

Measurement Invariance (MI) in CFA and Differential Item Functioning (DIF) in IRT/IFA

- Topics:
 - What are MI and DIF?
 - Testing measurement invariance in CFA
 - Testing differential item functioning in IRT/IFA

- Btw: if you have many groups to compare, a newer “alignment” method may also be useful (see [Asparouhov & Muthén, 2014](#))

The Big Picture

- **In CFA**, we can assess “**measurement invariance**” (**MI**), also known as “factorial invariance” or “measurement equivalence”
- Concerns the extent to which the psychometric properties of the observed indicators are transportable or generalizable across groups (e.g., gender, country) or over time/conditions
 - In other words, we are testing whether the indicators measure the same construct *in the same way* in different groups or over time/conditions
 - If so, then indicator responses should depend only on latent trait scores, and not on group membership or time/conditions, such that observed response differences are only caused by TRUE differences in the trait
- **In IRT/IFA**, lack of measurement invariance is known as “**differential item functioning**” (**DIF**), but it’s the same idea
 - But note the inversion: Measurement Invariance = *Non*-DIF
Measurement *Non*-Invariance = DIF

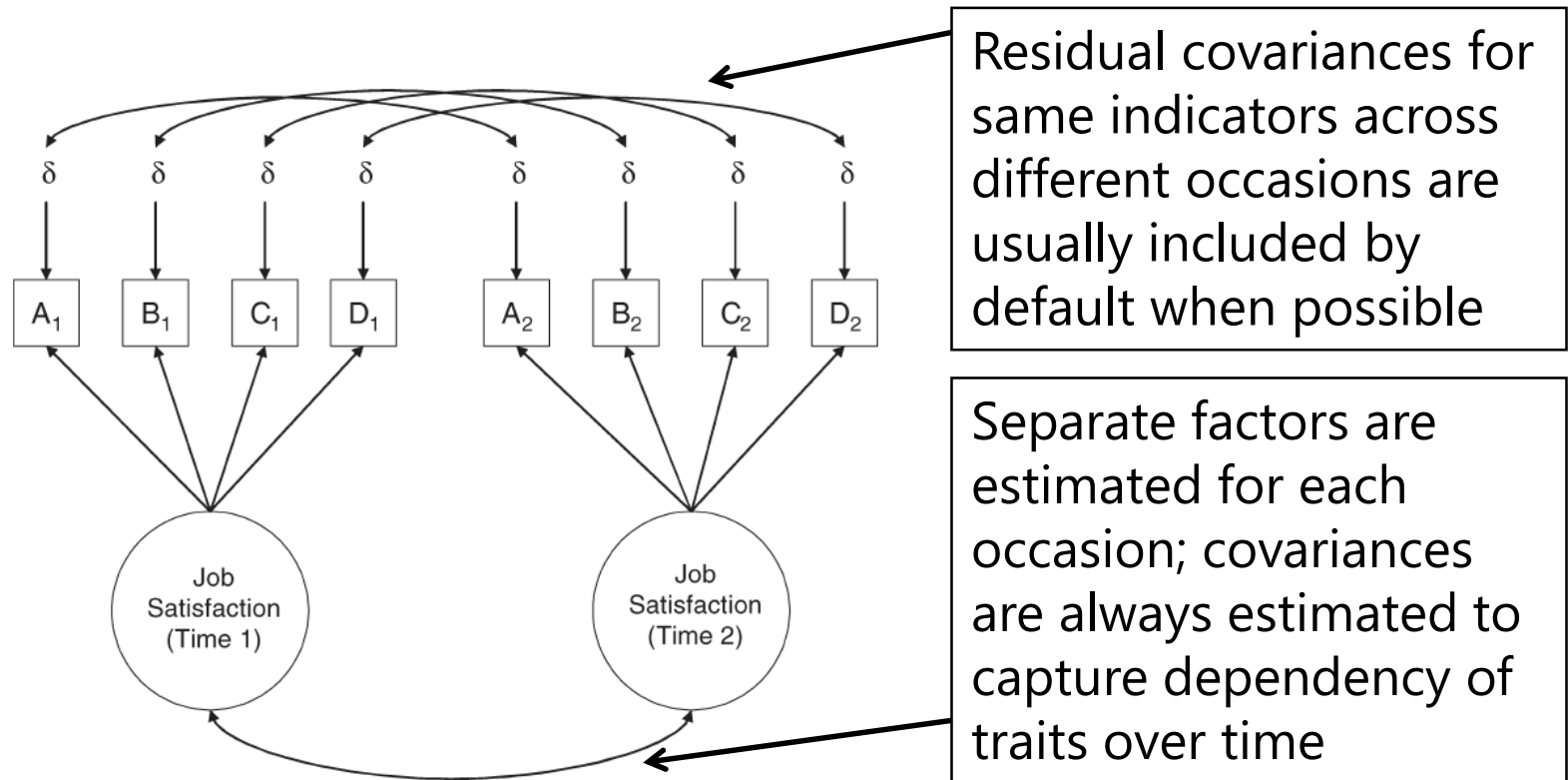
2 Distinct Types of Invariance

- **Measurement Invariance** concerns how the indicators (items) measure the latent trait across groups or time/conditions
 - An invariant measurement model has the same factor **loadings**, item **intercepts/thresholds**, and **residual variances** (and covariances)
 - Measurement model invariance is a precursor to ANY group or time/condition comparison (whether it is explicitly tested or not)
 - **It's NOT ok** if you don't have at least partial measurement invariance to make subsequent comparisons across groups or time/condition
- **Structural Invariance** concerns how the latent traits are distributed and related across groups or time/condition
 - An invariant structural model has the same **factor variances**, **factor covariances** (or same higher-order structure) and **factor means**
 - Given (at least partial) measurement invariance, **it IS ok** if you don't have structural invariance, **because trait differences may be real**

