Discriminant Validity: A Comparison of CBSEM and Consistent PLS using Fornell & Larcker and HTMT Approaches

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Abstract. Discriminant validity is recognized as the essential approach in structural equation modelling method to determine the construct uniqueness in a research model. Using this approach, the applied researchers can identify the distinction role on each construct applied in the study. To date, there are several available approaches has been introduced to perform the discriminant validity. In applied research, the Fornell & Larcker approach is known as the method of choice for discriminant validity. Thus, this study attempt to make a comparison Fornell & Larcker approach with HTMT using CBSEM and Consistent PLS. From here, the results revealed that HTMT based Consistent PLS approach is comparable to Fornell & Larcker based CBSEM but not empirical standard to Fornell & Larcker based Consistent PLS. The discussion and recommendations also provided for this justifications.

Keywords: CBSEM, Consistent PLS, Fornell & Larcker, HTMT approach, Discriminant Validity

1. Fundamental of Discriminant Validity

Both CBSEM and PLS method are using Fornell & Larcker criterion for establishing the discriminant validity as have been widely reported in publications. Recent research suggest that Fornell & Larcker criterion is not effective under certain circumstances in PLS method [1-4] and therefore Henseler et al. [3] offered Hetetrotrait-Monotrait (HTMT) approach to replace Fornell & Larcker criterion. The management researcher routinely relies on the Fornell & Larcker criterion for establishing the discriminant validity under confirmatory research [3], [5]. This is because the Fornell & Larcker criterion does not rely on inference statistics which motivates the applied researchers keep using this approach. Instead, it uses Average Variance Extracted (AVE) to compare with the squared correlation with other construct in the model [6].

In the case of HTMT criterion, this approach is developed from the average of the heterotrait-heteromethod and monotrait-heteromethod correlations. It means that the correlations of indicators across constructs and within the same construct were assessed simultaneously [3] that can be formulated as follows:

\[
\frac{1}{K_i K_j} \sum_{g=1}^{k_i} \sum_{h=1}^{k_j} r_{gh} \div \left( \frac{2}{K_i(K_i-1)} \sum_{g=1}^{k_i-1} \sum_{h=1}^{k_i} r_{gh} \cdot \frac{2}{K_j(K_j-1)} \sum_{g=1}^{k_j-1} \sum_{h=1}^{k_j} r_{gh} \right)^{1/2}
\]  \quad (1)
Technically, the HTMT provides two advantages over Fornell & Larcker criterion which are it does not require a factor analysis to obtain the factor loadings and calculation of construct scores (i.e., construct correlation).

However, there are very few empirical findings on the suitability of these criteria for establishing discriminant validity and even recent research by Voorhoes et al. [7] is seemed limited for justification. This is happening since the model tested is not developed from the common factor modeling, consequently it motivates author to seek further in what situation that HTMT can be recommended.

2. Findings

The Monte Carlo simulation was used to compare the performance of CBSEM and Consistent PLS method using different sample size and model. The sample size involves 50, 100, 200 and 500 whereas the three established model was chosen from social sciences areas (TRA, Loyalty and UTAUT). The data was generated using R software and then the analysis for CBSEM and Consistent PLS were performed using AMOS and ADANCO software respectively. The results were shown in the following tables.

Table 1: Discriminant Validity between CBSSEM and Consistent PLS using Fornell & Larcker and HTMT approach

