Partial Least Squares Stuctural Equation Modeling (PLS-SEM)

Understanding the Acceptance of Mobile Wallet in Bamboo-based Enterprises using extended UTAUT Model

Methodology

PLS-SEM, or Partial Least Squares – Structural Equation Modelling is a component-based approach to structural equation modeling that aims to maximize the explained variance of the dependent variables by estimating the relationships between the observed indicators and the latent constructs (variables that are not directly observed but inferred).

In this study, six constructs (PE, EE, SI, FC, PI, PR, BI) were used to model the construct for Behavioral Intention (BI). In terms of data modification, PR4 was omitted for the PR construct. All data used in the analysis was the coded Likert scale from 1 (Strongly Disagree) to 5 (Strongly Agree).

Implementation of PLS-SEM in RStudio is provided by the package 'SEMinR' and its functions. The first step in the initial set up is to load the dataset. Second, build all measurement models by connecting it to all of its indicators using the 'construct' function. Next, connect all path relationships in the structural model using the 'relationships' function. Afterwards, estimate the model using the 'estimate_pls' function. Lastly, use 'bootstrap_model' to bootstrap the estimated model allowing the estimation of standard errors and computation of confidence intervals. Bootstrapping is a statistical method that involves resampling a dataset with replacement to estimate the distribution of a statistic. In this case, the statistic of interest is the path coefficient from one construct to another.

The next step is the evaluation of all measurement models. This involves evaluating the indicator reliability using indicator loadings, internal consistency using reliability measures, convergent validity using average variance extracted, and discriminant validity using the Heterotrait-Monotrait Ratio. All of these descriptive measures came from the summarized PLS model using the 'summary' function on the estimated and bootstrapped PLS model.

The last step is the evaluation of the overall structural model describing the relationship among the latent constructs. The first step is to evaluate each construct using its variance inflation factors. Afterwards, path coefficients are analyzed to determine the strength and direction of relationship across the defined paths. Lastly, the values of the R-Square and effect size are evaluated to determine model adequacy and measure practical significance, respectively.

The evaluation of measurement and structural models will determine which of the indicators or construct can be dropped for the next iteration of the PLS model.

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Evaluation of Measurement Models

For this study, there are seven measurement model for the seven constructs. The following are evaluated for each:

Indicator Reliability

This measures how each construct is represented by its indicators. Low indicator reliability may result in biased construct results. Indicator loadings above 0.70 are recommended, as they correspond to an explained variance (indicator reliability) of at least 50%. Indicators with loadings between 0.40 and 0.70 should be considered for removal. Indicators with loadings below 0.40 should be removed.

Table. Loadings of each indicator to their respective construct.

Indicators	PE	EE	SI	FC	PI	PR	BI
PE1	0.92	-	-	-	-	-	-
PE2	0.92	-	-	-	-	-	-
PE3	0.86	-	-	-	-	-	-
EE1	-	0.79	-	-	-	-	-
EE2	-	0.89	-	-	-	-	-
EE3	-	0.81	-	-	-	-	-
SI1	-	-	0.96	-	-	-	-
SI2	-	-	0.97	-	-	-	-
FC1	-	-	-	0.80	-	-	-
FC2	-	-	-	0.78	-	-	-
FC3	-	-	-	0.46	-	-	-
PI1	-	-	-	-	0.66	-	-
PI2	-	-	-	-	0.45	-	-
PI3	-	-	-	-	0.83	-	-
PI4	-	-	-	-	0.83	-	-
PR1	-	-	-	-	-	0.88	-
PR2	-	-	-	-	-	0.87	-
PR3	-	-	-	-	-	0.62	-
BI1	-	-	-	-	-	-	0.94
BI2	-	-	-	-	-	-	0.93

Note: Indicators with loadings in red are considered for question revision or removal.

As indicated above, questions like FC3 for FC, PI1 and PI2 for PI, and PR3 should be further checked for face validity and can be considered for revision or removal.

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Internal Consistency

Internal consistency measures how well indicators that measure the same construct are associated with each other. A construct is considered to have internal consistency when its reliability measurement values (α, ρ_A, and ρ_C) are at least 0.7.

Table. Internal consistency coefficients for each construct.

