# R syntax to accomany Which Omega is Right?

This .rmd file provides all syntax described in the article "Your coefficient alpha is probably wrong, but which coefficient omega is right? A tutorial on using R to obtain better reliability estimates" by David B. Flora.

This document assumes some prior familiarity with R, particularly how to install and load packages and how to import data files. We recommend using RStudio as an environment for all R sessions.

---

**Begin by installing (if necessary) and loading all packages needed for this tutorial:**

```
#install.packages("lavaan")
#install.packages("semTools")
#install.packages("psych")
#install.packages("MBESS")

library(lavaan)

## This is lavaan 0.6-5

## lavaan is BETA software! Please report any bugs.

library(semTools)

##

##
###############################################################################
##

## This is semTools 0.5-2.920

## All users of R (or SEM) are invited to submit functions or ideas for
functions.

##
###############################################################################
##

library(psych)

##
## Attaching package: 'psych'

## The following object is masked from 'package:semTools':
##
##     skew
```

```
## The following object is masked from 'package:lavaan':
##
##     cor2cov
```

```r
library(MBESS)
```

```
##
## Attaching package: 'MBESS'

## The following object is masked from 'package:psych':
##
##     cor2cov

## The following object is masked from 'package:lavaan':
##
##     cor2cov
```

---

## Obtaining omega-u from a one-factor model for the Openness scale.

**Download the open.csv data from the web to create a data frame called "open", or import the open.csv data file if you have already saved it to the same directory as this .rmd file. These data are from the "bfi" dataset in the psych package. Note that in the the "open" data file used below, items 2 and 5 are already reverse-coded.**

```r
open <- read.csv("https://osf.io/53wdz/download")

#OR
#open <- read.csv("open.csv")
```

**Specify the one-factor model for the Openness items (i.e., congeneric model):**

```r
mod1f <- 'open =~ O1 + O2+ O3 + O4 + O5'
```

**Estimate the one-factor model:**

```r
fit1f <- cfa(mod1f, data=open, std.lv=T, missing='direct', estimator='MLR')
```

**Obtain the results summary:**

```r
summary(fit1f, fit.measures=T)
```

```
## lavaan 0.6-5 ended normally after 31 iterations
##
##   Estimator                                         ML
##   Optimization method                           NLMINB
##   Number of free parameters                         15
##
##   Number of observations                          2800
##   Number of missing patterns                         7
##
```

```
## Model Test User Model:
##                                               Standard      Robust
##   Test Statistic                                92.411      77.828
##   Degrees of freedom                                 5           5
##   P-value (Chi-square)                           0.000       0.000
##   Scaling correction factor                                  1.187
##     for the Yuan-Bentler correction (Mplus variant)
##
## Model Test Baseline Model:
##
##   Test statistic                              1399.423    1066.430
##   Degrees of freedom                                10          10
##   P-value                                        0.000       0.000
##   Scaling correction factor                                  1.312
##
## User Model versus Baseline Model:
##
##   Comparative Fit Index (CFI)                    0.937       0.931
##   Tucker-Lewis Index (TLI)                       0.874       0.862
##
##   Robust Comparative Fit Index (CFI)                         0.938
##   Robust Tucker-Lewis Index (TLI)                            0.875
##
## Loglikelihood and Information Criteria:
##
##   Loglikelihood user model (H0)             -22581.302  -22581.302
##   Scaling correction factor                                  1.171
##       for the MLR correction
##   Loglikelihood unrestricted model (H1)     -22535.096  -22535.096
##   Scaling correction factor                                  1.175
##       for the MLR correction
##
##   Akaike (AIC)                               45192.603   45192.603
##   Bayesian (BIC)                             45281.664   45281.664
##   Sample-size adjusted Bayesian (BIC)        45234.004   45234.004
##
## Root Mean Square Error of Approximation:
##
##   RMSEA                                          0.079       0.072
##   90 Percent confidence interval - lower         0.065       0.060
##   90 Percent confidence interval - upper         0.094       0.085
##   P-value RMSEA <= 0.05                          0.000       0.002
##
##   Robust RMSEA                                               0.079
##   90 Percent confidence interval - lower                     0.064
##   90 Percent confidence interval - upper                     0.094
##
## Standardized Root Mean Square Residual:
##
##   SRMR                                           0.031       0.031
```

```
##
## Parameter Estimates:
##
##   Information                                       Observed
##   Observed information based on                      Hessian
##   Standard errors                          Robust.huber.white
##
## Latent Variables:
##                    Estimate  Std.Err  z-value  P(>|z|)
##   open =~
##     O1                0.622    0.029   21.536    0.000
##     O2                0.684    0.042   16.466    0.000
##     O3                0.794    0.032   24.572    0.000
##     O4                0.361    0.031   11.779    0.000
##     O5                0.685    0.036   19.069    0.000
##
## Intercepts:
##                    Estimate  Std.Err  z-value  P(>|z|)
##    .O1                4.816    0.021  224.892    0.000
##    .O2                4.287    0.030  144.955    0.000
##    .O3                4.436    0.023  191.353    0.000
##    .O4                4.893    0.023  211.544    0.000
##    .O5                4.509    0.025  179.095    0.000
##     open              0.000
##
## Variances:
##                    Estimate  Std.Err  z-value  P(>|z|)
##    .O1                0.888    0.037   23.887    0.000
##    .O2                1.981    0.068   29.245    0.000
##    .O3                0.860    0.050   17.051    0.000
##    .O4                1.361    0.052   26.271    0.000
##    .O5                1.294    0.059   21.957    0.000
##     open              1.000
```

