Multiple Trait, Multiple Method Models

Issues and Applications

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Multi-Trait, Multi-Method (MTMM) Models

First implemented in a *Psychological Bulletin* article by Campbell & Fiske (1959), who noted:

- Scores can be tainted by method-specific influences
- Studies need to use several methods to analyze validity appropriately
- Different methods should converge in the measurement of the same trait (convergent validity); whereas a particular method should be able to discriminate between traits (discriminant validity)
- Need to be able to separate trait effects from method effects

Campbell & Fiske's MTMM Model

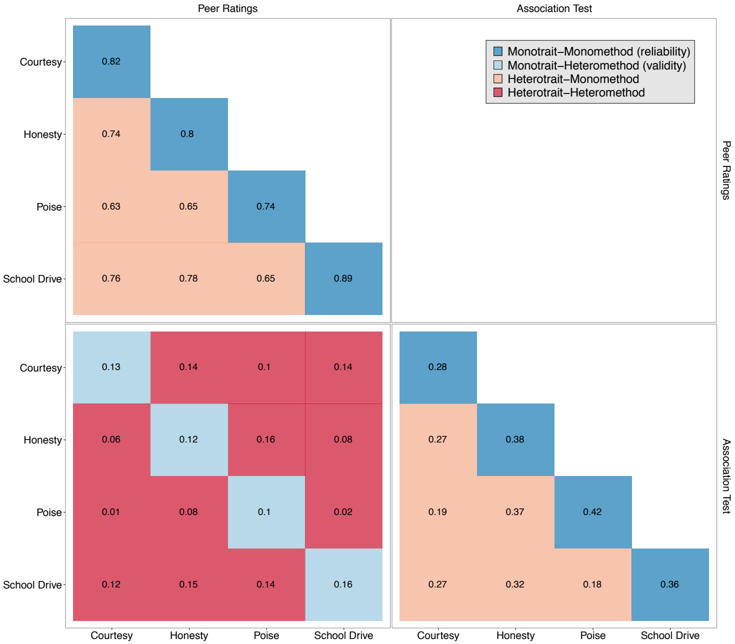
- Originally, MTMM analysis was based upon the raw correlation matrix (R) from a study
- R could be blocked into four components:
    - Monotrait, Monomethod (reliability estimates)
    - Monotrait, Heteromethod (validity)
    - Heterotrait, Monomethod
    - Heterotrait, Heteromethod
- This could then be visualized to address different concerns.

An example of the basic MTMM Model

For this approach, we need: multiple ways of measuring what we are interested in (methods), and multiple constructs to compare (traits).

In one (of many) examples provided in Campbell and Fiske (1959), the investigators looked at personality traits of school children.

- Two methods: Peer Ratings, and an Association Test
- Four traits: Courtesy, Honesty, Poise, and School Drive
- R is 8x8, with the first four columns pertaining to peer ratings, and the second four columns related to the association test.
- This can be visualized in terms of the mono/hetero distinctions above.


Peer Ratings
Association Test
Monotrait–Monomethod (reliability)
Monotrait–Heteromethod (validity)
Heterotrait–Monomethod
Heterotrait–Heteromethod
Courtesy
Honesty
Poise
School Drive
0.82
0.74
0.8
0.63
0.65
0.74
0.76
0.78
0.65
0.89
0.13
0.14
0.1
0.14
0.06
0.12
0.16
0.08
0.01
0.08
0.1
0.02
0.12
0.15
0.14
0.16
0.28
0.27
0.38
0.19
0.37
0.42
0.27
0.32
0.18
0.36

General Observations

Interpretting the MTMM matrix:

- Monotrait-Monomethod blocks: The diagonal elements of R are replaced with an estimate of reliability (usually Cronbach's α or a test-retest intraclass correlation).
- Monotrait-Heteromethod blocks: If methods were developed independently, large correlations support convergent validity.
- Heterotrait-Monomethod: These should be low, as a method should discriminate between traits.
- Heterotrait-Heteromethod: Smallest correlations in R.

General Observations

Issues:

- Requires a follow-up analysis to actually determine the proportion of variance shared among traits and methods.
- The MTMM matrix only lets us view bivariate relationships.
- Cannot account for measurement error.

How can we better estimate these relationships?

Confirmatory Factor Analysis Models for MTMM

Confirmatory Factor Analysis (CFA) for MTMM:

- Most widely used approach
- Allows for separation of trait, method, and error components
- Allows for empirical tests of underlying model assumptions
- Allows linking of latent trait and method factors to other latent constructs

Issues:

- Can yield non-proper parameter estimations
- Can face problems with identification
- Can be hard to interpret
- Which model do we use?