| ESTIMATION METHOD | CB-SEM   | Consistent PLS (Fornell-Larcker Criterion) | Consistent PLS (HTMT Criterion) |
|-------------------|----------|-------------------------------------------|---------------------------------|
| MODEL             | CORRELATION | 50  | 100  | 200  | 500  | 50  | 100  | 200  | 500  | 50  | 100  | 200  | 500  |
| TRA               | X1 <> X2 | .891 | .620 | .673 | .572 | .389 | .166 | .202 | .145 | .893 | .617 | .663 | .571 |
|                  |          | .625 | .541 | .657 | .654 | .177 | .091 | .180 | .195 | .624 | .495 | .645 | .651 |
|                  | X1 <> Y  | .383 | .671 | .569 | .650 | .096 | .155 | .151 | .199 | .453 | .605 | .583 | .653 |
|                  | X1 <> M3 | .872 | .447 | .690 | .525 | .341 | .083 | .197 | .121 | .872 | .449 | .680 | .530 |
|                  | X1 <> M2 | .771 | .572 | .625 | .620 | .282 | .160 | .194 | .179 | .799 | .634 | .633 | .631 |
|                  | X2 <> M1 | .541 | .506 | .441 | .464 | .122 | .124 | .087 | .101 | .472 | .495 | .447 | .477 |
|                  | X2 <> Y  | .409 | .387 | .528 | .419 | .099 | .066 | .133 | .079 | .421 | .358 | .541 | .414 |
|                  | X2 <> M3 | .637 | .423 | .443 | .419 | .222 | .087 | .067 | .046 | .640 | .416 | .448 | .416 |
|                  | X2 <> M2 | .666 | .276 | .544 | .391 | .161 | .047 | .149 | .068 | .549 | .317 | .549 | .392 |
|                  | M1 <> Y  | .446 | .328 | .336 | .089 | .090 | .045 | .051 | .462 | .429 | .316 | .323 |
|                  |          | .005 |     |     |     |     |     |     |     |     |     |     |     |
|                  | M1 <> M3 | .176 | .060 | .283 | .357 | .071 | .002 | .030 | .056 | .398 | .074 | .267 | .356 |
|                  | M1 <> M2 | .626 | .245 | .400 | .295 | .126 | .026 | .075 | .041 | .524 | .247 | .400 | .302 |
|                  | Y <> M3  | .168 | .131 | .183 | .027 | .005 | .007 | .014 | .247 | .099 | .134 | .177 |
|                  |          | .107 |     |     |     |     |     |     |     |     |     |     |     |
|                  | Y <> M2  | .402 | .140 | .218 | .211 | .095 | .013 | .024 | .022 | .450 | .154 | .220 | .218 |
|                  | M3 <> M2 | .526 | .163 | .290 | .252 | .156 | .012 | .533 | .030 | .595 | .160 | .298 | .262 |
| LOYALTY           | X1<>X2  | .845 | .685 | .649 | .733 | .054 | .214 | .200 | .220 | .590 | .674 | .652 | .726 |
|                  | X1<>M   | .990 | .556 | .602 | .518 | .235 | .127 | .175 | .114 | 1.057 | .524 | .600 | .514 |
|                  | X1<>Y   | .974 | .585 | .655 | .624 | .088 | .182 | .253 | .194 | .693 | .578 | .678 | .626 |
|                  | X2<>M   | .329 | .469 | .423 | .501 | .053 | .103 | .079 | .110 | .332 | .489 | .414 | .504 |
|                  | X2<>Y   | .721 | .614 | .651 | .723 | .299 | .194 | .224 | .258 | .747 | .600 | .645 | .725 |
|                  | M<>Y    | .224 | .087 | .364 | .233 | .028 | .004 | .067 | .029 | .226 | .090 | .347 | .240 |
|                  | X1<>X2  | .805 | .740 | .593 | .639 | .370 | .247 | .156 | .190 | .831 | .737 | .605 | .631 |
|                  | X1<>X3  | .903 | .747 | .725 | .633 | .310 | .220 | .200 | .190 | .847 | .756 | .711 | .642 |
|                  | X1<>Y   | .559 | .879 | .704 | .645 | .164 | .370 | .256 | .221 | .537 | .860 | .706 | .645 |
Table 1 and Table 2 showing the result of discriminant validity and the raw bias of discriminant validity that involves of three approaches which are CBSEM based Fornell-Larcker criterion, Consistent PLS based Fornell-Larcker criterion and Consistent PLS based Heterotrait-Monotrait (HTMT). In the SEM context, the discriminant validity is an essential analysis to discover to which construct is truly diverse from other constructs by empirical standard [8]. Thus, establishing of the discriminant validity in the SEM context is implying the constructs involved in the study is unique and capture phenomena not evoke by other construct in the assessment of measurement model.