**As reported in the article, the output above indicates that the model does not fit the data very well. One reason is that there is a notable residual correlation (.097) between items O2 and O5, which can be seen by running the residuals command on the fitted model:**

```
residuals(fit1f, type="cor")

## $type
## [1] "cor.bollen"
##
## $cov
##     O1     O2     O3     O4     O5
## O1  0.000
## O2 -0.028  0.000
## O3  0.037 -0.024  0.000
## O4  0.015 -0.061  0.002  0.000
```

```
## O5 -0.046  0.097 -0.024  0.026  0.000
##
## $mean
## O1 O2 O3 O4 O5
##  0  0  0  0  0
```

**Despite that the model fit is not great, for illustrative reasons we will continue to estimate omega based on this one-factor model. (Syntax to account for the large error correlation between O2 and O5 and thus obtain a better omega estimate is given later in this document).**

**Obtain coefficient omega as an estimate of the reliability of the opennness scale total score as a measure of the 'open' factor:**

```
reliability(fit1f)

##             open
## alpha  0.5999111
## omega  0.6079033
## omega2 0.6079033
## omega3 0.6078732
## avevar 0.2461983
```

**Call the ci.reliability function to obtain a bootstrap 95% CI for omega. Note that for this tutorial, the number of bootstrap samples is set to only 100 (the default number of samples is 10,000, which may take a long time to run). Also, due to random sampling variability inherent to the bootstrap procedure, the resulting CI from the code below may not exactly match the CI reported in the actual article:**

```
ci.reliability(data=open, type = "omega", interval.type = "perc", B = 100)

## $est
## [1] 0.6079033
##
## $se
## [1] 0.0142746
##
## $ci.lower
## [1] 0.5766502
##
## $ci.upper
## [1] 0.6300214
##
## $conf.level
## [1] 0.95
##
## $type
## [1] "omega"
##
## $interval.type
## [1] "percentile bootstrap"
```

**It is also possible to calculate omega-u directly within lavaan as a defined parameter. To do so, it is necessary to assign a name to each factor loading and error variance in the model specifiction; below, l1 through l5 are the names of the factor loadings, and e1 through e5 are the names of the error variances. Then the formula for the defined omega parameter is given following the " := " operator**

```
open1f <- 'open=~l1*O1+l2*O2+l3*O3+l4*O4+l5*O5
           O1 ~~ e1*O1
           O2 ~~ e2*O2
           O3 ~~ e3*O3
           O4 ~~ e4*O4
           O5 ~~ e5*O5
omega := ((l1+l2+l3+l4+l5)^2)
/ ((l1+l2+l3+l4+l5)^2 +
     (e1+e2+e3+e4+e5))'
```

**Fit the model using the cfa() function as above, then the estimate of omega in the results summary matches the omega estimate returned by the reliability() function:**

```
fit1f <- cfa(open1f, data=open, missing="direct", estimator="MLR", std.lv=T)
summary(fit1f, fit.measures=T)

## lavaan 0.6-5 ended normally after 31 iterations
##
##   Estimator                                         ML
##   Optimization method                           NLMINB
##   Number of free parameters                         15
##
##   Number of observations                          2800
##   Number of missing patterns                         7
##
## Model Test User Model:
##                                               Standard      Robust
##   Test Statistic                                92.411      77.828
##   Degrees of freedom                                 5           5
##   P-value (Chi-square)                           0.000       0.000
##   Scaling correction factor                                  1.187
##     for the Yuan-Bentler correction (Mplus variant)
##
## Model Test Baseline Model:
##
##   Test statistic                              1399.423    1066.430
##   Degrees of freedom                                10          10
##   P-value                                        0.000       0.000
##   Scaling correction factor                                  1.312
##
## User Model versus Baseline Model:
##
##   Comparative Fit Index (CFI)                    0.937       0.931
##   Tucker-Lewis Index (TLI)                       0.874       0.862
```

```
##
##   Robust Comparative Fit Index (CFI)                         0.938
##   Robust Tucker-Lewis Index (TLI)                            0.875
##
## Loglikelihood and Information Criteria:
##
##   Loglikelihood user model (H0)           -22581.302  -22581.302
##   Scaling correction factor                                1.171
##       for the MLR correction
##   Loglikelihood unrestricted model (H1)   -22535.096  -22535.096
##   Scaling correction factor                                1.175
##       for the MLR correction
##
##   Akaike (AIC)                             45192.603   45192.603
##   Bayesian (BIC)                           45281.664   45281.664
##   Sample-size adjusted Bayesian (BIC)      45234.004   45234.004
##
## Root Mean Square Error of Approximation:
##
##   RMSEA                                        0.079       0.072
##   90 Percent confidence interval - lower       0.065       0.060
##   90 Percent confidence interval - upper       0.094       0.085
##   P-value RMSEA <= 0.05                        0.000       0.002
##
##   Robust RMSEA                                             0.079
##   90 Percent confidence interval - lower                   0.064
##   90 Percent confidence interval - upper                   0.094
##
## Standardized Root Mean Square Residual:
##
##   SRMR                                         0.031       0.031
##
## Parameter Estimates:
##
##   Information                                 Observed
##   Observed information based on                Hessian
##   Standard errors                   Robust.huber.white
##
## Latent Variables:
##                    Estimate  Std.Err  z-value  P(>|z|)
##   open =~
##     O1        (l1)    0.622    0.029   21.536    0.000
##     O2        (l2)    0.684    0.042   16.466    0.000
##     O3        (l3)    0.794    0.032   24.572    0.000
##     O4        (l4)    0.361    0.031   11.779    0.000
##     O5        (l5)    0.685    0.036   19.069    0.000
##
## Intercepts:
##                    Estimate  Std.Err  z-value  P(>|z|)
##    .O1                4.816    0.021  224.892    0.000
```

```
##    .O2                  4.287    0.030  144.955    0.000
##    .O3                  4.436    0.023  191.353    0.000
##    .O4                  4.893    0.023  211.544    0.000
##    .O5                  4.509    0.025  179.095    0.000
##     open                0.000
##
## Variances:
##                    Estimate  Std.Err  z-value  P(>|z|)
##    .O1         (e1)    0.888    0.037   23.887    0.000
##    .O2         (e2)    1.981    0.068   29.245    0.000
##    .O3         (e3)    0.860    0.050   17.051    0.000
##    .O4         (e4)    1.361    0.052   26.271    0.000
##    .O5         (e5)    1.294    0.059   21.957    0.000
##     open                1.000
##
## Defined Parameters:
##                    Estimate  Std.Err  z-value  P(>|z|)
##     omega               0.608    0.013   47.829    0.000
```