Constructs	α	ρ_A	ρ_C
PE	0.95	0.95	0.96
EE	0.90	0.90	0.94
SI	0.96	0.97	0.98
FC	0.76	0.82	0.86
PI	0.85	0.86	0.90
PR	0.87	0.97	0.92
BI	0.93	0.95	0.97

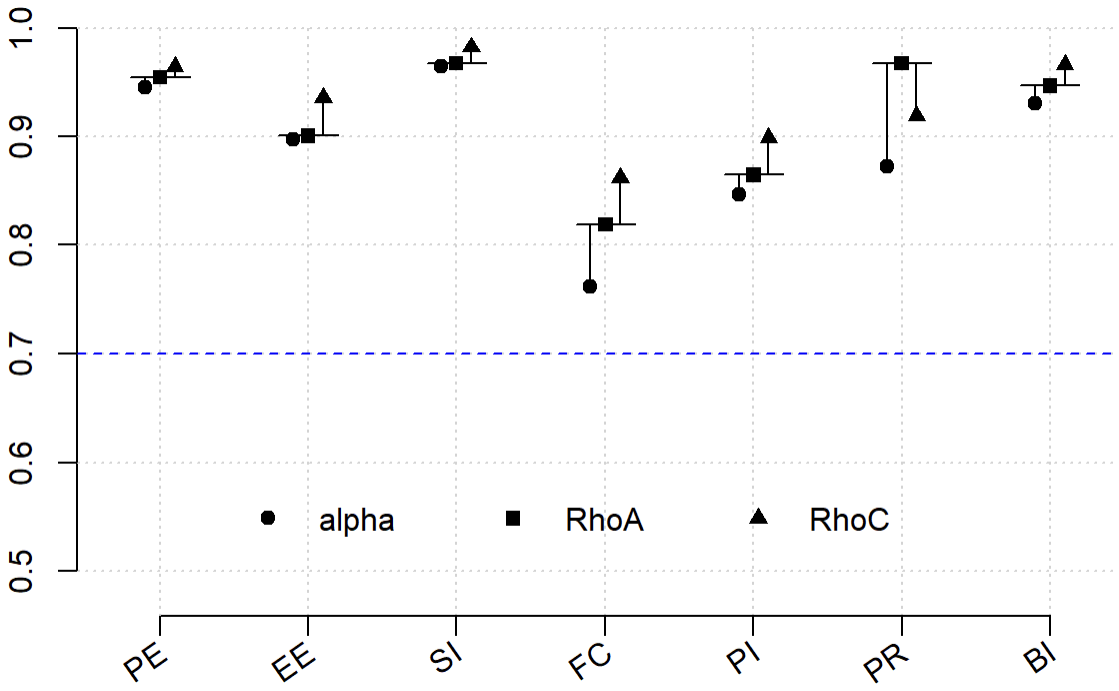

Figure. Internal consistency coefficients for each construct.

For these constructs, all are considered to have acceptable internal consistency measurement.

Note: Of the various indicators for internal consistency reliability, Cronbach's Alpha (α) is the lower bound, while the composite reliability (ρ_C) is the upper bound. The exact (or consistent) reliability coefficient (ρ_A) *usually* lies between these bounds and may serve as a good representation of a construct's internal consistency reliability.

Convergent Validity

Convergent validity measures how well a construct explains the variance of its indicators. Acceptable values of average variance extracted (AVE) should be at least 0.5, meaning the construct explains at least 50% of the variation in its indicators. This ensures that the indicators are more related to the construct than to measurement error, validating the construct.

Table. Average variance extracted (AVE) of each construct from its indicators.

Constructs	AVE
PE	0.90
EE	0.83
SI	0.97
FC	0.68
PI	0.69
PR	0.79
BI	0.94

For these constructs, all passed convergent validity.

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Discriminant Validity

Discriminant validity ensures that a construct is distinct from other constructs in the model. It verifies that the construct has stronger relationships with its own indicators than with those of any other construct. This can be measured using the Heterotrait-Monotrait Ratio (HTMT), where values should be below 0.90 after bootstrapping.

Table. Raw and bootstrapped HTMT values for each construct relationship.