Alternative Models presented in Eid et al. (2003)

In Eid et al. (2003), three models are presented (with extensions), and they are similar in some respects:

- Each model presented is based upon confirmatory factor analysis
- Each is analyzed using structural equation modeling
- Each is investigating the same underlying ideas about trait and method homogeneity

However, there are some key differences in terms of how they are parameterized.

The primary issues in the choice between these models pertain to their **identifiability** and **interpretability**.

Identification in CFA Models

As we have discussed in class, identifiability pertains to the number of unknown parameters we are estimating (t), and if we can obtain *unique* estimates of each using our observed covariance matrix (with J elements).

In a CFA of this nature, we have some general guidelines:

- The t-Rule, where $\left[\left(\frac{J(J+1)}{2}\right) - t\right] >= 0$
- The two- or three-indicator rules

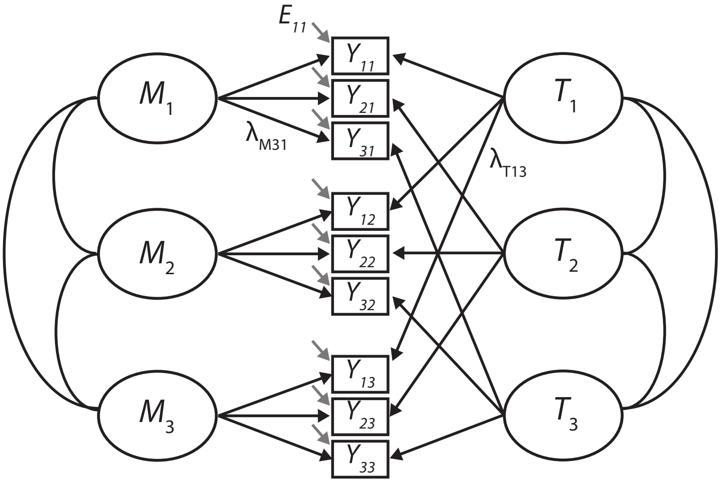
To estimate these models, we only have limited information to draw upon – the number of items or scales administered, and this may not be sufficient to find unique values for all the unknown parameters.

The Correlated Traits, Correlated Methods Model:

The first model, the CTCM, is a fairly straightforward mapping of the MTMM ideas into a CFA framework. This model allows:

- Observed variable (Y_{jk}) is designed to measure trait j by method k, and can be decomposed into a trait component (T_j), a method component (M_k), and a residual ($E_j k$)
- Each observed variable has two loadings: λ_{Tjk} and λ_{Mjk}
- Can be extended to as many traits or methods as desired

CT-CM Model


E11
Y11
Y21
Y31
Y12
Y22
Y32
Y13
Y23
Y33
M1
M2
M3
T1
T2
T3
λM31
λT13

The Correlated Traits, Correlated Methods Model:

Issues:

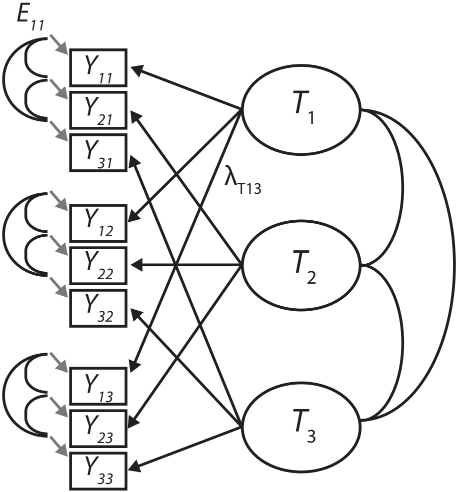
- Model **assumes** that trait and method factors are uncorrelated
- Not globally identified (often results in improper estimates)
- Problems with interpretation: when all methods are correlated, this does not really indicate specific method influences
- No underlying theory about when (if ever) the lack of correlation between traits and methods might be reasonable
- Assumes that the method effect due to one method generalizes across all applications of the method
- Reliability might be underestimated if trait-specific method effects exist but are not accounted for (since they will be pooled into the error variables)

The Correlated Traits, Correlated Uniqueness Model:

The second model presented, the CT-CU, attempts to fix some of the issues with the CT-CM model.

- Method factors are replaced with “method specific” residual correlations.
- Does not assume method effects due to one method are homogenous across all applications of the method because residuals belonging to the same method can covary
- This covariance structure does not have to follow the assumptions of a one-factor model

CT-CU Model



The Correlated Traits, Correlated Uniqueness Model:

Issues:

- Covariation between methods is not permitted
  - Some methods might be more similar than others!
- Measurement error is confounded with method specificity
- "True" method effects cannot be related to external variables

The Correlated Traits, Correlated Methods – 1 Model:

Finally, we have the CT-CM(-1) model proposed by Eid (2000).