**The code below specifies a tau-equivalence model for the Openness items. By assigning the same name ("lam") to each factor loading coefficient, those factor loadings will be constrained to be equal:**

```
modtaueq <- 'open =~ lam*O1 + lam*O2+ lam*O3 + lam*O4 + lam*O5'
fitte <- cfa(modtaueq, data=open, std.lv=T, missing='direct',
estimator='MLR')
```

**Check the results to see that the factor loading estimates are in fact equal:**

```
summary(fitte, fit.measures=T)

## lavaan 0.6-5 ended normally after 26 iterations
##
##   Estimator                                         ML
##   Optimization method                           NLMINB
##   Number of free parameters                         15
##   Number of equality constraints                     4
##   Row rank of the constraints matrix                 4
##
##   Number of observations                          2800
##   Number of missing patterns                         7
##
## Model Test User Model:
##                                               Standard      Robust
##   Test Statistic                               223.263     184.586
##   Degrees of freedom                                 9           9
##   P-value (Chi-square)                           0.000       0.000
##   Scaling correction factor                                  1.210
##     for the Yuan-Bentler correction (Mplus variant)
##
## Model Test Baseline Model:
```

```
##
##   Test statistic                              1399.423    1066.430
##   Degrees of freedom                                10          10
##   P-value                                        0.000       0.000
##   Scaling correction factor                                  1.312
##
## User Model versus Baseline Model:
##
##   Comparative Fit Index (CFI)                    0.846       0.834
##   Tucker-Lewis Index (TLI)                       0.829       0.815
##
##   Robust Comparative Fit Index (CFI)                         0.847
##   Robust Tucker-Lewis Index (TLI)                            0.830
##
## Loglikelihood and Information Criteria:
##
##   Loglikelihood user model (H0)             -22646.727  -22646.727
##   Scaling correction factor                                  0.841
##       for the MLR correction
##   Loglikelihood unrestricted model (H1)     -22535.096  -22535.096
##   Scaling correction factor                                  1.175
##       for the MLR correction
##
##   Akaike (AIC)                               45315.455   45315.455
##   Bayesian (BIC)                             45380.766   45380.766
##   Sample-size adjusted Bayesian (BIC)        45345.815   45345.815
##
## Root Mean Square Error of Approximation:
##
##   RMSEA                                          0.092       0.083
##   90 Percent confidence interval - lower         0.082       0.074
##   90 Percent confidence interval - upper         0.103       0.093
##   P-value RMSEA <= 0.05                          0.000       0.000
##
##   Robust RMSEA                                               0.092
##   90 Percent confidence interval - lower                     0.081
##   90 Percent confidence interval - upper                     0.104
##
## Standardized Root Mean Square Residual:
##
##   SRMR                                           0.070       0.070
##
## Parameter Estimates:
##
##   Information                                 Observed
##   Observed information based on                Hessian
##   Standard errors                   Robust.huber.white
##
## Latent Variables:
##                    Estimate  Std.Err  z-value  P(>|z|)
```

```
##   open =~
##     O1       (lam)    0.628    0.014   45.567    0.000
##     O2       (lam)    0.628    0.014   45.567    0.000
##     O3       (lam)    0.628    0.014   45.567    0.000
##     O4       (lam)    0.628    0.014   45.567    0.000
##     O5       (lam)    0.628    0.014   45.567    0.000
##
## Intercepts:
##                    Estimate  Std.Err  z-value  P(>|z|)
##    .O1                4.816    0.021  224.874    0.000
##    .O2                4.287    0.030  144.955    0.000
##    .O3                4.436    0.023  191.473    0.000
##    .O4                4.893    0.023  211.539    0.000
##    .O5                4.509    0.025  179.105    0.000
##     open              0.000
##
## Variances:
##                    Estimate  Std.Err  z-value  P(>|z|)
##    .O1                0.882    0.033   26.507    0.000
##    .O2                2.024    0.053   38.354    0.000
##    .O3                1.002    0.039   25.782    0.000
##    .O4                1.283    0.053   24.435    0.000
##    .O5                1.320    0.046   28.976    0.000
##     open              1.000
```

