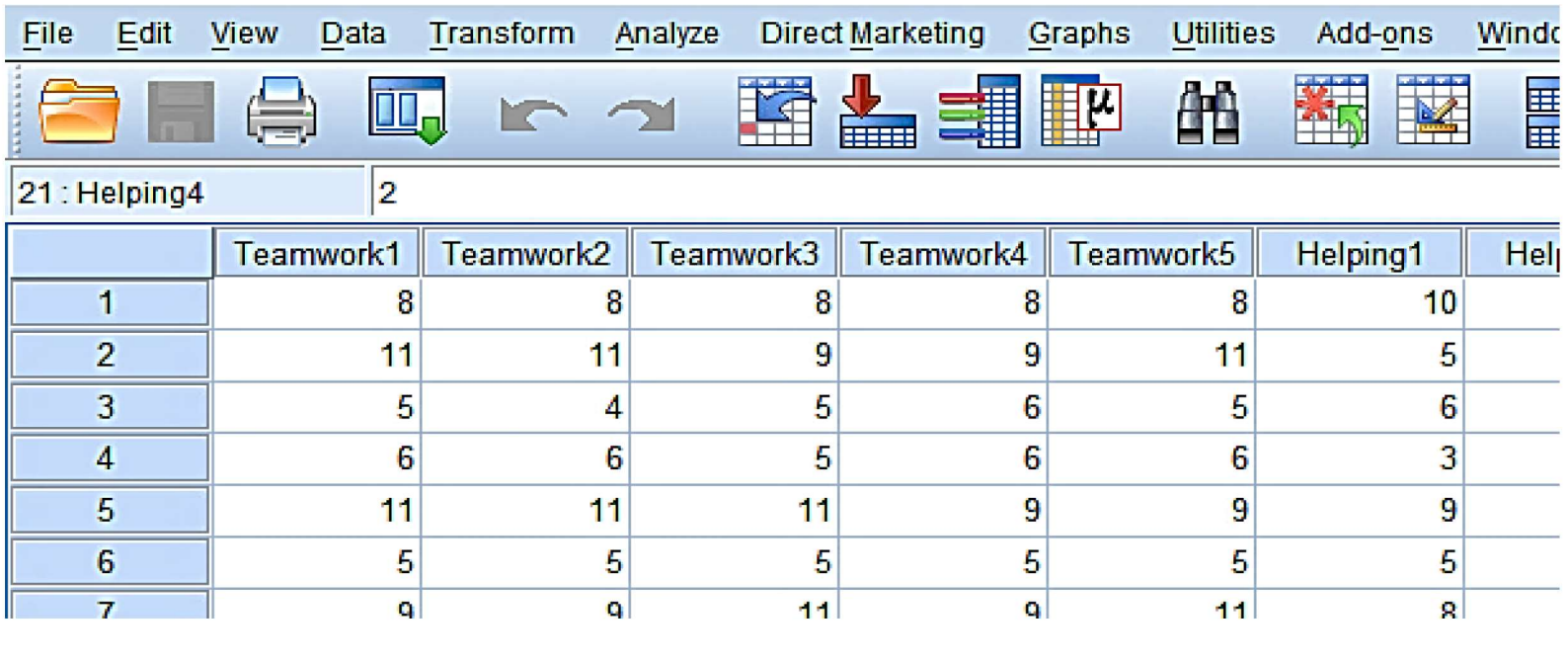

Figure 1.6: The hypothesized model of the study

The researcher randomly selects a sample consisting of 209 students from a student population in the Faculty of Law of the University A. The sample answers a questionnaire measuring three variables: (a) Teamwork with 5 items, (b) Helping behavior with 7 items, and (c) Work stress with 4 items (Table 1.1). All the items are measured with the Likert scale of 1-11 points.

Table 1.1: The indicators of the three variables

| No | Latent variable | Indicator |
|---|---|---|
| 1 | Teamwork | Teamwork1, Teamwork2, Teamwork3, Teamwork4, Teamwork5 |
| 2 | Helping behavior | Helping1, Helping2, Helping3, Helping4, Helping5, Helping6, Helping7 |
| 3 | Stress | Stress1, Stress2, Stress3, Stress4 |

The data of the study is entered into the **SPSS Data Statistics Editor** and saved as "**Data chapter 1**". The following is part of the data.



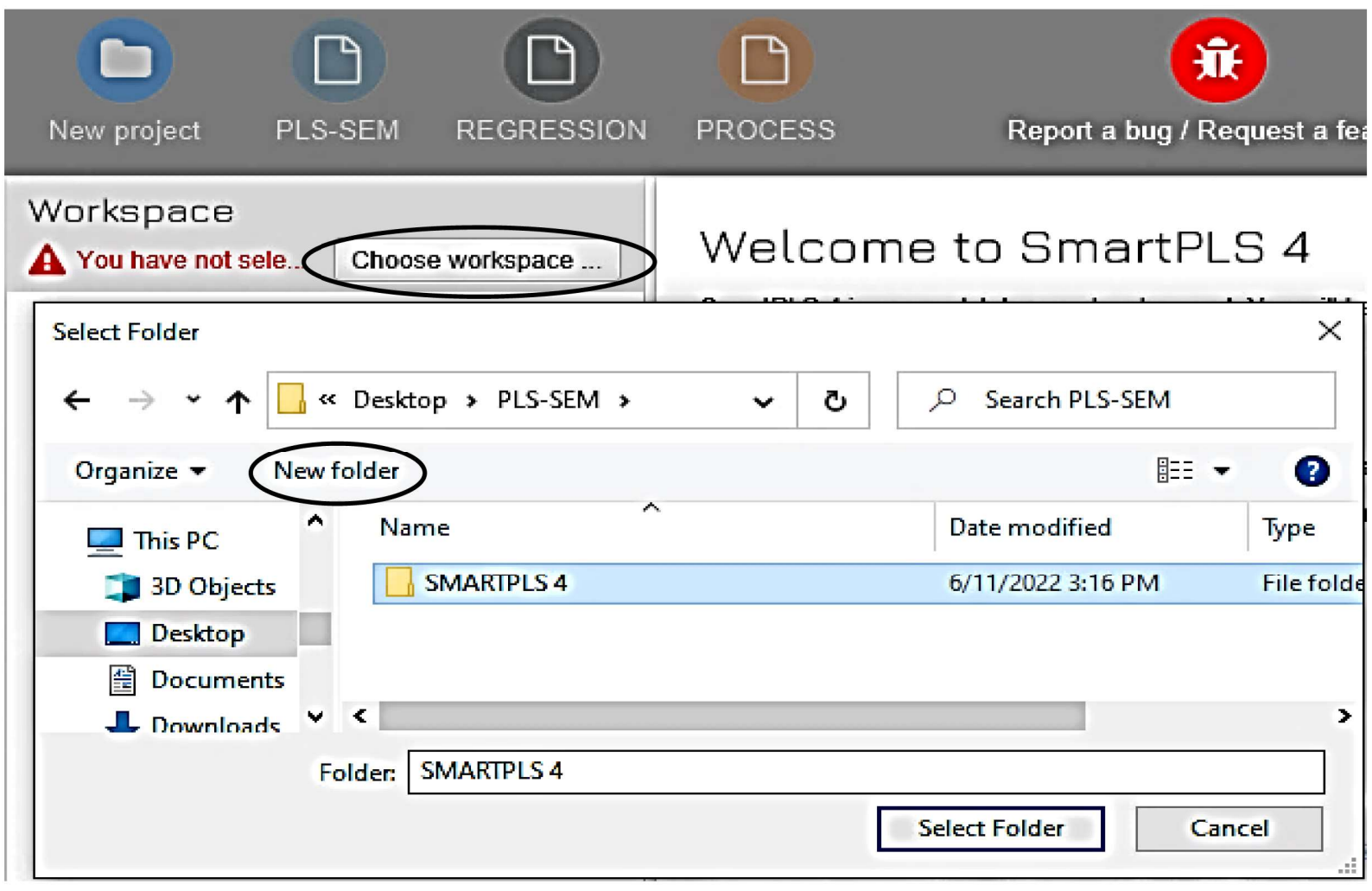

| | Teamwork1 | Teamwork2 | Teamwork3 | Teamwork4 | Teamwork5 | Helping1 | Hel |
|---|---|---|---|---|---|---|---|
| 1 | 8 | 8 | 8 | 8 | 8 | 10 | |
| 2 | 11 | 11 | 9 | 9 | 11 | 5 | |
| 3 | 5 | 4 | 5 | 6 | 5 | 6 | |
| 4 | 6 | 6 | 5 | 6 | 6 | 3 | |
| 5 | 11 | 11 | 11 | 9 | 9 | 9 | |
| 6 | 5 | 5 | 5 | 5 | 5 | 5 | |
| 7 | 9 | 9 | 11 | 9 | 11 | 8 | |