Indicators	Raw HTMT	Bootstrapped HTMT	Bootstrapped SD
PE and EE	0.89	0.89	0.07
PE and SI	0.87	0.87	0.04
PE and FC	0.92	0.92	0.04
PE and PI	0.83	0.83	0.05
PE and PR	0.49	0.50	0.10
PE and BI	0.82	0.81	0.06
EE and SI	0.79	0.79	0.05
EE and FC	0.99	0.99	0.06
EE and PI	0.85	0.85	0.07
EE and PR	0.27	0.30	0.14
EE and BI	0.77	0.77	0.06
SI and FC	0.76	0.76	0.06
SI and PI	0.64	0.64	0.08
SI and PR	0.29	0.31	0.11
SI and BI	0.73	0.73	0.08
FC and PI	0.96	0.96	0.08
FC and PR	0.56	0.58	0.12
FC and BI	0.78	0.79	0.08
PI and PR	0.54	0.55	0.08
PI and BI	0.69	0.69	0.07
PR and BI	0.23	0.26	0.14

Note: Indicators with values in red show very high HTMT which violates discriminant validity.

For these constructs, FC has high HTMT values with PE, EE, and PI. Thus, FC can be tested to be removed from the model.

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Evaluation of Structural Model

Before evaluating the structural model, variance inflation factors (VIF) values of the constructs can be assed for multicollinearity issues. A VIF value greater than five may indicate multicollinearity issues.

Table. Variance-inflation factor (VIF) of each construct in the structural model.

Constructs	VIF
PE	6.15
EE	5.53
SI	3.39
FC	4.78
PI	3.03
PR	1.58

For these constructs, PE and EE have high VIF values indicating multicollinearity issues. PE can be removed for the revised model and assess if EE will lower its VIF value.

Path coefficients show the strength and direction of the relationship between the dependent and independent construct while the effect size quantify the practical significance of their relationship.

In PLS-SEM, Cohen's guidelines for effect size help evaluate the significance of relationships between constructs. An effect size (f^2) of 0.02 is considered small, indicating a modest relationship that may still be important in certain contexts. A medium effect size of 0.15 or higher suggests a more substantial relationship, warranting further investigation. A large effect size of 0.35 or higher represents a strong relationship, highlighting a critical connection between constructs.

Small effect sizes can still be meaningful in research, especially in fields where even small changes are important. However, they might indicate that other, stronger predictors exist or that the relationship is less influential. Additional variables or factors that could have a more substantial impact can be investigated further.

The table below shows the original and bootstrapped coefficients for the paths between the constructs as well as their corresponding effect size. The R-square value of 0.64 suggests that 64% of the variation in the dependent construct (BI) is explained by the six independent constructs in the model.

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Table. Coefficient and effect size of each path between constructs ($R^2 = 0.64$)

Path	Raw Path Coefficient	Bootstrapped Path Coefficient	Bootstrapped SD	p-value	Effect Size
PE to BI	0.54	0.49	0.24	0.0293*	0.14
EE to BI	0.03	0.04	0.19	0.8841	0.00
SI to BI	0.13	0.14	0.18	0.4559	0.01
FC to BI	0.14	0.14	0.19	0.4765	0.01
PI to BI	0.09	0.10	0.12	0.4462	0.01
PR to BI	-0.16	-0.12	0.13	0.2410	0.05

*Significant at 5% level of significance.

Positive path coefficients indicate direct relationship between the two constructs, while a negative path coefficient shows indirect relationship. From all the paths mentioned, only PR has an indirect relationship with BI, while the rest has direct relationship. However, only PE showed significant relationship with BI, but still shows below medium practical significance.

Note: The results may be attributed to problematic constructs identified during the model evaluation. For reference, the revised model is provided below. The construct FC was removed due to issues with divergent validity, and PE was excluded because of multicollinearity concerns.

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Results for Revised Model (FC and PE excluded)

Table. Loadings of each indicator to their respective construct in the revised model.

Indicators	EE	SI	PI	PR	BI
EE1	0.79	-	-	-	-
EE2	0.89	-	-	-	-
EE3	0.81	-	-	-	-
SI1	-	0.96	-	-	-
SI2	-	0.97	-	-	-
PI1	-	-	0.66	-	-
PI2	-	-	0.45	-	-
PI3	-	-	0.83	-	-
PI4	-	-	0.83	-	-
PR1	-	-	-	0.88	-
PR2	-	-	-	0.87	-
PR3	-	-	-	0.62	-
BI1	-	-	-	-	0.94
BI2	-	-	-	-	0.93

Note: Indicators with loadings in red are considered for question revision or removal.

Table. Internal consistency coefficients for each construct.