Table 2: Raw Bias correlation

| MODEL | CORRELATION | CB-SEM | Consistent PLS (Fornell-Larcker Criterion) | Consistent PLS (HTMT Criterion) |
|-------|-------------|--------|-------------------------------------------|---------------------------------|
|       |             | 50     | 100 | 200 | 500 | 50 | 100 | 200 | 500 | 50 | 100 | 200 | 500 | 50 | 100 | 200 | 500 |
| TRA   | X1 <-> X2   | 0.012  | 0.002 | 0.001 | 0.004 | 0.013 | -0.024 | 0.022 | 0.025 | 0.012 | 0.002 | 0.001 | 0.004 |     |     |     |     |
|       | X1 <-> M1   | 0.001  | 0.005 | 0.000 | 0.000 | 0.024 | -0.028 | 0.024 | 0.023 | 0.001 | 0.008 | 0.000 | 0.000 |     |     |     |     |
|       | X1 <-> Y    | 0.013  | 0.001 | 0.004 | 0.000 | 0.028 | -0.025 | 0.025 | 0.023 | 0.010 | 0.002 | 0.003 | 0.000 |     |     |     |     |
|       | X1 <-> M3   | 0.011  | 0.010 | 0.002 | 0.006 | 0.015 | -0.028 | 0.023 | 0.026 | 0.011 | 0.010 | 0.002 | 0.006 |     |     |     |     |
|       | X1 <-> M2   | 0.006  | 0.004 | 0.001 | 0.002 | 0.018 | -0.025 | 0.023 | 0.024 | 0.007 | 0.001 | 0.001 | 0.001 |     |     |     |     |
|       | X2 <-> M1   | 0.005  | 0.003 | 0.000 | 0.001 | 0.016 | -0.016 | 0.018 | 0.017 | 0.001 | 0.002 | 0.000 | 0.001 |     |     |     |     |
|       | X2 <-> M2   | 0.002  | 0.003 | 0.004 | 0.002 | 0.018 | -0.019 | 0.016 | 0.019 | 0.001 | 0.005 | 0.005 | 0.002 |     |     |     |     |
|       | X2 <-> M3   | 0.009  | 0.001 | 0.000 | 0.002 | 0.011 | -0.018 | 0.019 | 0.019 | 0.010 | 0.002 | 0.000 | 0.002 |     |     |     |     |
|       | X2 <-> M4   | 0.011  | 0.009 | 0.005 | 0.003 | 0.014 | -0.020 | 0.015 | 0.019 | 0.005 | 0.007 | 0.005 | 0.003 |     |     |     |     |
|       | M1 <-> Y    | 0.018  | 0.005 | 0.001 | 0.001 | 0.013 | -0.013 | 0.015 | 0.015 | 0.006 | 0.004 | 0.002 | 0.001 |     |     |     |     |
|       | M1 <-> M3   | 0.009  | 0.015 | 0.003 | 0.000 | 0.014 | -0.017 | 0.016 | 0.015 | 0.002 | 0.014 | 0.004 | 0.000 |     |     |     |     |
|       | M1 <-> M2   | 0.014  | 0.005 | 0.003 | 0.003 | 0.011 | -0.016 | 0.014 | 0.015 | 0.009 | 0.005 | 0.003 | 0.002 |     |     |     |     |
|       | Y <-> M3    | 0.001  | 0.013 | 0.001 | 0.002 | 0.006 | -0.007 | 0.007 | 0.007 | 0.005 | 0.003 | 0.001 | 0.001 |     |     |     |     |
|       | Y <-> M2    | 0.008  | 0.006 | 0.002 | 0.002 | 0.008 | -0.012 | 0.011 | 0.011 | 0.010 | 0.005 | 0.002 | 0.002 |     |     |     |     |
|       | M3 <-> M2   | 0.014  | 0.004 | 0.002 | 0.000 | 0.005 | -0.012 | 0.015 | 0.011 | 0.017 | 0.005 | 0.002 | 0.001 |     |     |     |     |
| LOYALTY | X1 <-> X2 | 0.010  | 0.002 | 0.000 | 0.004 | 0.030 | -0.022 | 0.023 | 0.022 | 0.003 | 0.001 | 0.000 | 0.004 |     |     |     |     |
|       | X1 <-> M    | 0.022  | 0.000 | 0.003 | 0.002 | 0.016 | -0.021 | 0.019 | 0.022 | 0.025 | 0.001 | 0.003 | 0.002 |     |     |     |     |
|       | X1 <-> Y    | 0.019  | 0.001 | 0.003 | 0.001 | 0.026 | -0.021 | 0.017 | 0.020 | 0.005 | 0.001 | 0.004 | 0.001 |     |     |     |     |
|       | X2 <-> M    | 0.009  | 0.002 | 0.004 | 0.000 | 0.022 | -0.020 | 0.021 | 0.020 | 0.008 | 0.001 | 0.004 | 0.000 |     |     |     |     |
|       | X2 <-> Y    | 0.001  | 0.004 | 0.002 | 0.001 | 0.020 | -0.025 | 0.024 | 0.022 | 0.002 | 0.005 | 0.003 | 0.001 |     |     |     |     |
that the Fornell-Larcker criterion is becomes smaller as the sample size increases which are involves of three established construct cannot be converges discriminant (the bias effect higher than 0.20).