**Next, results from the anova() function show that the original congeneric model fits better than the tau-equivalence model. Because the sample size is so large, the chi-square difference test is easily significant. But the AIC and BIC indices are also lower for the congeneric model, indicating that the congeneric model is more appropriate for these data then the tau-equivalence model:**

```
anova(fit1f, fitte)

## Scaled Chi-Squared Difference Test (method = "satorra.bentler.2001")
##
## lavaan NOTE:
##     The "Chisq" column contains standard test statistics, not the
##     robust test that should be reported per model. A robust difference
##     test is a function of two standard (not robust) statistics.
##
##       Df   AIC   BIC   Chisq Chisq diff Df diff Pr(>Chisq)
## fit1f  5 45193 45282  92.411
## fitte  9 45315 45381 223.263     105.76       4  < 2.2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

## Incorporating the error covariance in the one-factor model for the Openness scale to obtain omega-u from a better-fitting model.

**Re-specify the one-factor model for the Openness items, but now include a new line to specify the free error covariance between items O2 and O5 using the ~~ operator:**

```
mod1fR <- 'open =~ O1 + O2+ O3 + O4 + O5
                  O2 ~~ O5'
```

**Estimate the revised model and obtain the results summary:**

```
fit1fR <- cfa(mod1fR, data=open, std.lv=T, missing='direct', estimator='MLR')
summary(fit1fR, fit.measures=T)

## lavaan 0.6-5 ended normally after 37 iterations
##
##   Estimator                                         ML
##   Optimization method                           NLMINB
##   Number of free parameters                         16
##
##   Number of observations                          2800
##   Number of missing patterns                         7
##
## Model Test User Model:
##                                               Standard      Robust
##   Test Statistic                                19.968      16.569
##   Degrees of freedom                                 4           4
##   P-value (Chi-square)                           0.001       0.002
##   Scaling correction factor                                  1.205
##     for the Yuan-Bentler correction (Mplus variant)
##
## Model Test Baseline Model:
##
##   Test statistic                              1399.423    1066.430
##   Degrees of freedom                                10          10
##   P-value                                        0.000       0.000
##   Scaling correction factor                                  1.312
##
## User Model versus Baseline Model:
##
##   Comparative Fit Index (CFI)                    0.989       0.988
##   Tucker-Lewis Index (TLI)                       0.971       0.970
##
##   Robust Comparative Fit Index (CFI)                         0.989
##   Robust Tucker-Lewis Index (TLI)                            0.973
##
## Loglikelihood and Information Criteria:
##
##   Loglikelihood user model (H0)             -22545.080  -22545.080
##   Scaling correction factor                                  1.168
```

```
##       for the MLR correction
##   Loglikelihood unrestricted model (H1)     -22535.096  -22535.096
##   Scaling correction factor                              1.175
##       for the MLR correction
##
##   Akaike (AIC)                               45122.160   45122.160
##   Bayesian (BIC)                             45217.158   45217.158
##   Sample-size adjusted Bayesian (BIC)        45166.321   45166.321
##
## Root Mean Square Error of Approximation:
##
##   RMSEA                                          0.038       0.033
##   90 Percent confidence interval - lower         0.022       0.019
##   90 Percent confidence interval - upper         0.055       0.049
##   P-value RMSEA <= 0.05                          0.871       0.957
##
##   Robust RMSEA                                              0.037
##   90 Percent confidence interval - lower                    0.020
##   90 Percent confidence interval - upper                    0.056
##
## Standardized Root Mean Square Residual:
##
##   SRMR                                           0.015       0.015
##
## Parameter Estimates:
##
##   Information                                 Observed
##   Observed information based on                Hessian
##   Standard errors                    Robust.huber.white
##
## Latent Variables:
##                    Estimate  Std.Err  z-value  P(>|z|)
##   open =~
##     O1                0.640    0.029   22.171    0.000
##     O2                0.573    0.040   14.248    0.000
##     O3                0.846    0.033   25.304    0.000
##     O4                0.363    0.031   11.639    0.000
##     O5                0.597    0.034   17.606    0.000
##
## Covariances:
##                    Estimate  Std.Err  z-value  P(>|z|)
##  .O2 ~~
##    .O5                0.329    0.046    7.155    0.000
##
## Intercepts:
##                    Estimate  Std.Err  z-value  P(>|z|)
##    .O1                4.816    0.021  224.930    0.000
##    .O2                4.287    0.030  144.955    0.000
##    .O3                4.436    0.023  191.343    0.000
##    .O4                4.893    0.023  211.552    0.000
```

```
##    .O5                  4.509    0.025  179.133    0.000
##     open                0.000
##
## Variances:
##                      Estimate  Std.Err  z-value  P(>|z|)
##    .O1                  0.865    0.038   22.703    0.000
##    .O2                  2.120    0.062   33.937    0.000
##    .O3                  0.775    0.054   14.431    0.000
##    .O4                  1.359    0.052   26.120    0.000
##    .O5                  1.406    0.055   25.676    0.000
##     open                1.000
```

**One use the anova() function to see that the revised model fits better then the original congeneric model:**