Constructs	α	ρ_A	ρ_C
EE	0.90	0.90	0.94
SI	0.96	0.97	0.98
PI	0.85	0.86	0.90
PR	0.87	0.97	0.92
BI	0.93	0.95	0.97

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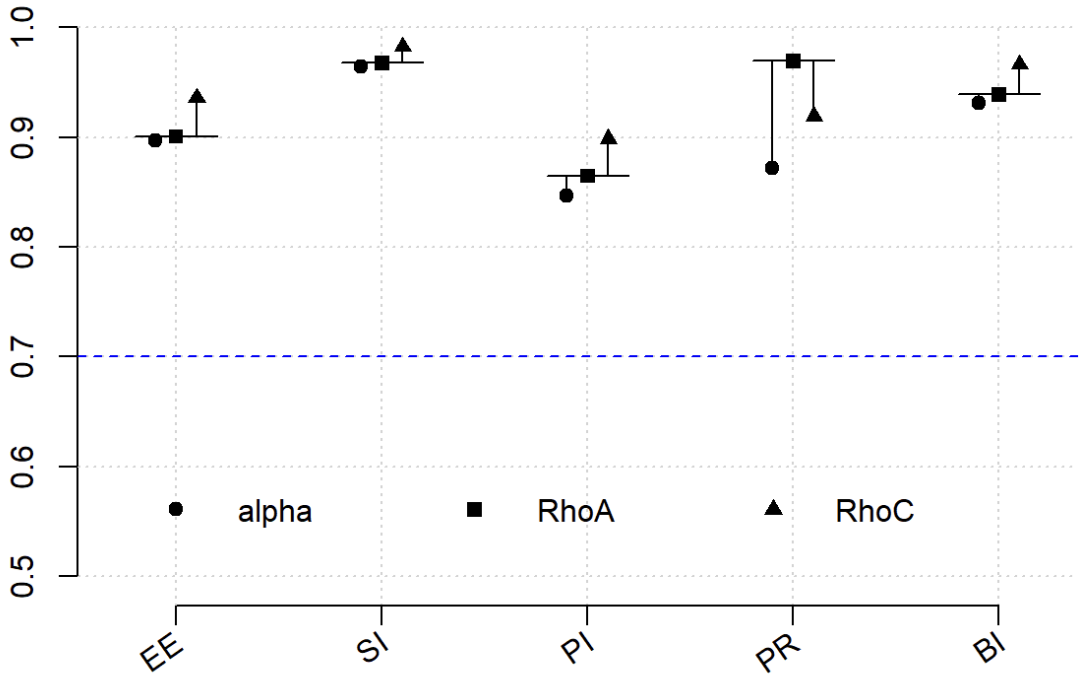

Figure. Internal consistency coefficients for each construct in the revised model.

Table. AVE of each construct from its indicators in the revised model.

Constructs	AVE
EE	0.83
SI	0.97
PI	0.69
PR	0.79
BI	0.94

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Table. Raw and bootstrapped HTMT values for each construct relationship in the revised model.

Indicators	Raw HTMT	Bootstrapped HTMT	Bootstrapped SD
EE and SI	0.79	0.79	0.05
EE and PI	0.85	0.85	0.07
EE and PR	0.27	0.30	0.14
EE and BI	0.77	0.77	0.06
SI and PI	0.64	0.64	0.08
SI and PR	0.29	0.31	0.11
SI and BI	0.73	0.73	0.08
PI and PR	0.54	0.55	0.08
PI and BI	0.69	0.69	0.07
PR and BI	0.23	0.26	0.14

Table. Variance-inflation factor (VIF) of each construct in the revised structural model.

Constructs	VIF
EE	3.29
SI	2.19
PI	2.67
PR	1.31

Table. Coefficient and effect size of each path between constructs ($R^2 = 0.59$)

Path	Raw Path Coefficient	Bootstrapped Path Coefficient	Bootstrapped SD	p-value	Effect Size
EE to BI	0.30	0.30	0.15	0.0577**	0.06
SI to BI	0.38	0.37	0.14	0.0089*	0.16
PI to BI	0.20	0.21	0.12	0.0889**	0.04
PR to BI	-0.04	-0.02	0.11	0.7077	0.00

*Significant at 5% level of significance. **Significant at 10% level of significance.

For the revised model, the R-squared changes from 64% to 59%, a small drop considering two constructs were removed. Moreover, the direction of the relationships stayed the same with the original model. Only SI showed significant relationship to BI at 5% level of significance but at a higher level of significance of 10%, EE and PI show statistical significance. In terms of effect size, SI shows medium practical significance, while EE and PI show small practical significance.

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