Measurement Invariance Explorer

a Shiny App

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Motivation

Measurement invariance

"The general question of invariance of measurement is one of whether or not, under different conditions of observing and studying phenomena, measurement operations yield measures of the same attribute"

(Horn and McArdle, 1992)

Procedures to assess measurement invariance with confirmatory factor models

Run several nested multiple groups CFA models with a growing set of constraints, usually:

- configural (overall similarity of structures);
- metric (equality of loadings);
- scalar (equality of loadings and intercepts).

and compare their model fit, that should be approximately the same.

When invariance is not supported

Given the model is specified correctly, several options:

- approximate invariance (relax strict equality of parameters, Bayesian zero priors on differences);
- find a subset of groups or parameters that possess invariance:
    - partial invariance (relax some constraints, but not less than two per each factor - Byrne, Shavelson, & Muthen, 1989);
    - repeatedly re-run an MGCFA model with different subsets of groups;
    - alignment method (Muthen & Asparouhov, 2013, 2014a, 2014b), minimizing non-invariance by finding convenient factor means and variances (available only in Mplus), however: *"The assumption of the alignment method is that a majority of the parameters are invariant and a minority of the parameters are non-invariant." (Muthen & Asparouhov, 2013)*

Case 1. Four types of measurement models

True model - 20 groups (with 500 observations) with 4 clusters

```
F1 =~ v1  + v2  + v3  + v4;
F2 =~ v11 + v12 + v13 + v14;
```

Parameter	Gr.1_5	Gr.6_10	Gr.11_15	Gr.16_20
F1 by v1	1	1.0	1.0	1.0
F1 by v2	1	0.4	0.4	0.4
F1 by v3	1	0.3	0.7	0.1
F1 by v4	1	0.2	0.7	1.0
F2 by v11	1	1.0	1.0	1.0
F2 by v12	1	0.4	0.4	0.4
F2 by v13	1	0.3	0.7	0.1
F2 by v14	1	0.2	0.7	1.0

Conventional tests of invariance: there is no metric invariance

```
semTools::measurementInvariance output:

Chi Square Difference Test
                 Df Chisq Chisq diff Df diff Pr(>Chisq)
fit.configural 380 379.29
fit.loadings   494 2188.84    1809.55     114     <2e-16 **
fit.intercepts 608 2312.18     123.34     114     0.2590

Fit measures:
                  cfi rmsea cfi.delta rmsea.delta
fit.configural 1.000 0.000        NA          NA
fit.loadings   0.850 0.083     0.150       0.083
fit.intercepts 0.849 0.075     0.001       0.008
```

Modification indices: $>$50 large ones, hard to captrue the pattern

	lhs	op	rhs	block	mi	epc	sepc.lv	sepc.all	sepc.
1267	v11	~~	v14	16	101.139	0.833	0.833	0.457	0.
1411	v11	~~	v14	20	86.267	0.727	0.727	0.411	0.
1317	v1	~~	v4	18	85.138	0.704	0.704	0.395	0.
1339	v11	~~	v14	18	83.521	0.779	0.779	0.400	0.
1375	v11	~~	v14	19	78.240	0.715	0.715	0.381	0.
1353	v1	~~	v4	19	77.748	0.719	0.719	0.393	0.
1389	v1	~~	v4	20	73.318	0.715	0.715	0.385	0.
1281	v1	~~	v4	17	70.707	0.688	0.688	0.373	0.
1303	v11	~~	v14	17	50.789	0.581	0.581	0.307	0.
1245	v1	~~	v4	16	37.319	0.491	0.491	0.263	0.
498	f2	=~	v11	18	37.038	1.018	0.698	0.511	0.

Alignment in Mplus (fixed mode): right direction, but

Loadings for F1

V1 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

V2 **(1) (2) (3) (4) (5)** 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

V3 **(1) (2) (3) (4) (5)** 6 7 8 9 10 **(11) (12) (13) (14) (15)** 16 17 18 19 20

V4 1 2 3 4 5 **(6) (7) (8) (9) (10)** 11 12 13 14 15 16 17 18 19 20

Loadings for F2

V11 1 2 **(3) (4) (5)** 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

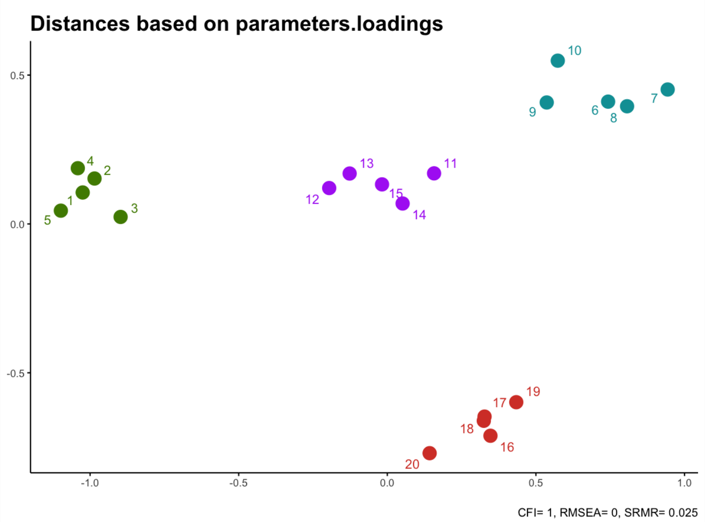
V12 **(1) (2) (3) (4) (5)** 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