Based Fornell-Larcker criterion is severely suffered from the bias effects which is most of the assessment using raw bias showing the same result indicating that the raw bias with Consistent PLS this assessment the discriminant validity can be achieved.

Construct’s AVE should be greater than its highest correlation with any other construct and only with Variance Extracted (AVE) with the latent variable correlations. Specifically, the square root of each between Consistent PLS based Fornell-Larcker and Consistent PLS based HTMT is different for this assessment the discriminant validity can be achieved.

In the assessment of Fornell-Larcker criterion, it compares the square root of Average Variance Extracted (AVE) with the latent variable correlations. Specifically, the square root of each construct’s AVE should be greater than its highest correlation with any other construct and only with this assessment the discriminant validity can be achieved.

In this case, the result showed from Consistent PLS based Fornell-Larcker is not similar with CBSEM based Fornell-Larcker although the Consistent PLS is noted appropriate for handling two types of construct measurements which are common factor method and composite factor method [9-10]. It seems that CBSEM and Consistent PLS are different across samples and models. Also, the assessment using raw bias showing the same result indicating that the raw bias with Consistent PLS based Fornell-Larcker criterion is severely suffered from the bias effects which is most of the construct cannot be converges discriminant (the bias effect higher than 0.20).

This, however, the problem of lack of discriminant is remedied when the study adopt the analysis for HTMT criterion based on Table 1 and Table 2. In terms of the discriminant accuracy, the CBSEM and Consistent PLS based HTMT are equivalent. Additionally, the bias effect between those methods is becomes smaller as the sample size increases which are involves of three established models. Based on this, the author concurred with the prior research from Voorhoeve et al. [7] indicating that the Fornell-Larcker criterion’s performance in detecting discriminant validity issues improves but is still rather poor overall when indicator loadings vary strongly. It means that, the lack of discriminant with Consistent PLS can be more danger if the indicator loadings are equal loadings as exercised for the current study.

Nevertheless, there are more recent literature stagnant to assess their model based on the idea of Fornell-Larcker criterion. These result show clearly that the discriminant validity with Consistent PLS based Fornell-Larcker criterion is overestimated and cannot be trusted if the studies are associated with the goals for estimating rather than the predicting the conceptualization of reflective measurement model. Strictly speaking, the use of Consistent PLS based Fornell-Larcker criterion should be abandoned when testing the common factor method. This is because this finding cannot see advantage attributes of their use with common factor method as it is always downwards bias.
Alternatively, the researcher must consider to use the Consistent PLS based HTMT which is seem efficient as CBSEM.

3. Conclusion and Discussion

In the SEM context, the construct validity is important to know the degree to which instrument truly measure the construct which they are intended to measure [11]. To further the definition of this, construct validity assessment is commonly split into two sub-classes which are convergent and discriminant validity [12-13]. In this section, the study shows the performance of Consistent PLS in terms of their discriminant validity that related with three population models where convergent validity would be further explain in another section.

Discriminant validity is the extent to which the measure is indeed novel and not simply reflection of other constructs [7]. Motivation to do so is related to the need to the content and substance lies in the model. The researchers are advised to show evidence that all constructs involved in the study are not just empirically reflection of each other so that the information for explaining the measurement theory are not overlapped. The assessment of discriminant validity can be measured by two informative approaches: 1. Fornell & Larcker criterion [14] and 2. Heterotrait-Monotrait Ratio (HTMT).

The HTMT is only relevant for the composite method known as Consistent PLS but not probable for common factor method. According to the recent literature, the Fornell & Larcker criterion is suggested for CBSEM technique and HTMT criterion is recommended for Consistent PLS [7], [15].

With this reason, the study interest to replicate the investigation between Fornell & Larcker criterion and HTMT approach on selected three population models with application of CBSEM and Consistent PLS. This study using Fornell & Larcker criterion for CBSEM and Consistent PLS and HTMT for Consistent PLS. Based on the finding revealed, it is indeed HTMT based Consistent PLS approach is comparable to Fornell & Larcker based CBSEM but not empirical standard to Fornell & Larcker based Consistent PLS.