## FIRST STEP: CREATING A PROJECT, IMPORTING THE DATA, AND DRAWING THE PLS-SEM MODEL

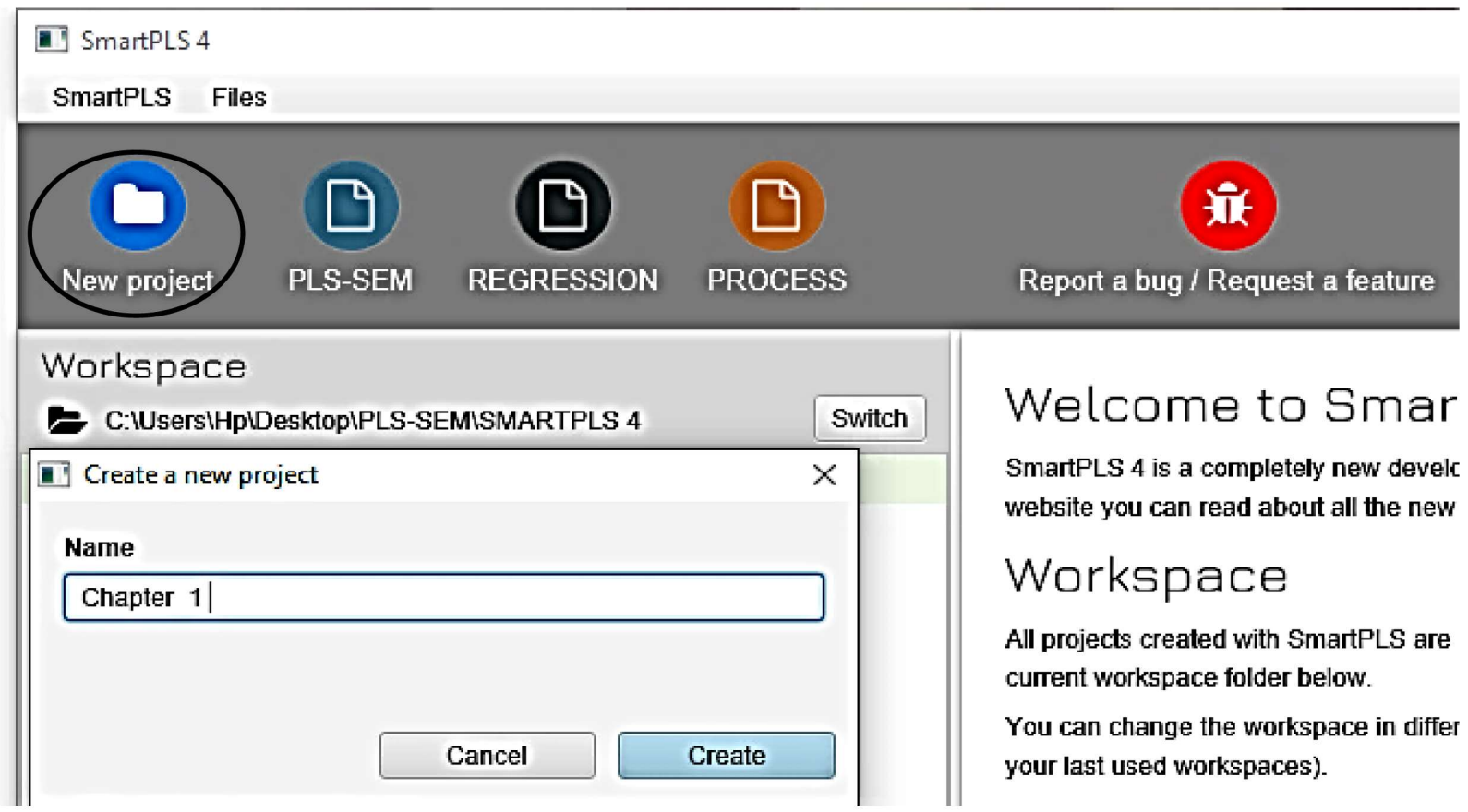
### 1. Creating the project and importing the data into SmartPLS

**STEPS**

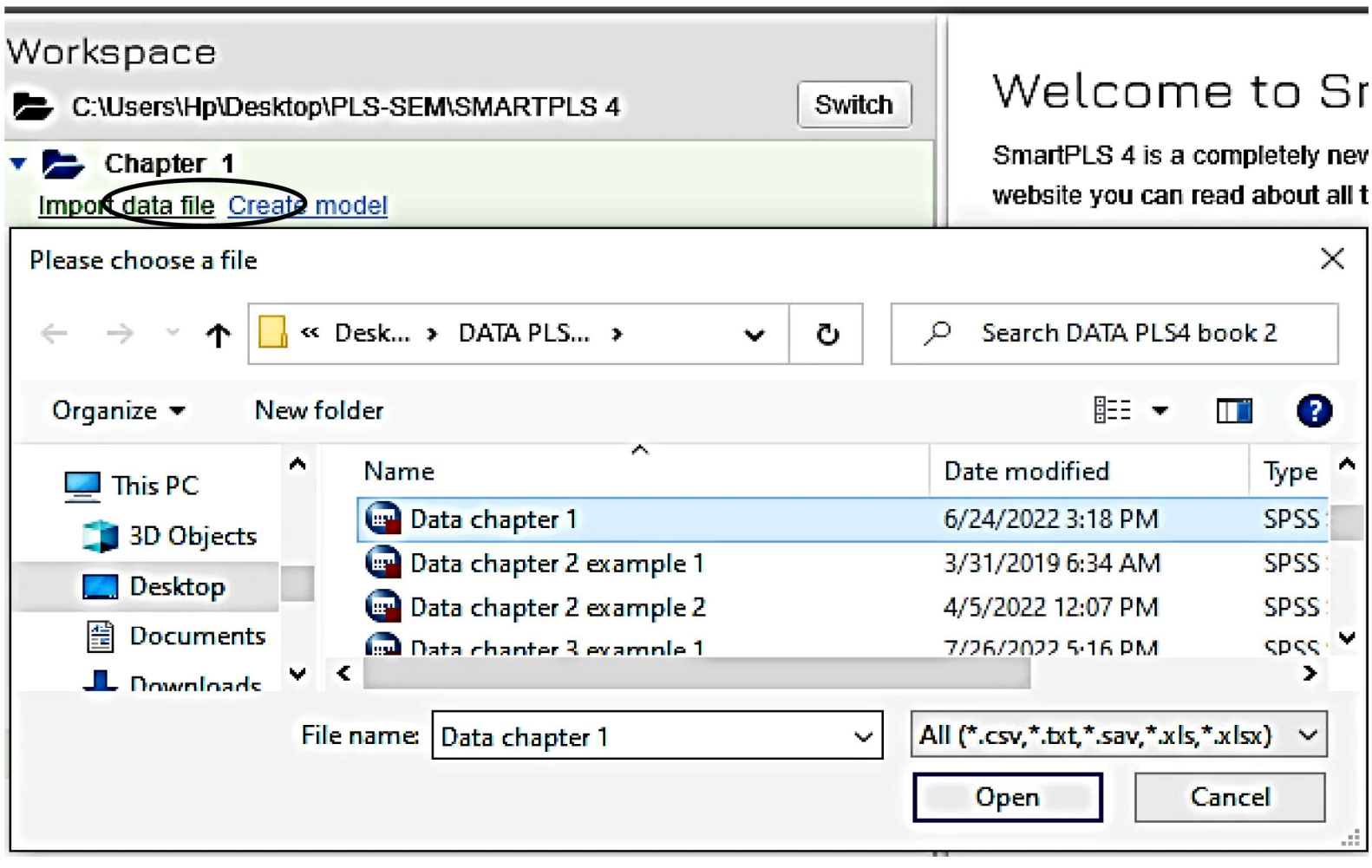
1. Double-click the icon of the SmartPLS to open the software. Select the **Choose workspace** button to create a workspace for the project. Click the **New folder** button to create a new folder and type the name **SMARTPLS 4** to name the folder. Then click the **Select Folder** button to create the new workplace for the project.