```
anova(fit1f, fit1fR)
```

```
## Scaled Chi-Squared Difference Test (method = "satorra.bentler.2001")
##
## lavaan NOTE:
##     The "Chisq" column contains standard test statistics, not the
##     robust test that should be reported per model. A robust difference
##     test is a function of two standard (not robust) statistics.
##
##        Df   AIC   BIC  Chisq Chisq diff Df diff Pr(>Chisq)
## fit1fR  4 45122 45217 19.968
## fit1f   5 45193 45282 92.411     64.899       1  7.883e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

**Obtain an updated coefficient omega that correctly accounts for the error covariance:**

```
reliability(fit1fR)
```

```
##             open
## alpha  0.5999111
## omega  0.5593717
## omega2 0.5593717
## omega3 0.5601129
## avevar 0.2294343
```

**As above, an updated omega can be calculated directly within the lavaan syntax as a defined parameter. The new syntax below includes a formula for omega that accounts for the error covariance:**

```
open1fR <- 'open=~l1*O1+l2*O2+l3*O3+l4*O4+l5*O5
           O1 ~~ e1*O1
           O2 ~~ e2*O2
           O3 ~~ e3*O3
           O4 ~~ e4*O4
```

```
          O5 ~~ e5*O5
          O2 ~~ r*O5
omega := ((l1+l2+l3+l4+l5)^2)
/ ((l1+l2+l3+l4+l5)^2 +
     (e1+e2+e3+e4+e5)+2*r)'
```

**Fit the model using the cfa() function as above, then the estimate of omega in the results summary matches the omega estimate returned by the reliability() function:**

```
fit1fR <- cfa(open1fR, data=open, missing="direct", estimator="MLR",
std.lv=T)
summary(fit1fR, fit.measures=T)
```

```
## lavaan 0.6-5 ended normally after 37 iterations
##
##   Estimator                                         ML
##   Optimization method                           NLMINB
##   Number of free parameters                         16
##
##   Number of observations                          2800
##   Number of missing patterns                         7
##
## Model Test User Model:
##                                               Standard      Robust
##   Test Statistic                                19.968      16.569
##   Degrees of freedom                                 4           4
##   P-value (Chi-square)                           0.001       0.002
##   Scaling correction factor                                  1.205
##     for the Yuan-Bentler correction (Mplus variant)
##
## Model Test Baseline Model:
##
##   Test statistic                              1399.423    1066.430
##   Degrees of freedom                                10          10
##   P-value                                        0.000       0.000
##   Scaling correction factor                                  1.312
##
## User Model versus Baseline Model:
##
##   Comparative Fit Index (CFI)                    0.989       0.988
##   Tucker-Lewis Index (TLI)                       0.971       0.970
##
##   Robust Comparative Fit Index (CFI)                         0.989
##   Robust Tucker-Lewis Index (TLI)                            0.973
##
## Loglikelihood and Information Criteria:
##
##   Loglikelihood user model (H0)             -22545.080  -22545.080
##   Scaling correction factor                                  1.168
##       for the MLR correction
```

```
##   Loglikelihood unrestricted model (H1)     -22535.096  -22535.096
##   Scaling correction factor                                  1.175
##       for the MLR correction
##
##   Akaike (AIC)                               45122.160   45122.160
##   Bayesian (BIC)                             45217.158   45217.158
##   Sample-size adjusted Bayesian (BIC)        45166.321   45166.321
##
## Root Mean Square Error of Approximation:
##
##   RMSEA                                          0.038       0.033
##   90 Percent confidence interval - lower         0.022       0.019
##   90 Percent confidence interval - upper         0.055       0.049
##   P-value RMSEA <= 0.05                          0.871       0.957
##
##   Robust RMSEA                                               0.037
##   90 Percent confidence interval - lower                     0.020
##   90 Percent confidence interval - upper                     0.056
##
## Standardized Root Mean Square Residual:
##
##   SRMR                                           0.015       0.015
##
## Parameter Estimates:
##
##   Information                                 Observed
##   Observed information based on                Hessian
##   Standard errors                   Robust.huber.white
##
## Latent Variables:
##                    Estimate  Std.Err  z-value  P(>|z|)
##   open =~
##     O1        (l1)    0.640    0.029   22.171    0.000
##     O2        (l2)    0.573    0.040   14.248    0.000
##     O3        (l3)    0.846    0.033   25.304    0.000
##     O4        (l4)    0.363    0.031   11.639    0.000
##     O5        (l5)    0.597    0.034   17.606    0.000
##
## Covariances:
##                    Estimate  Std.Err  z-value  P(>|z|)
##  .O2 ~~
##    .O5         (r)    0.329    0.046    7.155    0.000
##
## Intercepts:
##                    Estimate  Std.Err  z-value  P(>|z|)
##    .O1                4.816    0.021  224.930    0.000
##    .O2                4.287    0.030  144.955    0.000
##    .O3                4.436    0.023  191.343    0.000
##    .O4                4.893    0.023  211.552    0.000
##    .O5                4.509    0.025  179.133    0.000
```

```
##     open                0.000
##
## Variances:
##                    Estimate  Std.Err  z-value  P(>|z|)
##    .O1        (e1)    0.865    0.038   22.703    0.000
##    .O2        (e2)    2.120    0.062   33.937    0.000
##    .O3        (e3)    0.775    0.054   14.431    0.000
##    .O4        (e4)    1.359    0.052   26.120    0.000
##    .O5        (e5)    1.406    0.055   25.676    0.000
##     open              1.000
##
## Defined Parameters:
##                    Estimate  Std.Err  z-value  P(>|z|)
##     omega             0.559    0.015   37.015    0.000
```