It is clearly showed that the bias effects are occurred in the Consistent PLS when adopting Fornell & Larcker criterion for assessing the discriminant validity. For this reason, indicator loading applied from Consistent PLS is always bias and thus establishing discriminant validity using Fornell & Larcker criterion is performs very poorly. Although the advent of HTMT approach is seem beneficial for discriminant validity but the idea to adopt this approach under Consistent PLS is lacking.

Some of the commercial PLS program has offered two types of criterion for assessing the discriminant validity: Fornell & Larcker and HTMT approaches. As such, the non-statistician would not sure to choose the best assessment for their model if both approaches are offered. It is important to note that the reviewers and readers have a right to know of their potential existence in order to fully understand of the arguments or debatable presented in a given paper. Moreover, this way will avoid the researchers from continues present false information about their construct validity per se.

Therefore, the Consistent PLS should not be treated equivalence as traditional PLS when assessing the discriminant validity. At best, the Consistent PLS is recommended to divorce itself completely from traditional PLS and concentrate on developing itself further as a potential method for confirmatory modeling. As such, the researchers could differentiate which validity assessment is the best for their research project.

References

[1]. Henseler, J., Dijkstra, T. K., Sarstedt, M., Ringle, C. M., Diamantopoulos, A., Straub, D. W., ... & Calantone, R. J. (2014). Common beliefs and reality about PLS: Comments on Rönkkö and Evermann (2013). Organizational Research Methods, 17(2), 182-209.

[2]. Rönkkö, M., & Evermann, J. (2013). A critical examination of common beliefs about partial least squares path modeling. Organizational Research Methods, 16(3), 425-448.
[3]. Henseler, J., Ringle, C. M., & Sarstedt, M. (2015). A new criterion for assessing discriminant validity in variance-based structural equation modeling. *Journal of the academy of marketing science, 43*(1), 115-135.

[4]. Afthanorhan, A., Mamun, A. A., Zainol, N. R., Foziah, H., & Awang, Z. (2020). Framing the retirement planning behavior model towards sustainable wellbeing among youth: The moderating effect of public profiles. *Sustainability, 12*(21), 8879.

[5]. Zainol, N., Zainol, F., Ibrahim, Y., & Afthanorhan, A. (2019). Scaling up social innovation for sustainability: The roles of social enterprise capabilities. *Management Science Letters, 9*(3), 457-466.

[6]. Aimran, A. N., Ahmad, S., Afthanorhan, A., & Awang, Z. (2017, August). The development of comparative bias index. In *AIP Conference Proceedings* (Vol. 1870, No. 1, p. 060008). AIP Publishing LLC.

[7]. Voorhees, C. M., Brady, M. K., Calantone, R., & Ramirez, E. (2016). Discriminant validity testing in marketing: an analysis, causes for concern, and proposed remedies. *Journal of the academy of marketing science, 44*(1), 119-134.

[8]. Hair, J. F., Hult, G. T. M., Ringle, C. M., Sarstedt, M., & Thiele, K. O. (2017). Mirror, mirror on the wall: a comparative evaluation of composite-based structural equation modeling methods. *Journal of the Academy of Marketing Science, 45*(5), 616-632.

[9]. Henseler, J., Hubona, G., & Ray, P. A. (2016). Using PLS path modeling in new technology research: updated guidelines. *Industrial management & data systems*.

[10]. Afthanorhan, A. (2020). General discussion on small sample size in consistent PLS. *Advances in Mathematics: Scientific Journal, 9*(3), 1053-1060. doi:10.37418/amsj.9.3.30

[11]. Peter, J. P. (1981). Construct validity: A review of basic issues and marketing practices. *Journal of marketing research, 18*(2), 133-145.

[12]. Churchill Jr, G. A. (1979). A paradigm for developing better measures of marketing constructs. *Journal of marketing research, 16*(1), 64-73.

[13]. Mohamad, M., Afthanorhan, A., Awang, Z., & Mohammad, M. (2019). Comparison between CB-SEM and PLS-SEM: Testing and confirming the maqasid syariah quality of life measurement model. *The Journal of Social Sciences Research, 5*(3), 608-614.

[14]. Fornell, C., & Larcker, D. F. (1981). Evaluating structural equation models with unobservable variables and measurement error. *Journal of marketing research, 18*(1), 39-50.

[15]. Dalila, Latif, H., Jaafar, N., Aziz, I., & Afthanorhan, A. (2020). The mediating effect of personal values on the relationships between attitudes, subjective norms, perceived behavioral control and intention to use. *Management Science Letters, 10*(1), 153-162. doi:10.5267/j.msl.2019.8.007