2. On the top-left corner in the SmartPLS window, click the **New project** button and type the project name **Chapter 1** in the **Name** box. Then click the **Create** button.

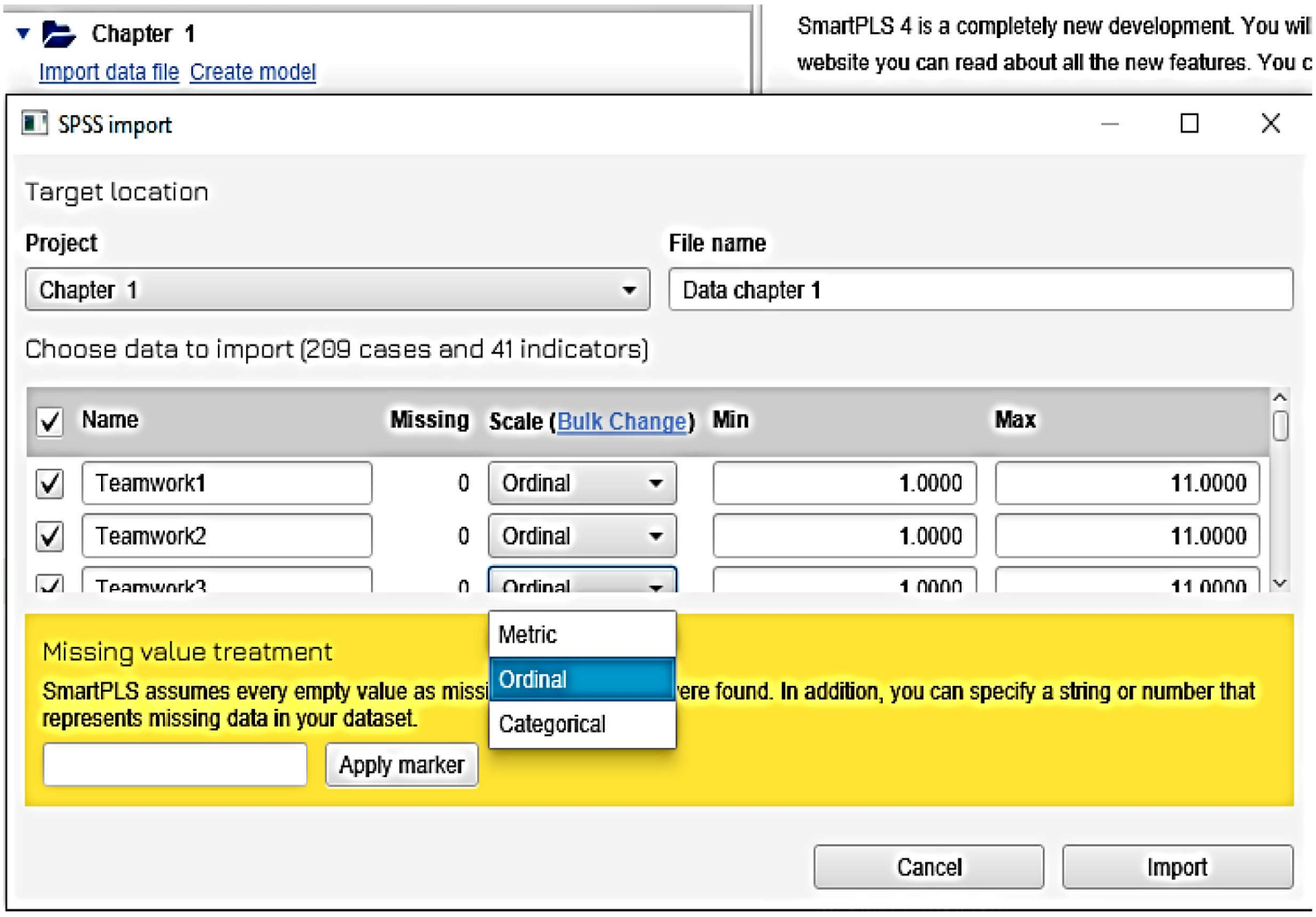



3. The project **Chapter 1** appears. Click the **Import data file** label. Then select the SPSS data, which is **Data chapter 1** from the folder it was saved earlier. Click the **Open** button to import the SPSS data into the SmartPLS.

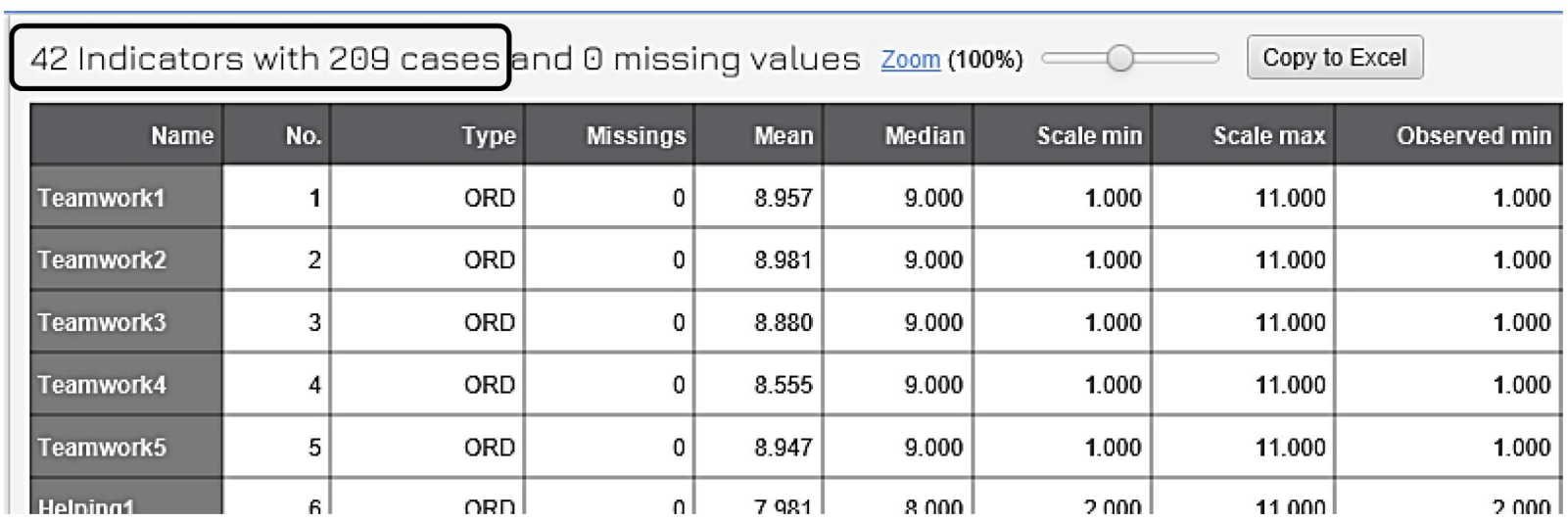



4. **Data chapter 1** appears. The data of the indicators of the three variables in this study is the Likert-type scale with 1-11 points, an *ordinal data*. Select **Ordinal** for all the indicators. Then click the

**Import** button to import the data into the project. [Note: **Matric** is for *interval* or *ratio* scale data, **Categorical** is for *nominal* scale data which has *more than 2 categories*.]