---

## Obtaining omega-u-cat from a one-factor model for the Psychoticism scale.

**Download the potic.csv data from the web to create a data frame called 'potic', or import the potic.csv data file if you have already saved it to the same directory as this .rmd file.**

```
potic <- read.csv("https://osf.io/atqc6/download")

#OR
#potic <- read.csv("potic.csv")
```

**Specify the one-factor model for the Psychoticism items (i.e., congeneric model):**

```
mod1f <- 'psyctcsm =~ DDP1 + DDP2 + DDP3 + DDP4'
```

**Estimate the one-factor model; note that the 'ordered' option is used to indicate that all items are ordered, categorical:**

```
fit1f <- cfa(mod1f, data=potic, std.lv=T, ordered = T)
```

**Obtain the results summary:**

```
summary(fit1f, fit.measures=T)

## lavaan 0.6-5 ended normally after 10 iterations
##
##   Estimator                                       DWLS
##   Optimization method                           NLMINB
##   Number of free parameters                         20
##
##                                                   Used       Total
##   Number of observations                           498         500
##
## Model Test User Model:
##                                               Standard      Robust
```

```
##   Test Statistic                                  7.117      14.910
##   Degrees of freedom                                  2           2
##   P-value (Chi-square)                            0.028       0.001
##   Scaling correction factor                                   0.480
##   Shift parameter                                             0.089
##     for the simple second-order correction
##
## Model Test Baseline Model:
##
##   Test statistic                               1635.647    1316.086
##   Degrees of freedom                                  6           6
##   P-value                                         0.000       0.000
##   Scaling correction factor                                   1.244
##
## User Model versus Baseline Model:
##
##   Comparative Fit Index (CFI)                     0.997       0.990
##   Tucker-Lewis Index (TLI)                        0.991       0.970
##
##   Robust Comparative Fit Index (CFI)                             NA
##   Robust Tucker-Lewis Index (TLI)                                NA
##
## Root Mean Square Error of Approximation:
##
##   RMSEA                                           0.072       0.114
##   90 Percent confidence interval - lower          0.020       0.065
##   90 Percent confidence interval - upper          0.132       0.171
##   P-value RMSEA <= 0.05                           0.200       0.019
##
##   Robust RMSEA                                                   NA
##   90 Percent confidence interval - lower                         NA
##   90 Percent confidence interval - upper                         NA
##
## Standardized Root Mean Square Residual:
##
##   SRMR                                            0.033       0.033
##
## Parameter Estimates:
##
##   Information                                  Expected
##   Information saturated (h1) model           Unstructured
##   Standard errors                            Robust.sem
##
## Latent Variables:
##                    Estimate  Std.Err  z-value  P(>|z|)
##   psyctcsm =~
##     DDP1              0.894    0.028   31.538    0.000
##     DDP2              0.753    0.028   26.711    0.000
##     DDP3              0.698    0.030   23.314    0.000
##     DDP4              0.513    0.040   12.738    0.000
```

```
##
## Intercepts:
##                    Estimate  Std.Err  z-value  P(>|z|)
##    .DDP1              0.000
##    .DDP2              0.000
##    .DDP3              0.000
##    .DDP4              0.000
##     psyctcsm          0.000
##
## Thresholds:
##                    Estimate  Std.Err  z-value  P(>|z|)
##     DDP1|t1           -0.716    0.062  -11.591    0.000
##     DDP1|t2           -0.040    0.056   -0.716    0.474
##     DDP1|t3            0.296    0.057    5.185    0.000
##     DDP1|t4            1.034    0.069   15.065    0.000
##     DDP2|t1           -0.580    0.060   -9.693    0.000
##     DDP2|t2            0.208    0.057    3.668    0.000
##     DDP2|t3            0.562    0.060    9.431    0.000
##     DDP2|t4            1.096    0.070   15.570    0.000
##     DDP3|t1           -1.203    0.074  -16.298    0.000
##     DDP3|t2           -0.425    0.058   -7.318    0.000
##     DDP3|t3            0.081    0.056    1.432    0.152
##     DDP3|t4            0.913    0.066   13.909    0.000
##     DDP4|t1           -1.605    0.092  -17.382    0.000
##     DDP4|t2           -1.060    0.069  -15.285    0.000
##     DDP4|t3           -0.521    0.059   -8.817    0.000
##     DDP4|t4            0.431    0.058    7.406    0.000
##
## Variances:
##                    Estimate  Std.Err  z-value  P(>|z|)
##    .DDP1              0.201
##    .DDP2              0.433
##    .DDP3              0.513
##    .DDP4              0.737
##     psyctcsm          1.000
##
## Scales y*:
##                    Estimate  Std.Err  z-value  P(>|z|)
##     DDP1              1.000
##     DDP2              1.000
##     DDP3              1.000
##     DDP4              1.000
```

**Obtain omega-u-cat as an estimate of the reliability of the total score for the Psychotcism items as a measure of the 'psyctcsm' factor:**

```
reliability(fit1f)
```

```
## For constructs with categorical indicators, the alpha and the average variance extracted are calculated from polychoric (polyserial) correlations, not from Pearson correlations.
```

```
##         psyctcsm
## alpha  0.8007496
## omega  0.7902953
## omega2 0.7902953
## omega3 0.7932682
## avevar 0.5289638
```