Model Options for Testing Invariance

- Invariance testing in CFA (or DIF testing in IRT/IFA) proceeds differently depending on the type of groups to be compared
- **Independent groups?** Use a “**multiple-group**” model
 - Test separate group-specific factor models **simultaneously**
 - Use GROUP= or KNOWNCLASS= in Mplus and separate MODEL: per group
 - An alternative approach of MIMIC models, in which the grouping variable is entered as a predictor, does not allow testing of equality of factor loadings or factor variances (so MIMIC is less useful than a full multiple-group model)
- **Dependent** (longitudinal, repeated, dyadic) groups?
 - All indicator responses go into **SAME model**, with separate factors per occasion/condition (allowing all factor covariances by default)
 - Usually, the same indicators also have residual covariances by default (which may have to be implemented as method/specific factors in IRT/IFA)
 - Given measurement invariance, growth modeling of the latent traits can serve as a specific type of structural invariance testing
 - It is **INCORRECT** to use a multiple-group model if the groups are dependent

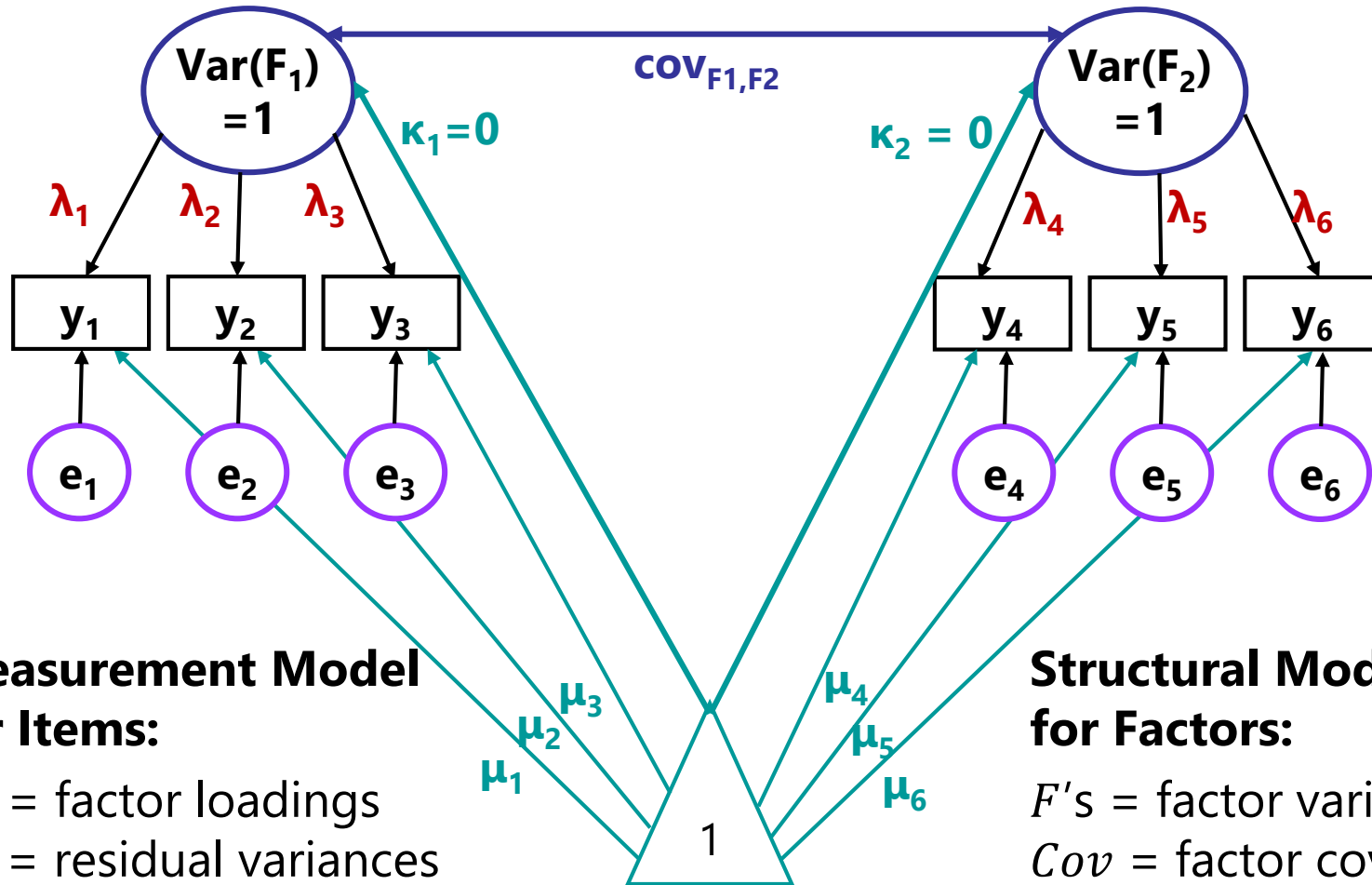
Longitudinal Invariance Model



FYI: A structural model in which all factor means, variances, and covariances are estimated is analogous to a "saturated means, unstructured variance model" for observed variables in MLM terms

Remember the CFA model? Let's start MI testing here....

We will begin with my preferred default of a fixed factor mean=0 and factor variance=1.



Measurement Model for Items:

λ 's = factor loadings
 e 's = residual variances
 μ 's = intercepts

Structural Model for Factors:

F 's = factor variances
 Cov = factor covariances
 K 's = factor means

Steps of Testing Invariance across Groups

- **Step 0 (optional): Omnibus test of equality of the overall indicator (i.e., item) covariance matrix across groups**
 - Do the covariances matrices differ between groups on the whole?
 - If not, game over. You are done. You have invariance. Congratulations.
 - Many people disagree with the necessity or usefulness of this omnibus test to begin testing invariance... *why might that be?*
 - People also differ in whether invariance should go from top-down or bottom-up directions... I favor bottom-up for the same reason.
- Let's proceed with an example with 2 factors, 6 indicators (3 per factor; simple structure), and 2 groups...
 - Total possible # parameters = $\frac{v(v+1)}{2} + v = \frac{6(6+1)}{2} + 6 = 27$ per group
 - So our COMBINED total possible $DF = 54$ across 2 groups

Step 1: Test “Configural” Invariance

- **Do the groups have the same general factor structure?**
- Same number of factors, same pattern of free/0 loadings
→ same conceptual definition of latent constructs
- In practice, begin by testing the factor structure within each group separately; hope they are “close enough”
- Then estimate group-specific models simultaneously, but **allow all estimated parameters to differ across groups**
 - This will be the baseline model for further comparisons
 - Absolute fit χ^2 and DF will be additive across groups (different group sample sizes will result in differential weighting of χ^2 across groups)
- This is as good fit as it gets! From here forward, our goal is to make model fit NOT WORSE by constraining parameters equal
 - That means if the configural model fits badly, game over...