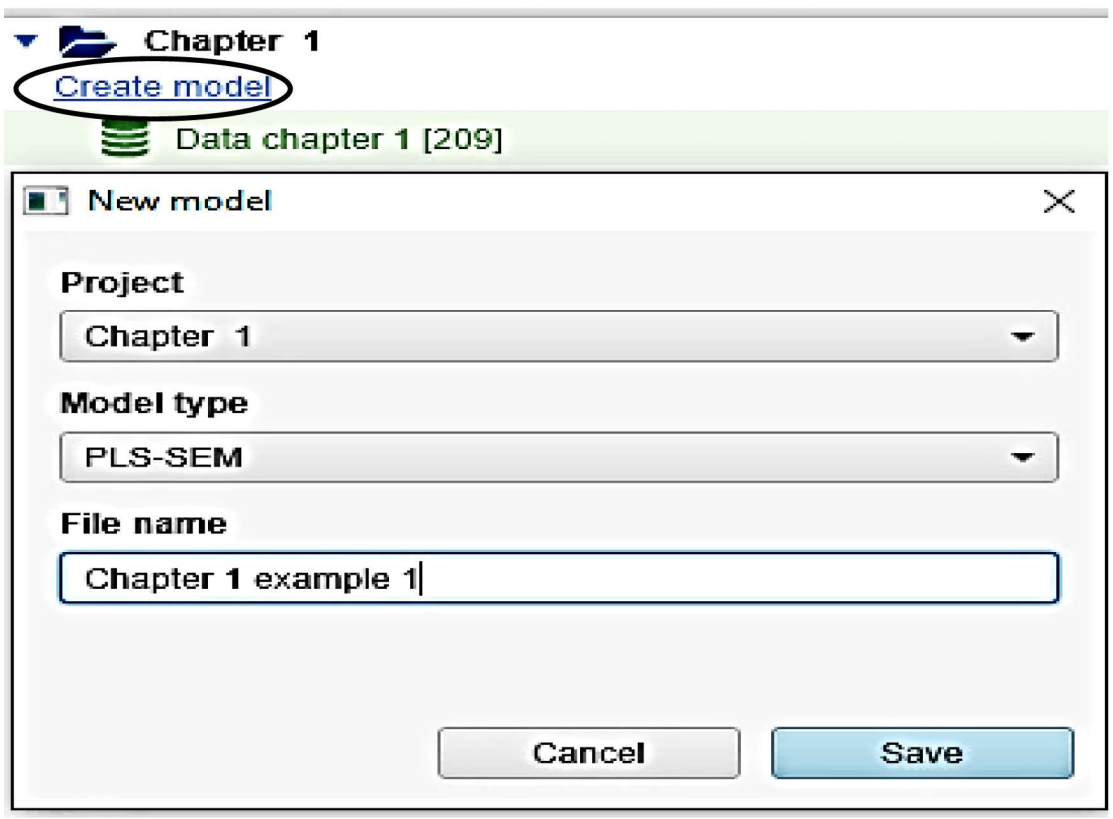



5. The **descriptive statistics** (mean, median, min, max) and **normality** (*excess kurtosis*, *skewness*, and the *p-values* of the *Cramer-van Mises* normality test) of the data (*42 indicators with 209 respondents*) are tabulated.

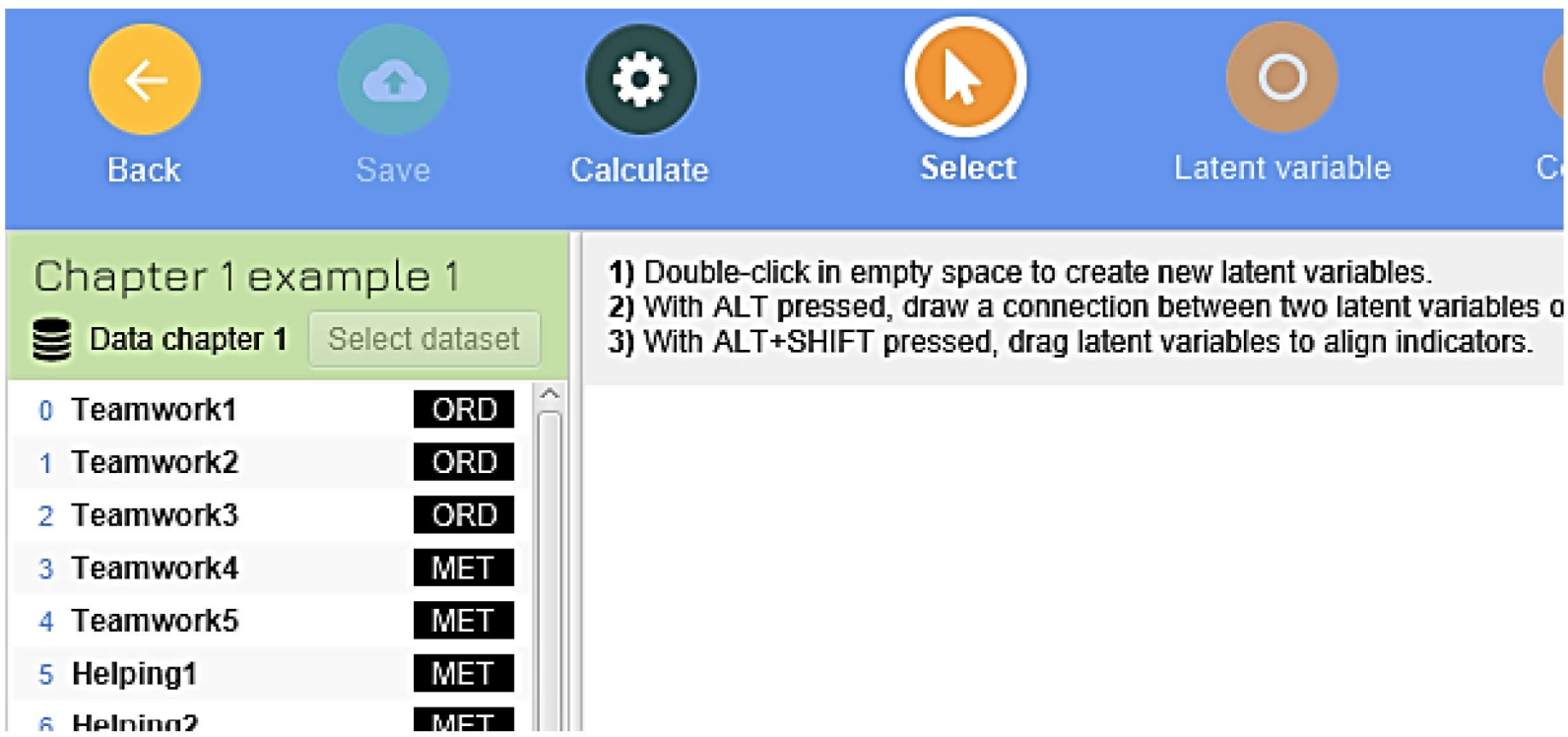



| Name | No. | Type | Missings | Mean | Median | Scale min | Scale max | Observed min |
|---|---|---|---|---|---|---|---|---|
| Teamwork1 | 1 | ORD | 0 | 8.957 | 9.000 | 1.000 | 11.000 | 1.000 |
| Teamwork2 | 2 | ORD | 0 | 8.981 | 9.000 | 1.000 | 11.000 | 1.000 |
| Teamwork3 | 3 | ORD | 0 | 8.880 | 9.000 | 1.000 | 11.000 | 1.000 |
| Teamwork4 | 4 | ORD | 0 | 8.555 | 9.000 | 1.000 | 11.000 | 1.000 |
| Teamwork5 | 5 | ORD | 0 | 8.947 | 9.000 | 1.000 | 11.000 | 1.000 |
| Helping1 | 6 | ORD | 0 | 7.981 | 8.000 | 2.000 | 11.000 | 2.000 |

6. Click the **Back** button. Under the **Chapter 1** project, click the **Create model** label. Select **PLS-SEM** under **Model type**, and in the **File name** box, type the file name **Chapter 1 example 1**. Then click the **Save** button. [Note: All examples in this book will be named according to the number of chapters and examples.]




7. The SmartPLS panel appears. The left panel lists all indicators in the dataset. The right panel is ready for drawing the graphical model.