**Although the message in red font in the output above indicates that alpha is calculated based on polychoric correlations, rest assured that the omega estimates are also omega-u-cat estimates obtained by fitting the one-factor model to polychoric correlations. The purpose of the message is to prevent confusion about the difference between alpha = .77 for this scale and ordinal alpha = .80, as described in the article.**

**Call the ci.reliability function to obtain a bootstrap 95% CI for omega. Again, the number of bootstrap samples is set to only 100 (the default number of samples is 10,000, which may take a long time to run). Also, due to random sampling variability inherent to the bootstrap procedure, the resulting CI from the code below may not exactly match the CI reported in the actual article:**

```
ci.reliability(data=potic, type = "categorical", interval.type = "perc", B = 100)
```

```
## $est
## [1] 0.7932682
##
## $se
## [1] 0.01490839
##
## $ci.lower
## [1] 0.7618729
##
## $ci.upper
## [1] 0.8196438
##
## $conf.level
## [1] 0.95
##
## $type
## [1] "categorical omega"
##
## $interval.type
## [1] "percentile bootstrap"
```

## Obtaining omega-h from a bifactor model for the Psychological Cost Scale

**Download the pcs.csv data from the web to create a data frame called 'pcs' or import the pcs.csv data file if you have already saved it to the same directory as this .rmd file**

```
pcs <- read.csv("https://osf.io/xd2tu/download")

#OR
#pcs <- read.csv("pcs.csv")
```

**Specify and estimate the bifactor model for the PCS items:**

```
modBf <- 'gen =~ TE1 + TE2 + TE3 + TE4 + TE5 + OE1 + OE2 + OE3 + OE4
              + LVA1 + LVA2 + LVA3 + LVA4 + EM1 + EM2 + EM3 + EM4 + EM5 + EM6
            s1 =~ TE1 + TE2 + TE3 + TE4 + TE5
            s2 =~ OE1 + OE2 + OE3 + OE4
            s3 =~ LVA1 + LVA2 + LVA3 + LVA4
            s4 =~ EM1 + EM2 + EM3 + EM4 + EM5 + EM6
                        '
fitBf <- cfa(modBf, data=pcs, std.lv=T, estimator='MLR', orthogonal=T)
summary(fitBf, fit.measures=T)
```

```
## lavaan 0.6-5 ended normally after 36 iterations
##
##   Estimator                                         ML
##   Optimization method                           NLMINB
##   Number of free parameters                         57
##
##                                                   Used       Total
##   Number of observations                           154         172
##
## Model Test User Model:
##                                               Standard      Robust
##   Test Statistic                               211.382     182.509
##   Degrees of freedom                               133         133
##   P-value (Chi-square)                           0.000       0.003
##   Scaling correction factor                                  1.158
##     for the Yuan-Bentler correction (Mplus variant)
##
## Model Test Baseline Model:
##
##   Test statistic                              2799.877    2260.239
##   Degrees of freedom                               171         171
##   P-value                                        0.000       0.000
##   Scaling correction factor                                  1.239
##
## User Model versus Baseline Model:
##
##   Comparative Fit Index (CFI)                    0.970       0.976
##   Tucker-Lewis Index (TLI)                       0.962       0.970
```

```
##
##   Robust Comparative Fit Index (CFI)                         0.978
##   Robust Tucker-Lewis Index (TLI)                            0.972
##
## Loglikelihood and Information Criteria:
##
##   Loglikelihood user model (H0)             -3456.819   -3456.819
##   Scaling correction factor                                 1.269
##       for the MLR correction
##   Loglikelihood unrestricted model (H1)     -3351.128   -3351.128
##   Scaling correction factor                                 1.191
##       for the MLR correction
##
##   Akaike (AIC)                               7027.638    7027.638
##   Bayesian (BIC)                             7200.744    7200.744
##   Sample-size adjusted Bayesian (BIC)        7020.331    7020.331
##
## Root Mean Square Error of Approximation:
##
##   RMSEA                                         0.062       0.049
##   90 Percent confidence interval - lower        0.046       0.031
##   90 Percent confidence interval - upper        0.077       0.065
##   P-value RMSEA <= 0.05                         0.108       0.520
##
##   Robust RMSEA                                              0.053
##   90 Percent confidence interval - lower                    0.032
##   90 Percent confidence interval - upper                    0.071
##
## Standardized Root Mean Square Residual:
##
##   SRMR                                          0.038       0.038
##
## Parameter Estimates:
##
##   Information                                 Observed
##   Observed information based on                Hessian
##   Standard errors                    Robust.huber.white
##
## Latent Variables:
##                    Estimate  Std.Err  z-value  P(>|z|)
##   gen =~
##     TE1               1.041    0.071   14.715    0.000
##     TE2               1.045    0.084   12.430    0.000
##     TE3               0.848    0.090    9.392    0.000
##     TE4               0.984    0.075   13.097    0.000
##     TE5               1.004    0.082   12.264    0.000
##     OE1               0.787    0.083    9.537    0.000
##     OE2               0.819    0.080   10.207    0.000
##     OE3               0.738    0.089    8.319    0.000
##     OE4               0.742    0.087    8.512    0.000
```

```
##     LVA1              0.937    0.084   11.180    0.000
##     LVA2              0.863    0.071   12.205    0.000
##     LVA3              0.816    0.085    9.649    0.000
##     LVA4              0.865    0.098    8.802    0.000
##     EM1               0.968    0.095   10.215    0.000
##     EM2               0.930    0.078   11.957    0.000
##     EM3               0.959    0.091   10.542    0.000
##     EM4               0.885    0.091    9.679    0.000
##     EM5               1.043    0.086   12.121    0.000
##     EM6               1.108    0.100   11.054    0.000
##   s1 =~
##     TE1               0.351    0.114    3.071    0.002
##     TE2               0.451    0.144    3.142    0.002
##     TE3               0.402    0.170    2.360    0.018
##     TE4               0.162    0.111    1.457    0.145
##     TE5               0.269    0.154    1.747    0.081
##   s2 =~
##     OE1               0.626    0.107    5.860    0.000
##     OE2               0.516    0.096    5.399    0.000
##     OE3               0.673    0.107    6.291    0.000
##     OE4               0.739    0.085    8.738    0.000
##   s3 =~
##     LVA1              0.253    0.107    2.357    0.018
##     LVA2              0.573    0.081    7.081    0.000
##     LVA3              0.422    0.104    4.051    0.000
##     LVA4              0.528    0.104    5.074    0.000
##   s4 =~
##     EM1               0.506    0.152    3.324    0.001
##     EM2               0.346    0.086    4.026    0.000
##     EM3               0.567    0.121    4.682    0.000
##     EM4               0.562    0.098    5.707    0.000
##     EM5               0.479    0.097    4.930    0.000
##     EM6               0.651    0.148    4.403    0.000
##
## Covariances:
##                    Estimate  Std.Err  z-value  P(>|z|)
##   gen ~~
##     s1                0.000
##     s2                0.000
##     s3                0.000
##     s4                0.000
##   s1 ~~
##     s2                0.000
##     s3                0.000
##     s4                0.000
##   s2 ~~
##     s3                0.000
##     s4                0.000
##   s3 ~~
##     s4                0.000
```

```
##
## Variances:
##                    Estimate  Std.Err  z-value  P(>|z|)
##    .TE1               0.318    0.067    4.777    0.000
##    .TE2               0.434    0.088    4.913    0.000
##    .TE3               0.501    0.104    4.827    0.000
##    .TE4               0.397    0.066    5.987    0.000
##    .TE5               0.421    0.073    5.799    0.000
##    .OE1               0.546    0.106    5.129    0.000
##    .OE2               0.451    0.075    6.003    0.000
##    .OE3               0.490    0.117    4.183    0.000
##    .OE4               0.263    0.071    3.718    0.000
##    .LVA1              0.442    0.064    6.873    0.000
##    .LVA2              0.100    0.062    1.607    0.108
##    .LVA3              0.443    0.075    5.892    0.000
##    .LVA4              0.523    0.088    5.954    0.000
##    .EM1               0.639    0.100    6.388    0.000
##    .EM2               0.365    0.060    6.049    0.000
##    .EM3               0.482    0.090    5.383    0.000
##    .EM4               0.364    0.083    4.395    0.000
##    .EM5               0.318    0.063    5.032    0.000
##    .EM6               0.534    0.117    4.564    0.000
##     gen               1.000
##     s1                1.000
##     s2                1.000
##     s3                1.000
##     s4                1.000
```

