

Partial Least Squares Based Structural Equation Modeling (PLS-SEM)

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Introduction to SEM **CB-SEM vs PLS-SEM** Various methodological issues Formative vs. reflective constructs **Evaluation of measurement & structural models** Advanced and innovative analytical approaches

Statistical Methods

Statistical analysis ^a	Independence	Measurement Level of variable(s) ^b		Normality	Linearity	Variance	
		Dependent	Independent				
CHI-SQUARE							
Single sample	Independent observations	Nominal+	N/A				
2+ samples	Independent observations	Nominal+	Nominal+				
T-TEST							
Single sample	Independent observations	Continuous	N/A	Univariate			
Dependent sample	Independent paired observations	Continuous	N/A	Univariate			
Independent sample	Independent observations	Continuous	Dichotomous	Univariate		Homogeneity of variance	
OVA-RELATED TESTS	S						
ANOVA	Independent observations	Continuous	Nominal	Univariate		Homogeneity of variance	
ANCOVA ^c	Independent observations	Continuous	Nominal	Univariate	\checkmark	Homogeneity of variance	
RM ANOVA	Independent repeated observations	Continuous	Nominal (opt.)	Multivariate	\checkmark	Sphericity	
MANOVA	Independent observations	Continuous	Nominal	Multivariate	\checkmark	Homogeneity of covariance matrix	
MANCOVA ^c	Independent observations	Continuous	Nominal	Multivariate	\checkmark	Homogeneity of covariance matrix	
REGRESSION							
Simple linear	Independent observations	Continuous	Continuous	Bivariate	\checkmark		
Multiple linear	Independent observations	Continuous	Continuous	Multivariate	\checkmark	Homoscedasticity	
Canonical correlation	Independent observations	Continuous	Continuous	Multivariate	\checkmark	Homoscedasticity	

*Across all analyses, data are assumed to be randomly sampled from the population. Data are assumed to be reliable. ANCOVA and MANCOVA also assumes homogeneity of regression and continuous covariate(s). Continuous refers to data that may be dichotomous, ordinal, interval, or ratio (cf. Tabachnick and Fidell, 2001).

Statistical Methods

- With first-generation statistical methods, the general assumption is that the data are error free.
 - Exploratory factor analysis
 - Multiple regression
 - Path analysis



Estimate a construct (η) underlying values on various related indicator variables (y1 – y3)

Estimate x -> y (parameter β) while controlling for confounders z1, z2, z3 that are related to x and to y Estimate relations (parameters β 1, β 2, β 3) between various construcs (x, y, z) at the same time

With second-generation statistical methods, the measurement model stage attempts to identify the error component of the data.

- SEM
 - CB SEM
 - PLS SEM

• Measurement error

- Types of measurement error
 - *Random error* can affect the reliability of construct
 - Systematic error can affect the validity of construct.
- Source of error
 - Poorly worded questions in survey
 - Incorrect application of statistical methods
 - Misunderstanding of scaling approach



Structural equation modeling (SEM)

• Complex models with many associations, incorporate both unobserved (latent) and observed variables.

• Factor analysis & multiple regressions



- Two SEM approaches
 - 1. Covariance-based SEM (CB-SEM)
 - 2. Variance-Based VB-SEM/ PLS-SEM.

CB-SEM vs PLS-SEM

Summary Comparison: PLS-SEM vs. CB-SEM

Criteria	Variance-Based Modeling (e.g. SmartPLS, PLS Graph)	Covariance-Based Modeling (e.g. LISREL, AMOS, Mplus)		
Objective	Prediction oriented	Parameter oriented		
Distribution Assumptions	Non-parametric	Normal distribution (parametric)		
Required sample size	Small (min. 30 - 100)	High (min. 100 - 800)		
Model complexity	Large models OK	Large models problematic (50+ indicator variables)		
Parameter Estimates	Potential Bias	Stable, if assumptions met		
Indicators per construct	One – two OK Large number OK	Typically 3 – 4 minimum to meet identification requirements		
Statistical tests for parameter estimates	Inference requires Jackknifing or Bootstrapping	Assumptions must be met		
Measurement Model	Formative and Reflective indicators OK	Typically only Reflective indicators		
Goodness-of-fit measures	None	Many		

- **CB-SEM** "reproducing the covariance matrix, without focusing on explained variance"
- **PLS-SEM** minimizing the error terms [and maximizing] the R² values of the endogenous constructs" (Hair et al., 2014, p. 14).

Justification for usage of PLS-SEM

prediction and explanation of target constructs.

Smaller sample sizes

Complex models

No data Normality

Support reflective and formative measurement models as well as single item construct.

Weaker theoretical support/ Integration of multiple theories.

Works with ordinal and binary scaled questions.

SEM Software / Applications

CB-SEM	PLS-SEM
AMOS	SmartPLS
LISREL	PLS-Graph
MPLUS	PLS-GUI
EQS	SPADPLS
SAS	LVPLS
R	WarpPLS
SEPATH	PLS-PM
CALIS	semPLS
LISCOMP	Visual PLS
Lavaan	PLSPath
COSAN	XLSTAT

PLS-SEM

>A PLS path model consists of two elements:

- > The structural model displays the relationships (paths) between the constructs.
- The measurement models display the relationships between the constructs and the indicator variables (rectangles).