Testing Invariance Constraints

- As before, we will test whether subtracting parameters worsens model fit via likelihood ratio (aka, $-2\Delta LL$, χ^2) tests
 - Implemented via a direct difference in H_0 model χ^2 values most often, but this is only appropriate when using regular ML estimation
- MLR requires a modified version of this $-2\Delta LL$ test (see Mplus website): <http://www.statmodel.com/chidiff.shtml>
 - Is called a “rescaled likelihood ratio test” when you explain it
 - Includes extra steps to incorporate scaling factors (1.00 = regular ML)
 - I built you a spreadsheet for this...you’re still welcome 😊
- If **removing parameters** (e.g., in invariance testing), H_0 model fit can get **worse OR not worse** (as indicated by smaller LL OR by larger $-2LL$ and χ^2)
 - This is what we are doing in testing invariance!
- If **adding parameters** (e.g., in adding factors), H_0 model fit can get **better OR not better** (as indicated by larger LL OR by smaller $-2LL$ and χ^2)

Testing Nested Models via $-2\Delta LL$

- Comparing nested models via a “**likelihood ratio test**” → $-2\Delta LL$ (MLR rescaled version)

Note: Your LL will always be listed as the H_0 (H_1 is for the saturated, perfectly fitting model)

- 1. Calculate $-2\Delta LL = -2*(LL_{\text{fewer}} - LL_{\text{more}})$

- 2. Calculate **difference scaling correction** =

$$\frac{(\#parms_{\text{fewer}} * scale_{\text{fewer}}) - (\#parms_{\text{more}} * scale_{\text{more}})}{(\#parms_{\text{fewer}} - \#parms_{\text{more}})}$$

Fewer = simpler model
More = more parameters

- 3. Calculate **rescaled difference** = $-2\Delta LL / \text{scaling correction}$

- 4. Calculate **Δdf** = $\#parms_{\text{more}} - \#parms_{\text{fewer}}$

- 5. **Compare rescaled difference to χ^2 with $df = \Delta df$**

- Add 1 parameter? $LL_{\text{diff}} > 3.84$, add 2 parameters: $LL_{\text{diff}} > 5.99...$
- Absolute values of LL are meaningless (is relative fit only)
- **Process generalizes to any other model estimated using maximum likelihood (such as IRT/IFA) that provides LL height for the H_0 model**

1. Configural Invariance Model:

Same Factor Structure; All Parameters Separate

$$\text{Total } DF \text{ across groups} = 54 - 38 = 16 = 54 - (12\mu + 12\sigma_e^2 + 12\lambda + 0\sigma_F^2 + 2\sigma_{F12} + 0\kappa_F) = 16$$

Group 1 (subscript = item, group):

- $y_{11s} = \mu_{11} + \lambda_{11}F_{1s} + e_{11s}$
- $y_{21s} = \mu_{21} + \lambda_{21}F_{1s} + e_{21s}$
- $y_{31s} = \mu_{31} + \lambda_{31}F_{1s} + e_{31s}$
- $y_{41s} = \mu_{41} + \lambda_{41}F_{2s} + e_{41s}$
- $y_{51s} = \mu_{51} + \lambda_{51}F_{2s} + e_{51s}$
- $y_{61s} = \mu_{61} + \lambda_{61}F_{2s} + e_{61s}$
- Estimated factor covariance, but both factor means = 0 and both factor variances = 1

Group 2 (subscript = item, group):

- $y_{12s} = \mu_{12} + \lambda_{12}F_{1s} + e_{12s}$
- $y_{22s} = \mu_{22} + \lambda_{22}F_{1s} + e_{22s}$
- $y_{32s} = \mu_{32} + \lambda_{32}F_{1s} + e_{32s}$
- $y_{42s} = \mu_{42} + \lambda_{42}F_{2s} + e_{42s}$
- $y_{52s} = \mu_{52} + \lambda_{52}F_{2s} + e_{52s}$
- $y_{62s} = \mu_{62} + \lambda_{62}F_{2s} + e_{62s}$
- Estimated factor covariance, but both factor means = 0 and both factor variances = 1

Step 2: Test “Metric” Invariance

- Also called “**weak** factorial invariance”
- Do the groups have the same **factor loadings**?
 - Each indicator is still allowed to have a different loading within each group → this is **not** a tau-equivalent model
 - Loadings for *same indicator* are constrained equal *across groups*
- Estimate all newly constrained factor loadings, but **fix all factor variances to 1 in the reference group** (freely estimate all factor variances in other group)
 - Why? Loadings for marker items (fixed=1 for identification) would be assumed invariant, and thus they could not be tested for invariance
 - This alternative specification allows us to evaluate ALL loadings and still identify the model (see Yoon & Millsap, 2007), which is BETTER

2. Metric Invariance Model:

Same Factor Loadings Only (saves 4 DF)

$$\text{Total } DF \text{ across groups} = 54 - 34 = 20 = 54 - (12\mu + 12\sigma_e^2 + 6\lambda + 2\sigma_F^2 + 2\sigma_{F12} + 0\kappa_F) = 20$$

Group 1 (subscript = item, group):

- $y_{11s} = \mu_{11} + \lambda_1 F_{1s} + e_{11s}$
- $y_{21s} = \mu_{21} + \lambda_2 F_{1s} + e_{21s}$
- $y_{31s} = \mu_{31} + \lambda_3 F_{1s} + e_{31s}$
- $y_{41s} = \mu_{41} + \lambda_4 F_{2s} + e_{41s}$
- $y_{51s} = \mu_{51} + \lambda_5 F_{2s} + e_{51s}$
- $y_{61s} = \mu_{61} + \lambda_6 F_{2s} + e_{61s}$
- **Both factor variances = 1 for identification**, factor covariance is estimated, but both factor means are STILL = 0