V13 **(1) (2) (3) (4) (5)** 6 7 8 9 10 **(11) (12) (13) (14) (15)** 16 **(17)** 18 19 20

V14 1 2 3 4 5 **(6) (7) (8) (9) (10)** 11 12 13 14 15 16 17 18 19 20

Average Invariance index: 0.383

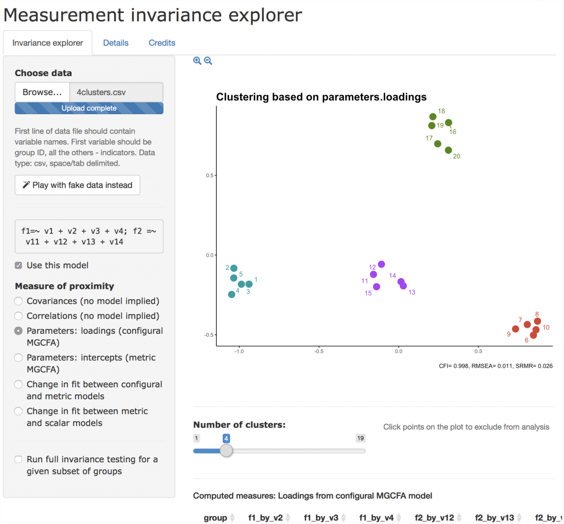
It would be nice to represent differences in measurement models in terms of distances on a plot (Ignacz, 2017)



(MI explorer plot - based on factor loadings from global MGCFA)

Introducing Measurement Invariance Explorer (MIE)

MIE interface



MIE logic

For user: User uploads data, specifies a model, chooses a measure, excludes/includes groups, looks for possible clusters and/or outlier groups.

Internally: Read data -> (Fit models in `lavaan`) -> Extract measures -> Subset measures -> Compute distance matrix (`dist`) -> Find two-dimensional projection (`cmdscale`) -> Compute kmeans clusters based on measures -> Plot using clusters for coloring points

Measures of “invariance distance”: no model implied

- **Covariances (no model implied)** Commonly used multidimensional scaling of all available indicators. Two dimensions are extracted.
- **Correlations (no model implied)** After applying Fisher’s z transformation, the distances are computed, sent to MDS and plotted.
    - If the model fits data well, corrleations/covariances and model parameters should differ across groups in a similar way.

Measures of “invariance distance”: parameters in a global model

- **Parameters: loadings (configural MGCFA)** A single multiple group confirmatory factor analysis with non-constrained factor loadings and intercepts. It extracts loadings, and uses them to compute distance matrix, which is then scaled and plotted.
- **Parameters: intercepts (metric MGCFA)** Analogous to previous one, but loadings are constrained and free intercepts are used as a measure of distance between groups.

Measures of "invariance distance": change in fit indices of pairwise models

- **Change in fit indices from configural to metric model**
    1. Configural and metric MGCFA models are fitted to subsamples of every possible pair of groups.
    2. Global fit indices are extracted and their change between the two models is computed, they reflect "invariance distances" between each pair of groups.
    3. Without further transformations, CFI, RMSEA, or SRMR for each pair of groups are used to compute two-dimensional scaling and plot the group points.
- **Change in fit indices from metric to scalar model**
  Analogous to previous one, only metric and scalar models are fitted to the pairs of groups.

Problematic point: CFA, RMSEA, and SRMR, as well as their decreases do not have known distributions.

How to speed up?

Global MGCFA is fitted only once, and while a user tries other options, the extracted measures are stored locally.

When pairwise fit index decrease is used, the corresponding models are computed for each pair of groups only once. They are stored locally during the whole session.