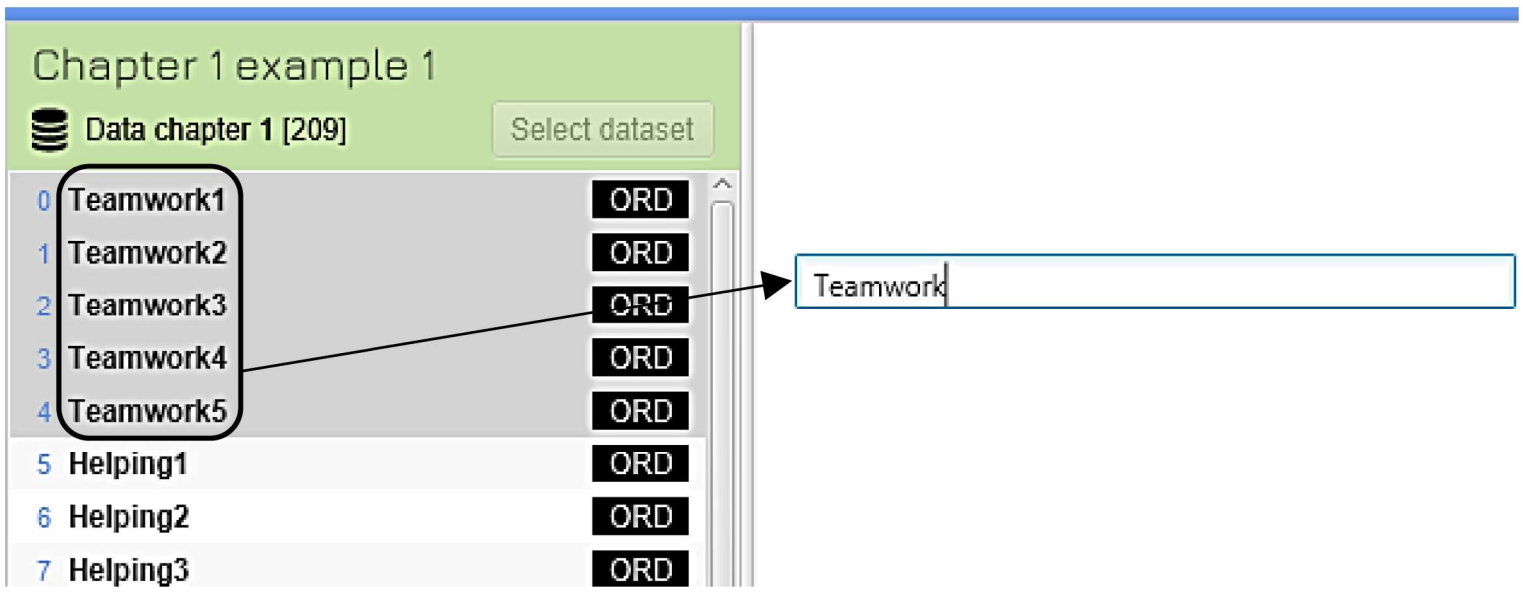



## 2. Drawing the PLS-SEM model

Before analyzing the data with PLS-SEM, the researcher draws the hypothesized model in the SmartPLS panel.

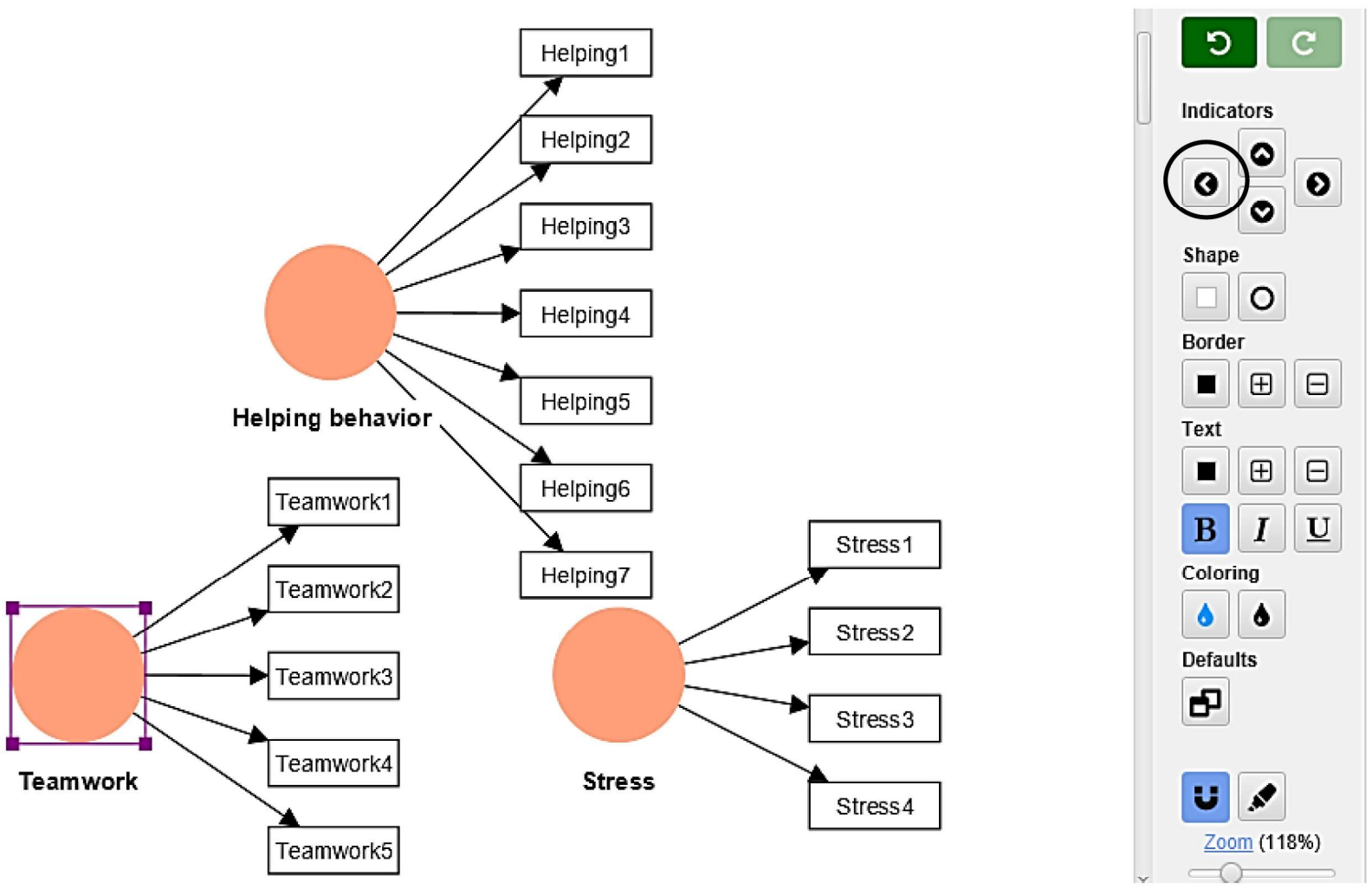
**STEPS**

1. Highlight the **five indicators** of **Teamwork**, and then drag and drop them onto the SmartPLS panel. The variable name **Teamwork** appears.