Group 2 (subscript = item, group):

- $y_{12s} = \mu_{12} + \lambda_1 F_{1s} + e_{12s}$
- $y_{22s} = \mu_{22} + \lambda_2 F_{1s} + e_{22s}$
- $y_{32s} = \mu_{32} + \lambda_3 F_{1s} + e_{32s}$
- $y_{42s} = \mu_{42} + \lambda_4 F_{2s} + e_{42s}$
- $y_{52s} = \mu_{52} + \lambda_5 F_{2s} + e_{52s}$
- $y_{62s} = \mu_{62} + \lambda_6 F_{2s} + e_{62s}$
- **Both factor variances are now estimated**, factor covariance is still estimated, but both factor means are STILL = 0

2. Metric Invariance Model

- Compare metric invariance to configural invariance model:
Is the model fit not worse ($-2\Delta LL$ not significant)?
 - Check that factor variances are fixed to 1 in reference group only: they should be freely estimated in the other group, otherwise you are imposing a structural constraint (that groups have same variability) too
 - Otherwise, inspect the **modification indices** (voo-doo) to see if there are any indicators whose loadings want to differ across groups
 - Retest the model as needed after releasing one loading at a time, starting with the largest modification index, and continue until your partial metric invariance model is **not worse** than the configural model
- Do you have partial metric invariance (1+ loading per factor)?
 - Your trait is (sort of) measured in the same way across groups
 - If not, it doesn't make sense to evaluate how relationships involving the factor differ across groups (because the factor itself differs)
 - Even if full invariance holds, check the modification indices anyway (because individual discrepancies can be washed out in overall test)

Step 3: Test “**Scalar**” Invariance

- Also called “**strong** factorial invariance”
- Do the groups have the same **indicator intercepts**?
 - Each indicator is still allowed to have a different intercept, but intercepts for same indicator are constrained equal across groups
 - Indicators that failed metric invariance traditionally do not get tested for scalar invariance (single-elimination), but they could be
 - Scalar invariance is required for factor mean comparisons!
- Previous (partial) metric invariance model is starting point
- Estimate all newly constrained intercepts, but **fix the factor means to 0 in reference group** (**free** the factor means in the other group)
 - Why? Intercepts for marker items (if fixed=0 for identification) would be assumed invariant, and thus they could not be tested

3. Scalar Invariance Model:

Same Factor Loadings + Same Intercepts (saves +4 DF)

$$\text{Total } DF \text{ across groups} = 54 - 30 = 24 = 54 - (6\mu + 12\sigma_e^2 + 6\lambda + 2\sigma_F^2 + 2\sigma_{F12} + 2\kappa_F) = 24$$

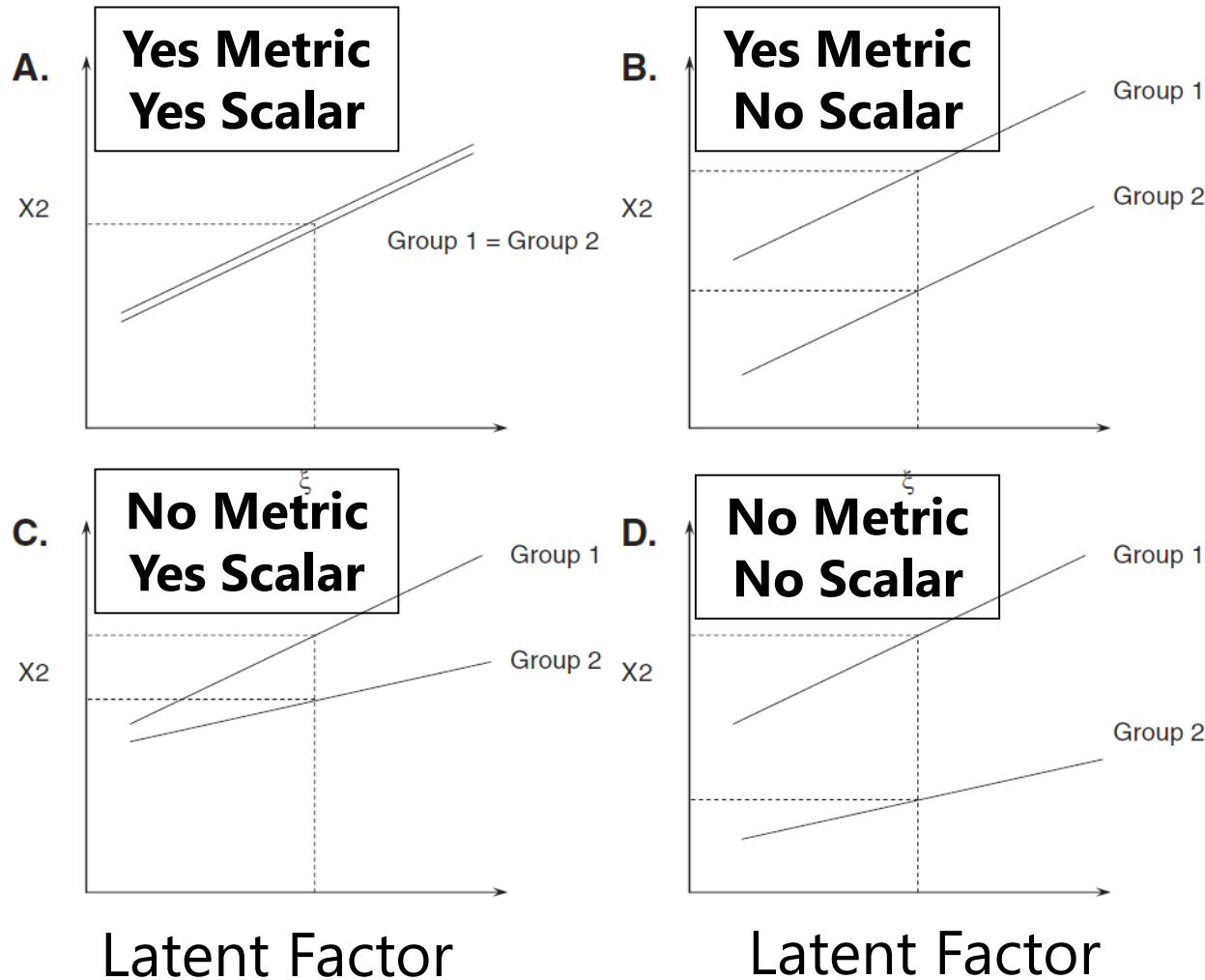
Group 1 (subscript = item, group):