Reflective vs. Formative



The decision of whether to measure a **construct reflectively** or **formatively** is not **clear-cut** (Hair et al., 2014).

Reflective: Consequences/trait

Formative: Causes/ Combination

IPTWI (Ajzen & Fishbein, 1980; Taylor & Baker, 1994)			5.077	23.271
I intend to purchase tourism weather insurance on my next trip.	I1	.927		
I plan to include tourism weather	I2	.927		
If tourism weather insurance had been offered during this trip, I would have	I3	.937		
purchased it. I need to purchase tourism weather	14	.878		
insurance when I travel.				
Loyalty (Yoon & Uysal, 2005)			1.650	16.920
I likely will revisit North Cyprus in the next	L1	.893		
few years.				
This visit was so highly satisfying that I will		.90		
repeat it.				
I will recommend North Cyprus to other people (e.g., friends, relatives).	L3	.909		



The goal of **reflective measurement model** assessment is **to ensure** the **reliability** and **validity** of the **construct measures** and therefore **provide support** for the **suitability** of their **inclusion** in the path model.

- **Reliability** is the extent to which an assessment tool produces stable and consistent results.
- Validity refers to the extent to which the construct measures what it is supposed to measure.

REFLECTIVE MEASUREMENT MODEL EVALUATION

Internal Consistency Reliability

- Composite Reliability (CR> 0.70 in exploratory research 0.60 to 0.70 is acceptable).
- Cronbach's alpha (α> 0.7 or 0.6)
- Indicator reliability (> 0.708)
 - Squared Loading the proportion of indicator variance that is explained by the latent variable

Convergent validity

Average Variance Extracted (AVE>0.5)

Discriminant validity

- Fornell-Larcker criterion
- Cross Loadings
- HTMT Criteria (<1).

Discriminant validity

Cross-Loadings: An indicator's outer loadings on a construct should be higher than all its cross loadings with other constructs.



Loadings and Cross-loadings

	ATTR	COMP	CSOR	CUSA	CUSL	LIKE
attr_1	0.758	0.496	0.405	0.064	0.062	0.430
attr_2	0.504	0.269	0.351	0.032	-0.003	0.346
attr_3	0.889	0.533	0.538	0.064	0.073	0.554
comp_1	0.546	0.801	0.601	0.082	0.103	0.607
comp_2	0.451	0.834	0.423	0.113	0.105	0.461
comp_3	0.519	0.858	0.427	0.100	0.108	0.498
csor_1	0.486	0.460	0.773	0.070	0.061	0.471
csor_2	0.335	0.292	0.572	0.105	0.145	0.394
csor_3	0.481	0.492	0.838	0.069	0.039	0.518
csor_4	0.422	0.313	0.618	0.068	0.038	0.429
csor_5	0.484	0.507	0.847	0.145	0.096	0.513
cusa	0.075	0.118	0.119	1.000	0.614	0.043
cusl_2	0.057	0.081	0.065	0.504	0.874	0.074
cusl_3	0.073	0.141	0.082	0.586	0.909	0.070
like_1	0.577	0.585	0.574	0.056	0.082	0.880
like_2	0.515	0.509	0.510	0.038	0.060	0.867
like_3	0.489	0.540	0.512	0.015	0.066	0.845

Bold values are loadings for item which are above for the recommended

value of 0.5

Discriminate Validity

• Fornell-Larcker criterion: The square root of the AVE of each construct should be higher than its highest correlation with any other construct.

Discriminant Validity



FORMATIVE MEASUREMENT MODEL

Formative Measurement Model

Assess Collinearity Among
Indicators (VIF < 3)
Assess the Significance and
relevance of outer weights (T Value > 1.645).

The estimated values of <u>outer</u> <u>weights</u> in formative measurement models are frequently <u>smaller</u> than the of reflective indicators



PLS-SEM Structural Model Evaluation

PLS-SEM relies on a <u>nonparametric bootstrap</u> procedure to test coefficients for their significance. In bootstrapping, a large number of subsamples (i.e., bootstrap samples) are drawn from the original sample with replacement (random from the sampling population).





Reflective-ReflectiveType

Reflective-FormativeType



Formative-ReflectiveType





Formative-FormativeType



Mediation analysis



Usage of SEM in Scopus-Indexed Research



➢Partial Least Squares (PLS) focuses on the prediction of a specific set of hypothesized relationships that maximizes the explained variance in the dependent variables (Hair, Ringle, & Sarstedt, 2011).

A critical look at the use of SEM in international business research

Richter, Nicole; Sinkovics, Rudolf R; Ringle, Christian; Schlägel, Christopher

International Marketing Review. 2016;33(3):(forthcoming).

Of the articles, 379 utilized CB-SEM and 45 PLS-SEM.

Methodological Issues Ignored in SEM Application



Nunkoo, R., Ramkissoon, H., & Gursoy, D. (2013). Use of structural equation modeling in tourism research: past, present, and future. *Journal of Travel Research*, *52*(6), 759-771. Olya, H. G., & Altinay, L. (2016). Asymmetric modeling of intention to purchase tourism weather insurance and loyalty. *Journal of Business Research*, *69*(8), 2791-2800.

2. SEM, fsQCA, NCA



It's just the beginning

Feedback is welcome

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