Case 2. Finding Outliers

True model

```
F1 =~ v1  + v2  + v3  + v4;
F2 =~ v11 + v12 + v13 + v14;
```

Parameter	Gr.1	Gr.2	Gr.3	Gr.4	Gr.5	Gr.6
F1 by v1	1	1	1	1	1.0	1.0
F1 by v2	1	1	1	1	0.6	0.7
F1 by v3	1	1	1	1	0.5	0.4
F1 by v4	1	1	1	1	0.4	0.6
F2 by v11	1	1	1	1	1.0	1.0
F2 by v12	1	1	1	1	0.6	0.7
F2 by v13	1	1	1	1	0.5	0.4
F2 by v14	1	1	1	1	0.4	0.6

Conventional tests: no metric invariance

```
Chi Square Difference Test
                 Df Chisq Chisq diff Df diff Pr(>Chisq)
fit.configural 114 107.44
fit.loadings   144 230.26    122.821      30  3.424e-13 ***
fit.intercepts 174 261.19     30.922      30     0.4192

Fit measures:
                 cfi rmsea cfi.delta rmsea.delta
fit.configural 1.000 0.000        NA          NA
fit.loadings   0.994 0.023     0.006       0.023
fit.intercepts 0.994 0.021     0.000       0.002
```

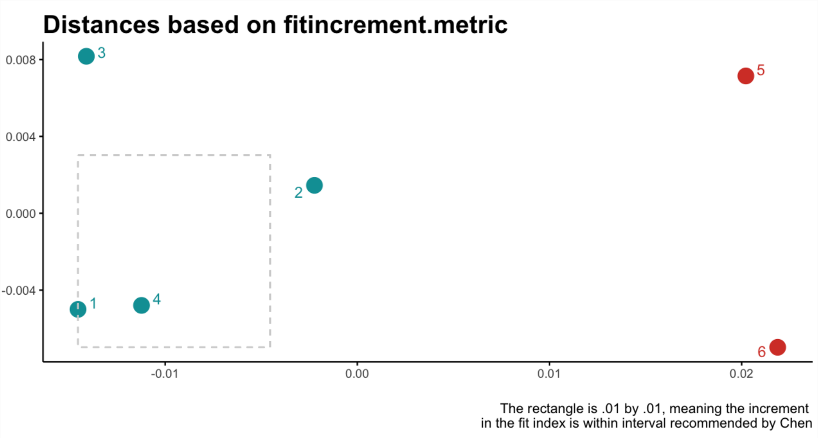
Alignment (fixed mode): something is messed up

```
Loadings for F1
  V1         1 (2) (3) 4 5 6
  V2         1 2 3 4 5 6
  V3         1 2 3 4 5 6
  V4         1 2 3 4 5 6

Loadings for F2
  V11        1 2 3 4 5 6
  V12        1 2 3 4 5 6
  V13        1 2 3 4 5 6
  V14        1 2 3 4 5 6

  Average Invariance index:      0.568
```

MI explorer (plot based on RMSEA increments): clear detection of outliers



Case 3. Real-data example

Depression scale in European Social Survey, round 7

Model:

```
depression =~  fltdpr + flteeff + slprl  + fltlnl+
              fltsd + cldgng +
              wrhpp + enjlf;

wrhpp ~~   enjlf; # reverse coded
```

1 factor, 21 countries, ~2000 observation in each.

Conventional tests

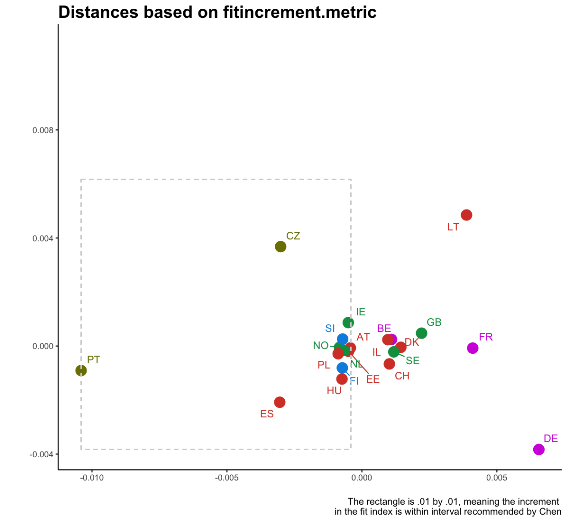
```
Chi Square Difference Test
                 Df   Chisq Chisq diff Df diff Pr(>Chisq)
fit.configural 399  4292.8
fit.loadings   539  5796.2     1503.5     140  < 2.2e-16 **
fit.intercepts 679 12243.9     6447.6     140  < 2.2e-16 **

Fit measures:
                  cfi rmsea cfi.delta rmsea.delta
fit.configural 0.960 0.072        NA          NA
fit.loadings   0.946 0.072     0.014       0.000
fit.intercepts 0.882 0.096     0.064       0.023
```