- $y_{11s} = \mu_1 + \lambda_1 F_{1s} + e_{11s}$
- $y_{21s} = \mu_2 + \lambda_2 F_{1s} + e_{21s}$
- $y_{31s} = \mu_3 + \lambda_3 F_{1s} + e_{31s}$
- $y_{41s} = \mu_4 + \lambda_4 F_{2s} + e_{41s}$
- $y_{51s} = \mu_5 + \lambda_5 F_{2s} + e_{51s}$
- $y_{61s} = \mu_6 + \lambda_6 F_{2s} + e_{61s}$
- **Both factor variances fixed to 1, both factor means fixed to 0 for identification, factor covariance is still estimated**

Group 2 (subscript = item, group):

- $y_{12s} = \mu_1 + \lambda_1 F_{1s} + e_{12s}$
- $y_{22s} = \mu_2 + \lambda_2 F_{1s} + e_{22s}$
- $y_{32s} = \mu_3 + \lambda_3 F_{1s} + e_{32s}$
- $y_{42s} = \mu_4 + \lambda_4 F_{2s} + e_{42s}$
- $y_{52s} = \mu_5 + \lambda_5 F_{2s} + e_{52s}$
- $y_{62s} = \mu_6 + \lambda_6 F_{2s} + e_{62s}$
- **Both factor variances estimated, both factor means estimated to become mean differences, and factor covariance is still estimated**

Implications of Non-Invariance



Without metric invariance:
 Because unequal loadings implies non-parallel slopes, the intercept will differ as a result. The size of the difference depends on where $\text{trait}=0$.

This is why scalar invariance is often not tested if metric invariance fails for a given indicator.

3. Scalar Invariance Model

- Compare scalar invariance to last metric invariance model:
Is the model fit not worse ($-2\Delta LL$ not significant)?
 - Check that factor means are fixed to 0 in reference group only: they should be freely estimated in the other group, otherwise you are imposing a structural constraint (groups have same means) too
 - Otherwise, inspect the **modification indices** (voo-doo) to see if there are any indicators whose intercepts want to differ across groups
 - Retest the model as needed after releasing one intercept at a time, starting with the largest modification index, and continue until your partial scalar invariance model is **not worse** than last metric model
- Do you have partial scalar invariance (1+ intercept per factor)?
 - Your trait is (sort of) responsible for mean differences across groups
 - If not, it doesn't make sense to evaluate factor means differs across groups (because something else is causing those differences)
 - Even if full invariance holds, check the modification indices anyway

Step 4: Test **Residual Variance** Invariance

- Also called “**strict** factorial invariance”
- Do the groups have the same **residual variances**?
 - Each indicator is still allowed to have a different residual variance (i.e., this is not a parallel items model), but residual variances for *same indicator* are constrained equal *across groups* (not parallel)
 - Indicators that failed scalar invariance traditionally do not get tested for residual variance invariance (although they could be)
 - Residual invariance is of debatable importance, because it means that whatever causes “not the factor” does not differ by group
 - Equal residual variances are commonly misinterpreted to mean “equal reliabilities”—this is **ONLY** the case if the factor variances are the same across groups, too (stay tuned)
- Without residual covariances, this is the last step of “measurement invariance” (otherwise they are last)

4. Residual Invariance Model:

+ Same Residual Variances (saves +6 DF)

$$\text{Total } DF \text{ across groups} = 54 - 24 = 30 = 54 - (6\mu + 6\sigma_e^2 + 6\lambda + 2\sigma_F^2 + 2\sigma_{F12} + 2\kappa_F) = 30$$

Group 1 (subscript = item, group):

- $y_{11s} = \mu_1 + \lambda_1 F_{1s} + e_{1s}$
- $y_{21s} = \mu_2 + \lambda_2 F_{1s} + e_{2s}$
- $y_{31s} = \mu_3 + \lambda_3 F_{1s} + e_{3s}$
- $y_{41s} = \mu_4 + \lambda_4 F_{2s} + e_{4s}$
- $y_{51s} = \mu_5 + \lambda_5 F_{2s} + e_{5s}$
- $y_{61s} = \mu_6 + \lambda_6 F_{2s} + e_{6s}$
- **Both factor variances fixed to 1, both factor means fixed to 0 for identification, factor covariance is still estimated**

Group 2 (subscript = item, group):

- $y_{12s} = \mu_1 + \lambda_1 F_{1s} + e_{1s}$
- $y_{22s} = \mu_2 + \lambda_2 F_{1s} + e_{2s}$
- $y_{32s} = \mu_3 + \lambda_3 F_{1s} + e_{3s}$
- $y_{42s} = \mu_4 + \lambda_4 F_{2s} + e_{4s}$
- $y_{52s} = \mu_5 + \lambda_5 F_{2s} + e_{5s}$
- $y_{62s} = \mu_6 + \lambda_6 F_{2s} + e_{6s}$
- **Both factor variances estimated, both factor means estimated to become mean differences, and factor covariance is still estimated**

4. Residual Variance Invariance Model

- Compare residual invariance to last scalar invariance model:
Is the model fit not worse ($-2\Delta LL$ not significant)?
 - Otherwise, inspect the **modification indices** (voo-doo) to see if there are any indicators whose residual variances want to differ across groups
 - Retest the model after releasing one residual variance at a time, starting with the largest modification index, and continue until your partial residual invariance model is **not worse** than last scalar model
- Do you have partial residual variance invariance (1+ residual variance per factor)?
 - Your groups have the same amount of “not the factor” variance in each item (so that’s good, I guess???)
 - Even if full invariance holds, check the modification indices anyway
 - Also assess **any residual covariances** across groups if you have those
- Your (partial) residual invariance model is the new baseline for assessing structural invariance...