This model is:

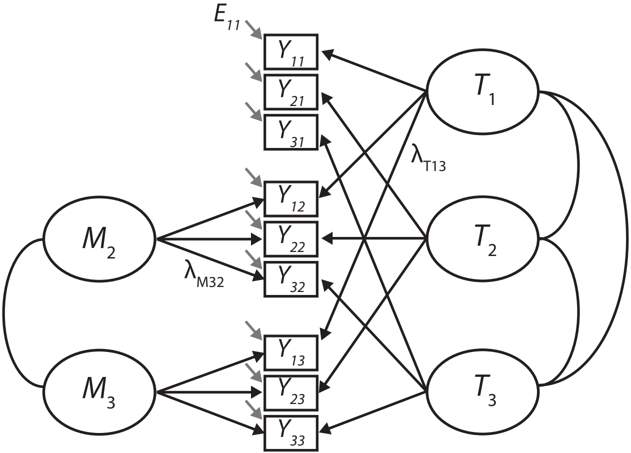
- Identifiable
- Able to separate the variance components due to trait and method effects without the identification problems of the CT-CM
- Allows correlated method factors, unlike the CT-CU
- Parameters have clear interpretations

The Correlated Traits, Correlated Methods – 1 Model:

How does it accomplish all of this?

- A method is chosen as the comparison "standard"
- Other methods are now defined as residual factors that are common to all variables measured by the same method, and represent the parts of a trait measured by a method that cannot be predicted by the true score variable of the indicator measured by the standard method

CT-C(M-1) Model



The Correlated Traits, Correlated Methods – 1 Model:

Issues:

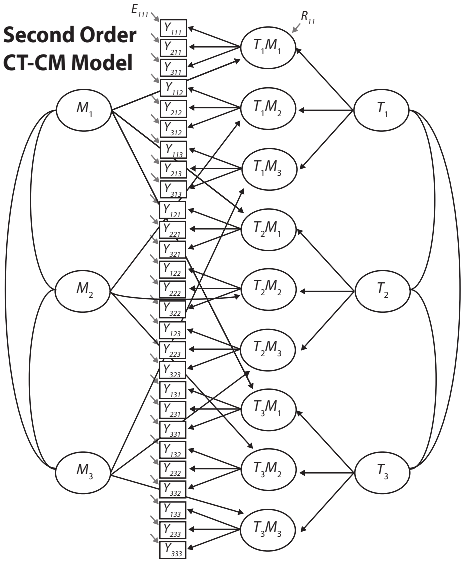
- Method and trait factors cannot be correlated
- Not symmetrical (meaning of parameters depends on which method is chosen as the comparison standard)

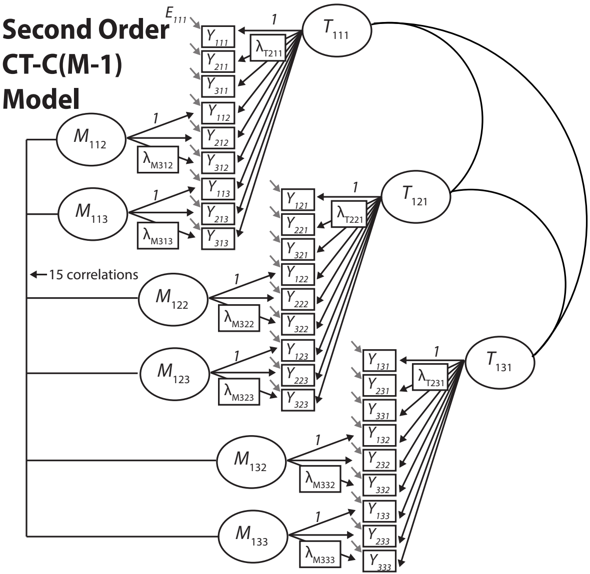
Second-Order Models:

However, an issue with each of the previous models is:

- They only have one indicator for each trait-method unit
  - For instance, Y_{11} was the indicator for the first method, first trait
- Trait-specific method effects cannot be assessed
- Cannot analyze the generalizability of a method effect across different traits
- Reliabilities will be underestimated because residuals represent not only measurement error but also method effects that are trait-specific

Second-order models have a similar structure as first-order models, but have **multiple indicators per trait-method combination**.