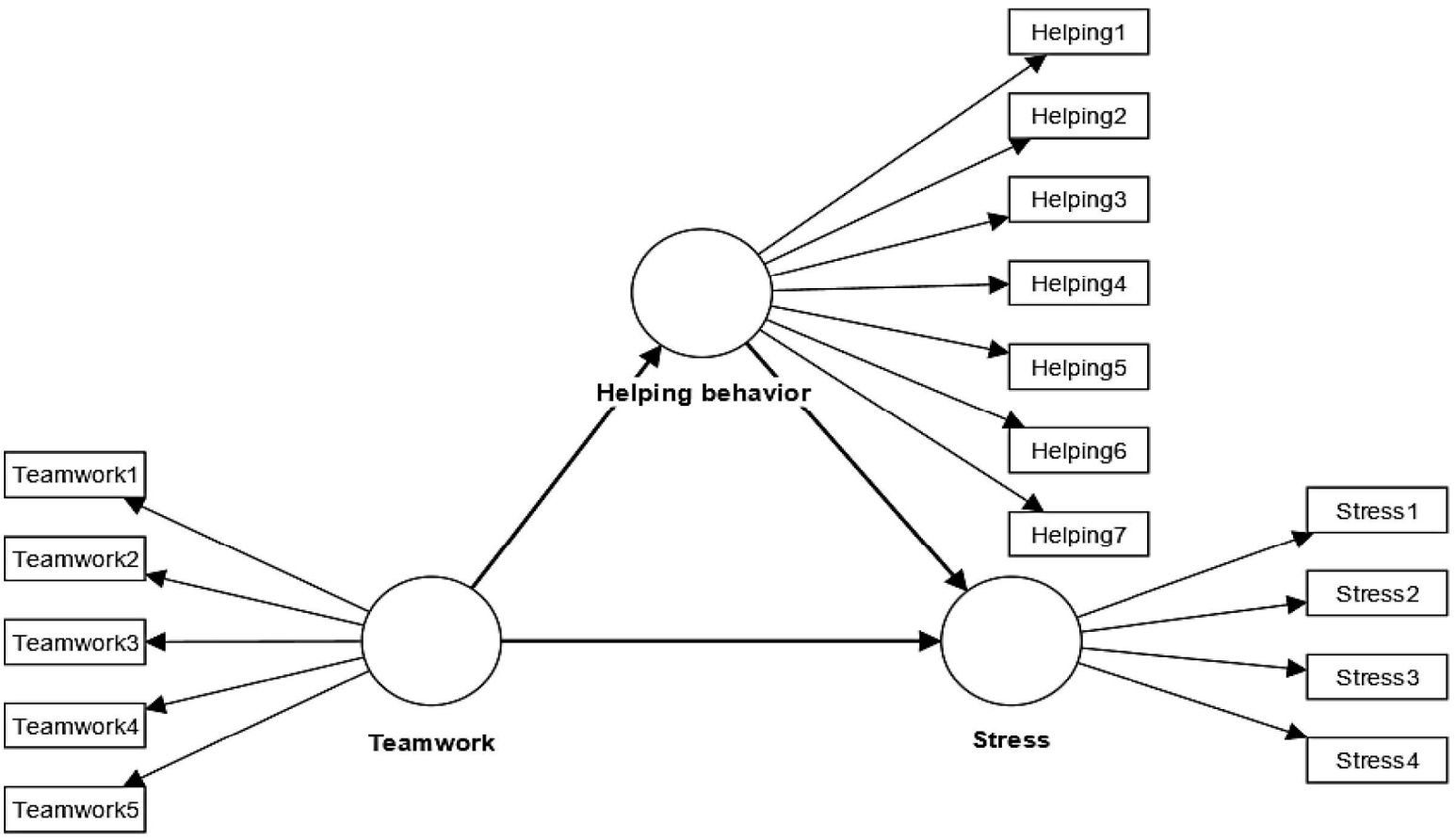



2. Press the **Enter** button on the computer keyboard to draw the measurement model of **Teamwork**.

3. Repeat **steps 1 and 2** to draw the measurement models of **Helping behavior** and **Work stress**. To turn the indicators of Teamwork to the left side, click the **latent variable** of Teamwork and select the **align indicators to the left (<)** button located on the right side of the SmartPLS panel.




4. Click the **Connect** button. Draw **three single-headed arrows** to connect the latent variables for **Teamwork → Helping behavior**, **Teamwork → Work stress**, and **Helping behavior → Work stress**. The PLS-SEM model is created and ready for analysis.




## SECOND STEP: ANALYZING THE MEASUREMENT MODELS FOR VALIDITY AND RELIABILITY

Table 1.2 presents the benchmarks of validity, reliability, and collinearity of indicators of reflective measurement models.

Table 1.2: Benchmarks of validity, reliability and collinearity (Source: modified from Hair et al., 2022)

| Index | Benchmark |
|---|---|
| **Construct validity** | |
| **a. Convergent validity** | |
| 1. Loading | ≥ 0.70 and significant ($p < 0.05$) |
| 2. Rho A | ≥ 0.70 |
| 3. AVE | ≥ 0.50 |
| **b. Discriminant validity** | |
| 1. Fornell-Larcker criterion | Achieved when the square root of AVE of a latent variable is larger than its correlations with other latent variables in the PLS-SEM model. |
| 2. Cross-loadings | Achieved when the loading value of an indicator to its latent variable is larger than its cross-loading values to other latent variables in the PLS-SEM model. |
| 3. Heterotrait-monotrait ratio (HTMT) | ≤ .90 |
| **Reliability** | |
| 1. Composite reliability | ≥ 0.70 |
| 2. Cronbach's alpha reliability | ≥ 0.70 |
| **Collinearity analysis** | |
| Collinearity statistics (VIF) | ≤ 5.0 |

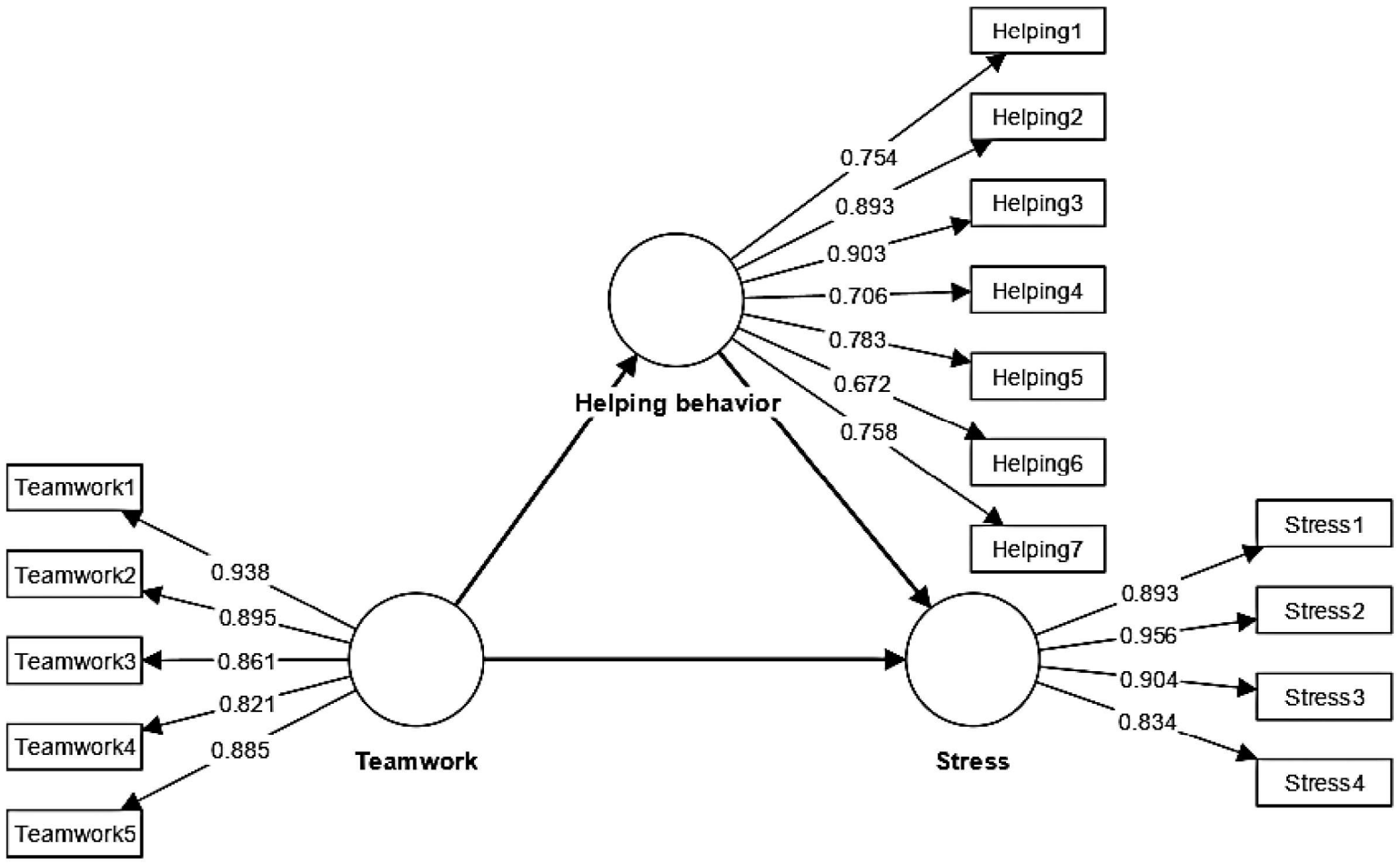
In this study, the three measurement models are *reflective models* (the single-headed arrows pointing to the indicators). Thus, the analysis will be conducted with the *Consistent PLS-SEM algorithm* and *Consistent PLS-SEM bootstrapping* procedures.