Testing Structural Invariance

- Are the **factor variances** the same across groups? (+1 *DF* per factor)
 - Fix each factor variance in the alternative group to 1 (as in the ref group)
 - Is model fit worse? If so, the groups differ in their factor variances
- Are the **factor covariances** the same across groups? (+1 *DF* per pair)
 - Fix each factor covariance equal across groups, is model fit worse?
 - Factor correlation will only be the same across groups if the factor variances are the same, too (if factor variances differ, then factor covariance will, too)
- Are the **factor means** the same across groups? (+1 *DF* per factor)
 - Fix each factor mean in the alternative group to 0 (as in the ref group)
 - Is model fit worse? If so, the groups differ in their factor means
 - Btw, the Wald test for the factor means already tell you this (difference from 0)
- It is **not problematic** if structural invariance doesn't hold
 - Given measurement invariance, this is a substantive issue about differences in the amounts and relations of the latent traits (and that's ok)
 - Might stop at measurement invariance for testing RQs involving the traits

Summary: Invariance Testing in CFA

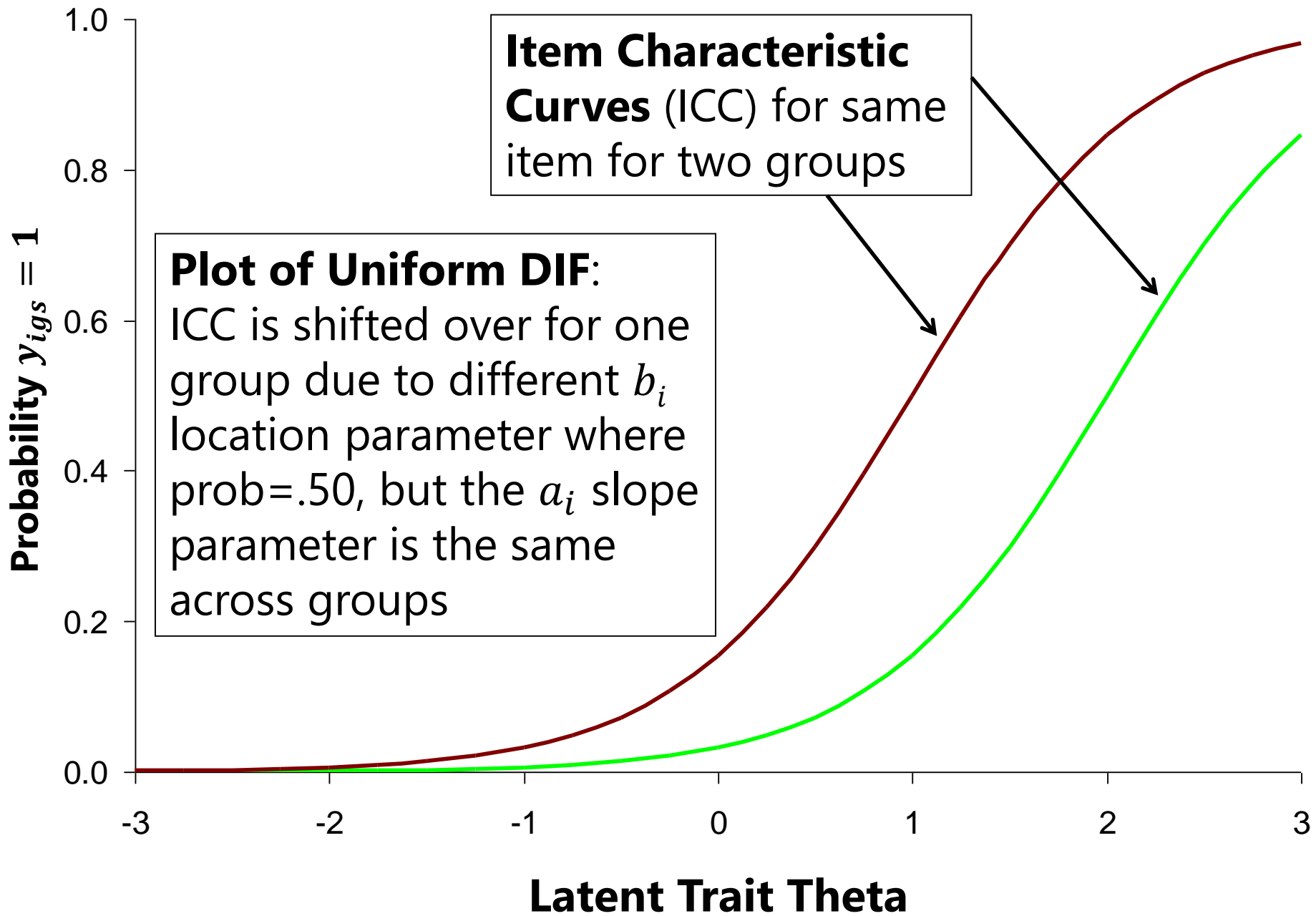
- In CFA: Testing invariance has two distinct parts:
 - Measurement invariance: Is your construct being measured in the same way by the indicators across groups/time?
 - Hope for at least “partial” invariance... otherwise, game over for comparing how factors relate (or mean differences) across groups
 - Structural invariance: Do your groups/times differ in their distribution and/or means of the construct? Let’s find out!
 - Structural differences are real and interpretable differences given measurement invariance of the constructs
- In IFA: Still called “testing invariance”
 - Conducted similarly (but not exactly the same) in Mplus
- In IRT: Now called testing “differential item functioning”
 - With different names and rules, not directly tested in Mplus