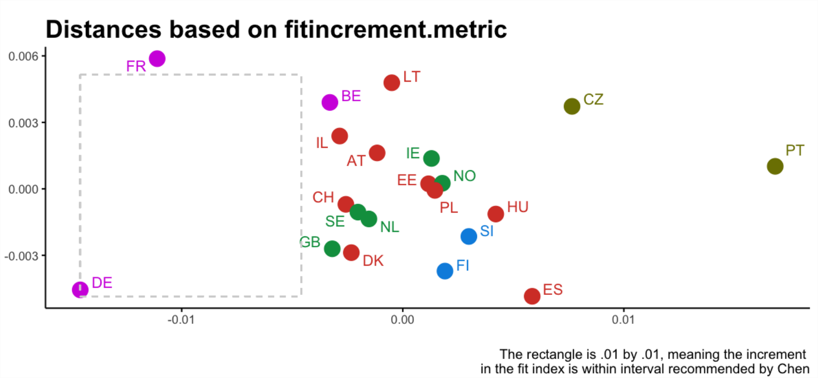
Alignment (fixed mode): few suggestions

5 non-invariant loadings for groups: “CZ” “LT” “PT”
4 non-invariant loadings for groups: “DE”
3 non-invarinat loadings for groups: “BE” “ES” “HU”

MI Explorer - RMSEA increments from configural to metric model



MI Explorer - CFI decreases from configural to metric model

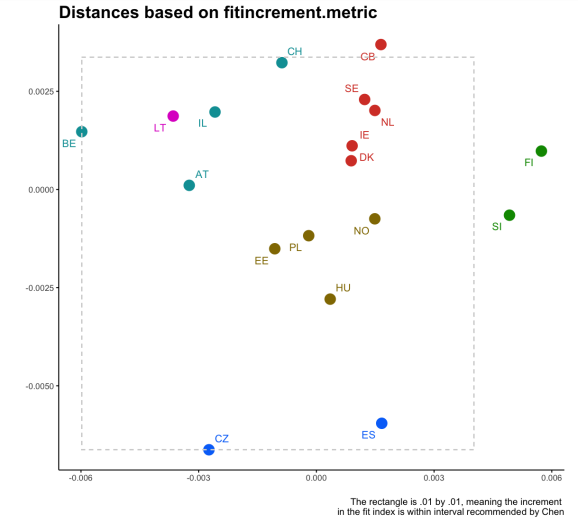


MI Explorer - check the CFI decreases

Computed measures: CFI difference between configural and metric models

Group.1	Group.2	configural	metric	difference
DE	PT	0.964	0.933	0.032
FR	PT	0.957	0.93	0.027
CZ	DE	0.961	0.938	0.023
GB	PT	0.965	0.944	0.021
ES	FR	0.957	0.936	0.02
CZ	FR	0.954	0.935	0.019
BE	PT	0.969	0.952	0.017
DE	SI	0.956	0.939	0.017
DK	PT	0.973	0.956	0.017

MI Explorer - CFI decreases after dropping DE, FR, and PT



MI Explorer - omnibus tests after exclusion of three groups

```
Chi Square Difference Test

                 Df  Chisq Chisq diff Df diff Pr(>Chisq)
fit.configural 342 3643.2
fit.loadings   461 4607.6      964.4     119  < 2.2e-16 **
fit.intercepts 580 9385.7     4778.1     119  < 2.2e-16 **

Fit measures:
                 cfi rmsea cfi.delta rmsea.delta
fit.configural 0.961 0.073        NA          NA
fit.loadings   0.951 0.070     0.010       0.003
fit.intercepts 0.896 0.091     0.055       0.021
```

Concluding remarks

Use of MI explorer

- effectively suggests clusters of measurement model groups;
- identifies outlier groups (in terms of measurement model);
- integrates different (soft and strict) crietria of measurement invariance on one page;
- interactive: updates models with a single click;
- fast: avoids excessive computations (+ better run locally);
- has a potential to integrate more different approaches in one (graphical) framework.

Misuse of MI explorer

- testing hypotheses (refer to "explorer");
- looking for model misspecifications.

Future features (in order of priority)

- a (set of) function that can be used in R, outside graphical interface;
- in graphical interface - find a way for user to override defaults while keeping the interface minimalistic;
- add features to improve the model: group-specific fit and modification indices;
- integrate partial and approximate (Bayesian) invariance functionality (probably via `blavaan`);
- survey weights (`lavaan.survey`);
- building bridges with Mplus and integrating communication with it (probably via `MplusAutomation`);
- add sensitivity analysis;
- ordinal models/categorical indicators;
- ... distant (futile?) measurement invariance hub.

Links

Web-version (quite slow):

https://rudnev.shinyapps.io/measurement_invariance_explorer/

Place for suggestions

(the code will be published after collecting feedback):

https://github.com/MaksimRudnev/MeasurementInvarianceExplorer/issues

Personal communication:

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Comments and questions: Suggestions and critique are especially welcome!