## 1. Convergent validity and reliability

**STEPS**

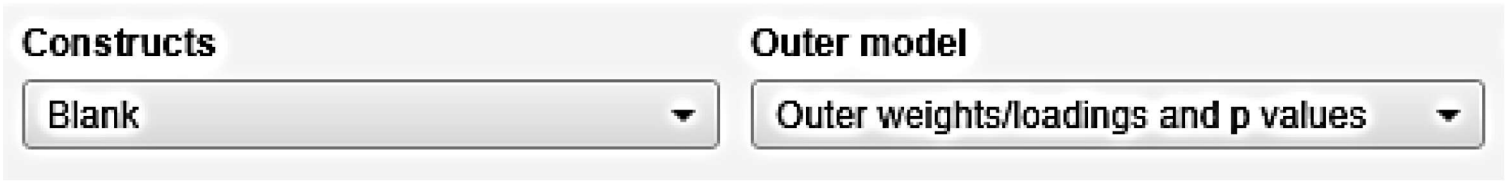
1. Click the **Calculate button** and select **Consistent PLS-SEM algorithm**. Then click the **Start calculation** button to run the analysis.


2. The loadings of the indicators of the three measurement models appear in the model.

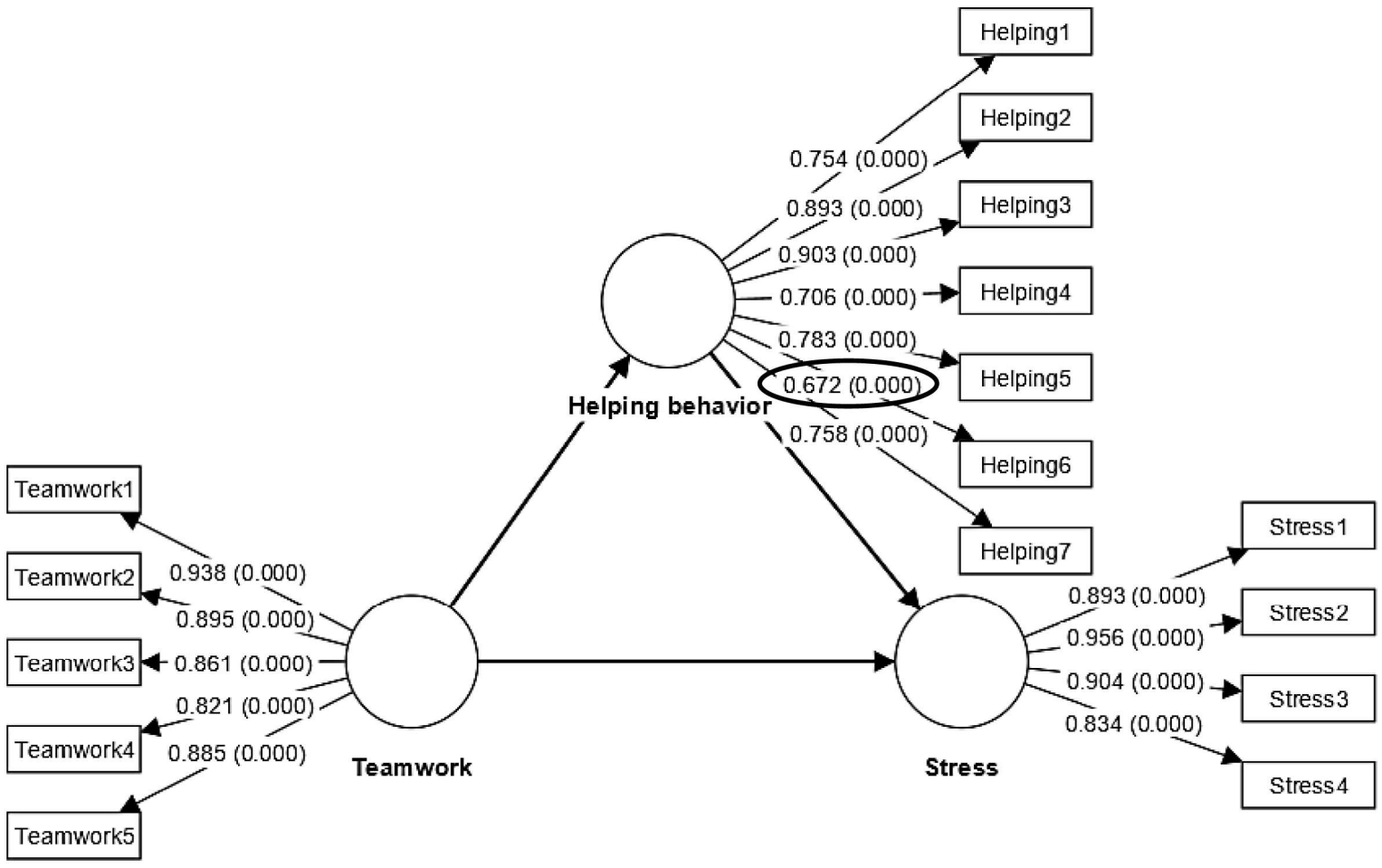



3. To check the significance (*p-value*) of the loadings, click the **Calculate** button, select **Consistent PLS-SEM bootstrapping**, and click the **Start calculation** button.


4. At the upper panel of the SmartPLS window, under the **Outer model** label, select **Outer weights/loadings and p values**. Leave **Inner model** and **Constructs** blank.