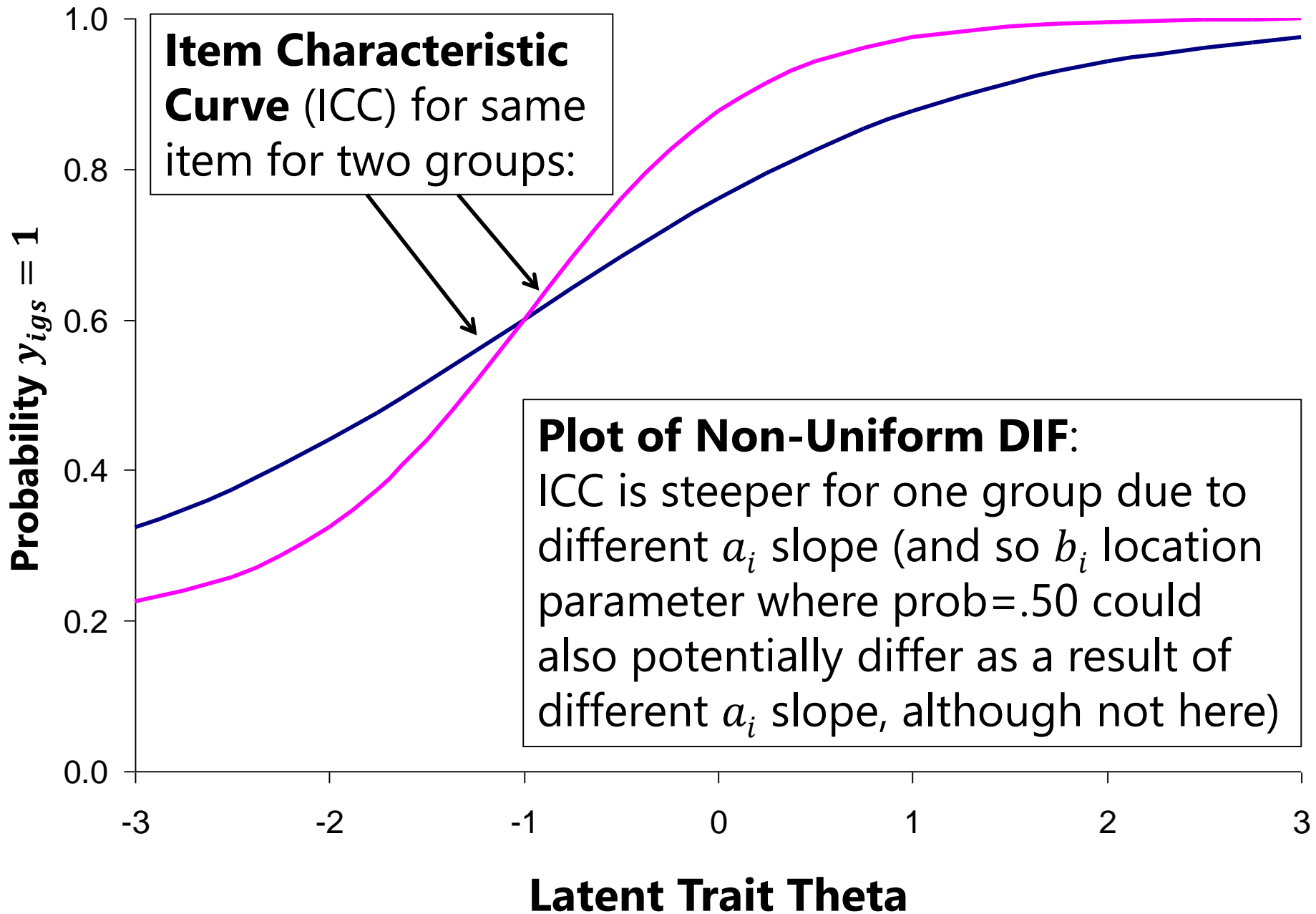
Differential Item Functioning (DIF)

- In IRT (model with a_i discrimination and b_i difficulty), measurement NON-invariance = DIF
 - Note the inversion: Measurement Invariance = *Non*-DIF
Measurement *Non*-Invariance = DIF
 - An item has "DIF" when persons with equal amounts of the traits, but from different groups, have different expected item responses
 - An item has "non-DIF" if persons with the same amount of the trait have the same expected item response, regardless of group
 - DIF can be examined across groups, over time, over conditions, etc., the same as in CFA/IFA
 - Independent groups? Multiple-group model
 - Dependent "groups"? One factor per "group" in same model

2 Types of DIF (as described in IRT)

- **“Uniform DIF”** → Analogous to scalar NON-invariance
 - IRT b_i parameters differ across groups
 - Item is systematically more difficult/severe for members of one group, *even for persons with the same amount of the theta trait*
 - Example: “I cry a lot” → Would men and women *with the same amount of depression* have the same expected item response?
- **“Non-Uniform DIF”** → Analogous to metric NON-invariance
 - IRT a_i (and possibly b_i) parameters differ across groups
 - Item is systematically more related to theta for members of one group → higher discrimination (item “works better”)
 - Group-related shift in item difficulty is not consistent across the trait
- What about residual variance invariance? It depends:
 - Doesn’t exist in ML: no estimated error variance (is logit=3.29 or probit=1.00)
 - Will exist in WLSMV after constraining loadings and thresholds, but not before...





Testing Measurement Invariance in Categorical Outcomes

- 2 versions of model for polytomous outcomes in Mplus:
 - IRT: $\text{Logit or Probit}(y_{kis} = 1) = a_i(\theta_s - b_{ki})$
 - IFA: $\text{Logit or Probit}(y_{kis} = 1) = -\tau_{ki} + \lambda_i\theta_s$
 - Logit or Probit in ML; only Probit in WLSMV
- Mplus estimates the IFA τ_{ki} and λ_i parameters, then *converts* to the IRT a_i and b_{ki} parameters for binary outcomes **after rescaling trait** (M=0, SD=1)
 - Tests of measurement invariance are thus specifically for τ_{ki} and λ_i , not a_i and b_{ki}
 - So Mplus does not directly allow examination of "DIF" for a_i and b_i directly
- **IFA τ_{ki} and λ_i parameters are held directly invariant, not IRT a_i and b_i**
 - So even if λ_i factor loadings are invariant across groups, the IRT a_i discriminations given by Mplus will still differ across groups due to differences in their theta variances (but you can calculate the invariant a_i parameters yourself via MODEL CONSTRAINT)
 - Likewise, even if τ_{ki} thresholds are invariant across groups/time, Mplus IRT b_i difficulty parameters will still differ due to their rescaling of the trait (but you can fix this)