Second Order
CT-CM Model
E111
R11
Y111
Y211
Y311
Y112
Y212
Y312
Y113
Y213
Y313
Y121
Y221
Y321
Y122
Y222
Y322
Y123
Y223
Y323
Y131
Y231
Y331
Y132
Y232
Y332
Y133
Y233
Y333
M1
M2
M3
T1M1
T1M2
T1M3
T2M1
T2M2
T2M3
T3M1
T3M2
T3M3
T1
T2
T3


Second Order
CT-C(M-1)
Model
E111
T111
T121
T131
M112
M113
M122
M123
M132
M133
λT211
λT221
λT231
λM312
λM313
λM322
λM323
λM332
λM333
1
Y111
Y211
Y311
Y112
Y212
Y312
Y113
Y213
Y313
Y121
Y221
Y321
Y122
Y222
Y322
Y123
Y223
Y323
Y131
Y231
Y331
Y132
Y232
Y332
Y133
Y233
Y333
15 correlations

The CTC(M–1) Second-Order Model

- The CTCM and the CTCU still are plagued with similar issues to their first-order counterparts, even with the additional factors.
- However, the revised CTC(M–1) is able to:
  - Separate measurement error from trait and method effects
  - Allow for more appropriate estimates of reliability
  - Allow for correlated method effects

Requirements of the CT-C(M-1) Model

- At least two indicators for each trait-method unit
  - Indicators can be item parcels, as in the example
- At least two traits
- At least two methods

Interpretation of the CT-C(M-1) Model

The example provided uses:

- three indicators; for each of...
- three traits (attention to feelings, clarity of feelings, and habitual mood); that have been measured in...
- three different ways: self-report, and two peer reports: one by a close friend, and one by an acquaintance.

Steps are given in the article for how to construct the model, with the additional aside that there are more allowable correlations than depicted in the provided figure (specifically, the trait with method correlations).

A substantial part of the interpretation of this model is based upon the correlation matrix.

Correlations from the CT-C(M-1) Model

Factor	T111	T121	T131	M112	M113	M122	M123	M132	M133
T111	-								
T121	0.26	-							
T131	-0.06	0.36	-						
M112	X	0.19	0.16	-					
M113	X	0.04	0.05	0.14	-				
M122	0.13	X	0.15	0.31	0.01	-			
M123	-0.05	X	0.11	-0.01	0.34	0.11	-		
M132	0.02	0.1	X	-0.16	-0.04	0.19	0.08	-	
M133	-0.02	-0.07	X	-0.15	-0.02	0.09	0.33	0.38	-

Xijk — i = indicator, j = Trait, k = Method

1) Correlations between latent traits (yellow)
2) Same method, different trait correlations (green)
3) Correlations between trait-specific method factors of one trait and the trait factor of another trait (red)
4) Correlations between method factors belonging to different trait-method units (purple)
5) Correlations between method factors belonging to the same trait-method unit (blue)

Correlations from the CT-C(M-1) Model

Interpreting these correlations:

1. Correlations between latent traits: Discriminant validity at the level of the standard method (coefficients should be low)
2. Same method, different traits: Generalizability of method effects across traits (if all 0, could fit 2 method factors instead of 6)
3. Trait-specific method factor belonging to one trait and the trait factor of another trait: Disciminінant validity, corrected for influences due to the standard method
4. Method factors belonging to different trait-method units: Between method, discriminant validity coefficients corrected for the discriminant validity on the level of the standard method
5. Method factors belonging to same trait-method unit: Indicate commonness between methods that differs from the standard method

Other Output from the CT-C(M-1) Model

- Factor loadings: Indicate relationships of parcels to traits/methods in relation to standard item, and indicate convergent validity.
- Variance components:
  - Reliability:
    - observed variables; $Rel(Y_{ijk}) = \frac{Var(T_{ijk})}{Var(Y_{ijk}}$
  - Consistency:
    - observed variables; $CO(Y_{ijk}) = \frac{\lambda^2_{Tijk} Var(T_{1j1})}{Var(Y_{ijk})}$
    - true-score variables; $CO(T_{ijk}) = \frac{\lambda^2_{Tijk} Var(T_{1j1})}{Var(T_{ijk})}$
  - Method Specificity:
    - observed variables; $MS(Y_{ijk}) = \frac{\lambda^2_{M1jk}}{Var(Y_{ijk})}$
    - true-score variables; $MS(T_{ijk}) = \frac{\lambda^2_{Mijk} Var(M_{1jk})}{Var(T_{ijk})}$
  - Latent Correlations; $\sqrt{consistency}$

General Issues and Applications

- Variance components can be expressed in terms of aggregated traits
- The CT-CU model is more appropriate if raters are exchangeable (no clear standard)
- All indicators are assumed to be homogenous indicators of the trait-method unit
    - e.g., no parcel performs better than the others

Conclusion

The CT-C(M-1) model seems like a reasonable approach for analyzing MTMM models.

This model circumvents some of the negative aspects of previous models (especially in terms of identifiability and interpretability) through careful consideration of the parameters that should be estimated.

This is especially useful when there is a clear reference method to use as a standard.