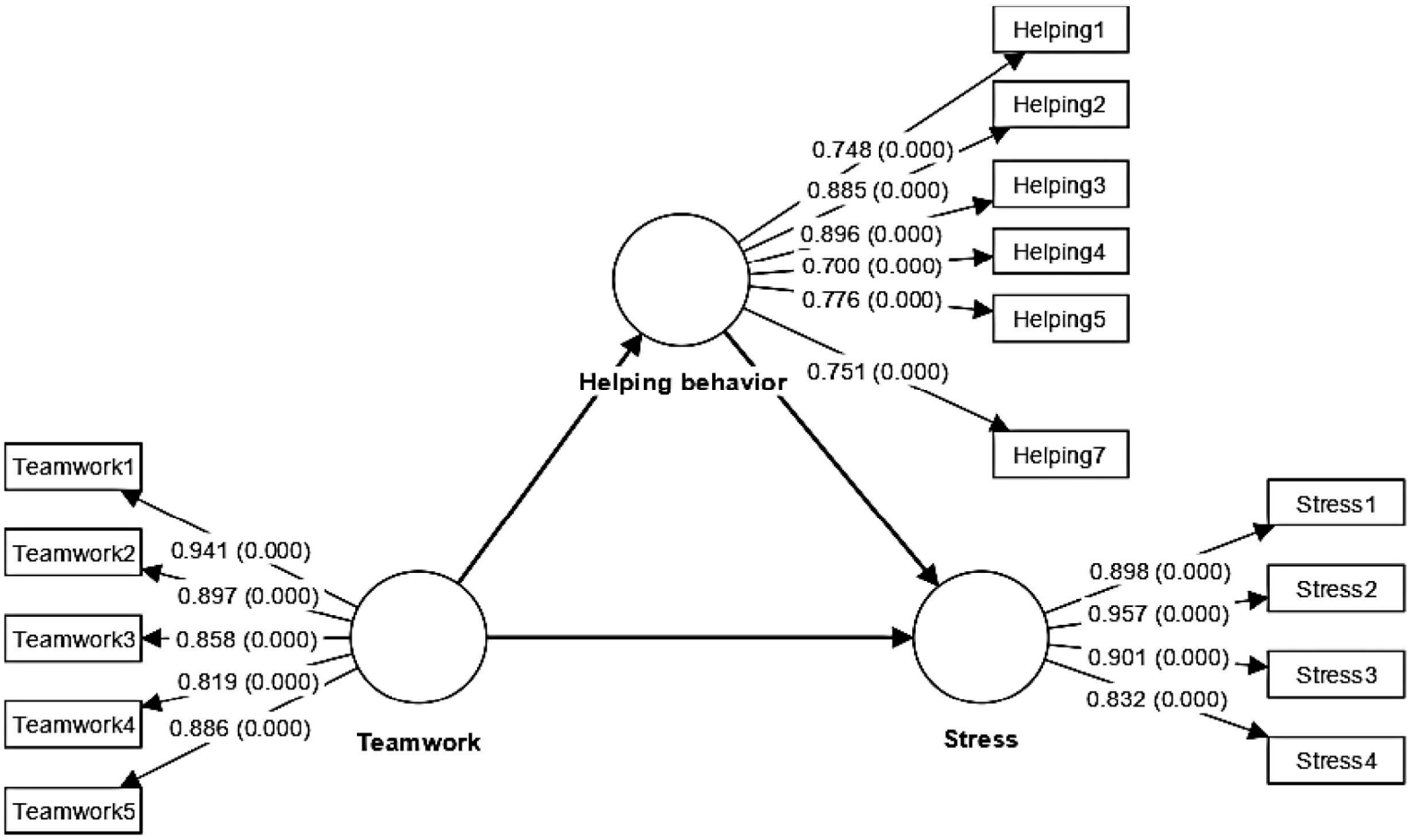



5. The output shows that all indicators of the **three latent variables** achieve convergent validity for loading (loading > 0.70 and significant at p < 0.05) except the indicator **Helping6** (loading = 0.672, p < 0.05). This indicator is less valid to be used to measure the concept of **Helping behavior**, and it can be removed from its latent variable before further analysis.



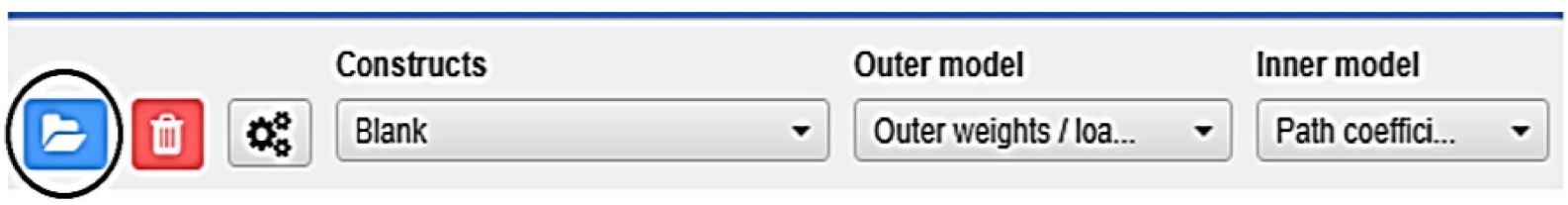

6. To remove it from **Helping behavior**, click on the indicator **Helping6** and press the **Delete** key on the computer keyboard. [Note: This can also be done by clicking the **Delete** button on the top panel of the SmartPLS and then clicking on the indicator.]

7. Reruns the **Consistent PLS-SEM bootstrapping** analysis. The output shows that all indicators achieve **convergent validity** for loading (loadings > 0.70, p < 0.05).

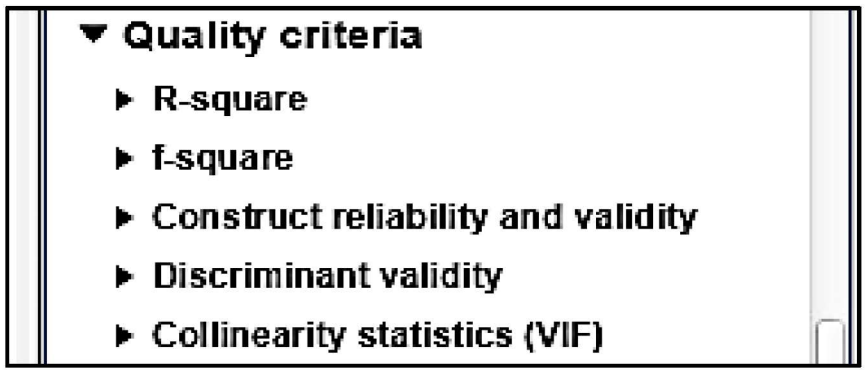



8. To further examine the validity and reliability of the indicators, select the **Calculate** button, then select **Consistent PLS-SEM algorithm**, and click the **Start calculation** button.

9. To view the output, click the **Open report** button at the upper panel (**Report panel**).




10. At the left panel, under the **Quality criteria** menu, select **Construct reliability and validity**.




11. The results of Cronbach's alpha, Rho A, Composite reliability, and AVE are tabulated.

| | Cronbach's alpha | rho_A | Composite reliability | Average variance extracted (AVE) |
|---|---|---|---|---|
| Helping behavior | 0.911 | 0.917 | 0.911 | 0.634 |
| Stress | 0.942 | 0.945 | 0.943 | 0.806 |
| Teamwork | 0.945 | 0.947 | 0.945 | 0.776 |

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# APPENDIX

## Guidelines for PLS-SEM Measures Table

| Measure | Criteria/benchmarks |
|---|---|
| **Path coefficients effect sizes ($f^2$)** | Small: 0.02<br>Medium: 0.15<br>Large: 0.35 |
| **Mediating effect sizes** | Small: 0.01<br>Medium: 0.09<br>Large: 0.25 |
| **Moderating effect sizes** | Small: 0.005<br>Medium: 0.010<br>Large: 0.025 |
| **Construct validity and reliability of reflective models** | *Convergent validity*<br>Loading ≥ 0.70, Rho A ≥ 0.70, AVE ≥ 0.50<br>*Internal consistency reliability*<br>Cronbach alpha reliability ≥ 0.70<br>Composite reliability ≥ 0.70<br>*Discriminant validity*<br>Fornell-Larcker criterion, Cross-loadings, HTMT ≤ 0.90<br>*Collinearity statistics*<br>Variance inflation factor (VIF) ≤ 5.0 |
| **Validity of formative models** | *Convergent validity (Redundancy analysis)*<br>Path coefficient of indicators: β ≥ 0.10, $p < 0.05$; Path coefficient between formative-reflective model: β ≥ 0.70<br>*Discriminant validity (Collinearity analysis)*<br>Variance inflation factor (VIF) ≤ 5.0 |
| **Model fit** | SRMR < 0.08<br>d_ULS > 0.05<br>d_G > 0.05<br>NFI > 0.90<br>RMS_theta < 0.12 |
| **Measurement invariance (MICOM)** | *Partial measurement invariance*<br>Step 1 and step 2 are established<br>*Full measurement invariance*<br>Step 3a (mean) and Step 3b (variance) are established |

# INDEX

## 5



## C



## D



## E



## F



## G



## H



## I

This book focuses on step-by-step guides for PLS-SEM data analysis using the SmartPLS 4, including 1. *Analyzing mediation models*, 2. *Analyzing moderation models using the two-stage approach*, 3. *Analyzing moderating effects using the multigroup analysis*, 4. *Analyzing multiple-order models*, and 5. *Analyzing formative models*. Concepts are explained in detail with ***11 step-by-step hands-on research examples*** to enable readers to carry out confidently each stage of the research and the PLS-SEM data analysis process:

- Analyzing the effects in a mediation model
- Analyzing the effects in a sequential mediation model
- Analyzing the effects in a parallel mediation model
- Analyzing the moderating effect of a single-moderator
- Analyzing the moderating effect on a mediation model (two-stage approach)
- Analyzing the moderating effect on a mediation model (multigroup analysis)
- Analyzing the moderating effects on a multiple regression model
- Analyzing the mediating effect of a reflective-reflective two-order model
- Analyzing the effects of a reflective-formative two-order model in a multivariate model
- Analyzing the effect of a single-order formative model
- Analyzing the effect of a formative-formative two-order model

The book is a useful teaching and learning tool for research courses. Exercises are provided at the end of each chapter to reinforce readers' understanding of the chapter.

Chua Yan Piaw is a professor in the Department of Mathematics and Science Education at the University of Malaya, Malaysia. In 2019, he was a visiting professor at the School of Social Work and Education, University of Sussex, Brighton, UK, and in 2014, he was a visiting professor at the Department of Sociology, University of Washington, Seattle, USA. His book series *Research Methods and Statistics*, books 1 to 5 with 62 chapters, are among *McGraw Hill's Top 10 Bestselling Titles* in Malaysia.

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