The k thresholds divide the C item responses into $C - 1$ cumulative binary submodels ($y = 0$ if lower, $y = 1$ if higher)

Review: From IFA to IRT

IFA with “easiness” **intercept** μ_i : **Logit or Probit** $y_{is} = \mu_i + \lambda_i F_s$ $\mu_i = -\tau_i$

IFA with “difficulty” **threshold** τ_i : **Logit or Probit** $y_{is} = -\tau_i + \lambda_i F_s$

IFA model with “difficulty” thresholds can be written as a **2-PL IRT Model**:

IRT model:

$$\text{Logit or Probit } y_{is} = a_i(\theta_s - b_i) = \underbrace{-a_i b_i}_{\tau_i} + \underbrace{a_i \theta_s}_{\lambda_i}$$

IFA model:

a_i = discrimination
 b_i = difficulty
 $\theta_s = F_s$ latent trait

Convert IFA to IRT:

$$a_i = \lambda_i * \sqrt{\text{Theta Variance}}$$

$$b_i = \frac{\tau_i - (\lambda_i * \text{Theta Mean})}{\lambda_i * \sqrt{\text{Theta Variance}}}$$

Convert IRT to IFA:

$$\lambda_i = \frac{a_i}{\sqrt{\text{Theta Variance}}}$$

$$\tau_i = a_i b_i + \frac{a_i * \text{Theta Mean}}{\sqrt{\text{Theta Variance}}}$$

Note: These formulas rescale a_i and b_i so that theta M=0, VAR=1

If you don't want to rescale theta, use M=0 and VAR=1 to keep your current scale

Invariance Testing in Mplus

- **IFA models using Full-Information MML:** Mplus must be tricked into estimating a multiple-group models (e.g., here, by group):
 - **VARIABLE:** CLASSES=group(2); KNOWNCLASS = group (female=0 1);
 - **ANALYSIS:** TYPE = MIXTURE; ESTIMATOR = ML; ALGORITHM = INTEGRATION;
 - **MODEL:** %OVERALL% (... model for reference group listed here)
%group#2% (... model for alternative group goes here)
- **IFA models using Limited-Information WLSMV:** Mplus directly estimates multiple-group models, with a few useful other benefits
 - Faster estimation if you have multiple factors/thetas (but assumes MCAR!)
 - DIFFTEST does nested model comparisons for you (still going for “not worse”)
 - Can get modification indices (voo-doo) to troubleshoot non-invariance
 - Can test differences in residual variances (in THETA parameterization)
- In WLSMV, the same category responses must be observed for each group, otherwise you cannot test the item thresholds
 - This is not the case in MML, in which you can estimate more thresholds in one group

Configural Invariance Baseline Model for Categorical Outcomes (2 Groups)

- **Factor variances:** fixed to 1 in both groups
- **Factor covariances:** if any, free in both groups
- **Factor means:** fixed to 0 in both groups
- **Factor loadings:** all freely estimated (so each can be tested later)
 - Remember: the IRT a_i parameters Mplus gives you will still vary across groups even after loadings are constrained because of group differences in theta variance
- **Item Thresholds:** all freely estimated (so each can be tested later)
 - Remember: the IRT b_{ki} parameters Mplus gives you will still vary across groups even after thresholds are constrained because of group differences in theta mean and theta variance
- **Fix all residual variances=1 in all groups if using WLSMV**
 - Groups will eventually be allowed to differ in both factor variance and “error variance” (proxy for total variation in WLSMV models; is a “slop” parameter)

We use the same configural model identification as in CFA for simplicity (but it doesn't really matter how it's identified here)

Sequential Invariance Models

Note: In WLSMV, save for DIFFTEST at each step!

- **Step 1:** Fit same baseline configural invariance model across groups
 - Should be “close enough” factor structures, otherwise game over
 - Alternative group is allowed different loadings and thresholds
- **Step 2 (Metric-ish):** Constrain all loadings equal, but free the factor variances in alternative group—is fit worse than the configural model?
 - If using WLSMV, check MODINDICES to see misfit of constraints; release problematic constrained loadings one at a time; check fit against configural model to see if it’s not worse yet
- **Step 3 (Scalar-ish):** Constrain thresholds equal for items (that passed metric) but free factor means in alternative group—is fit worse than the metric model?
 - If using WLSMV, check MODINDICES to see misfit of constraints; release problematic constrained thresholds one item at a time; check fit against metric model to see if it’s not worse yet
 - If using WLSMV, MODINDICES may want the “intercept” free, but this is not possible to do in IRT/IFA, so focus on problematic (non-invariant) item thresholds instead
 - Reasonable people disagree: Mplus recommends doing steps 2 and 3 in one step because loadings and thresholds are dependent; others disagree (e.g., Millsap’s 2011 book; all of IRT)

Sequential Invariance Models

Note: In WLSMV, save for DIFFTEST at each step!

- **Step 4:** *WLSMV only:* Test if residual variances for items (that passed scalar) in alternative group $\neq 1$ \rightarrow differ from reference group (of residual variance = 1)
 - Differences in residual variances between groups are not identified until you have at least some of the loadings and thresholds constrained across groups
 - Consequently, **this test proceeds backwards:** first estimated is the “bigger” non-invariant residual variance model, second estimated is the “smaller” original scalar invariance model with new name (in which residual variances were fixed to 1 for all items for all groups)
 - Differential residual variances can be a proxy for group differences in overall variability or slop, but this model may not always converge (if it doesn't, just skip this step, but note doing so)
- **Steps 5, 6, 7:** Test Structural Invariance (just like before in CFA):
 - Constrain equal across groups in sequential models: factor variances, then factor covariances, and then factor means (equal to 0) to test for “real” structural group differences
 - Same story as in CFA: Only if you have at least partial measurement invariance can structural group/time/condition differences be meaningfully interpreted
- Factors/Thetas all should have a multivariate normal distribution no matter what measurement model was used to create them... so now we can do SEM!