**Obtain omega-h as for the PCS total score as a measure of a general 'psychological cost' construct:**

```
reliability(fitBf)
```

```
##              gen         s1        s2        s3        s4
## alpha  0.9638781 0.92504205 0.8992820 0.9052459 0.9405882
## omega  0.9741033 0.56377307 0.7884791 0.6766430 0.7816839
## omega2 0.9094893 0.09237594 0.3666293 0.1880759 0.2054075
## omega3 0.9077636 0.09240479 0.3666634 0.1878380 0.2053012
## avevar        NA         NA        NA        NA        NA
```

---

## Obtaining omega-ho from a higher-order model for the Psychological Cost Scale

**This analysis uses the same pcs data frame used above.**

**Specify the higher-order factor model for the PCS items:**

```
homod <- 'TE =~ TE1 + TE2 + TE3 + TE4 + TE5
      OE =~ OE1 + OE2 + OE3 + OE4
      LV =~ LVA1 + LVA2 + LVA3 + LVA4
```

```
    EM =~ EM1 + EM2 + EM3 + EM4 + EM5 + EM6
    cost =~ TE + OE + LV + EM'
```

**Estimate the model and get the results:**

```
fitHo <- cfa(homod, data=pcs, std.lv=T, estimator='MLM')
summary(fitHo, fit.measures=T)

## lavaan 0.6-5 ended normally after 57 iterations
##
##   Estimator                                         ML
##   Optimization method                           NLMINB
##   Number of free parameters                         42
##
##                                                   Used       Total
##   Number of observations                           154         172
##
## Model Test User Model:
##                                               Standard      Robust
##   Test Statistic                               243.444     185.699
##   Degrees of freedom                               148         148
##   P-value (Chi-square)                           0.000       0.019
##   Scaling correction factor                                  1.311
##     for the Satorra-Bentler correction
##
## Model Test Baseline Model:
##
##   Test statistic                              2799.877    2282.637
##   Degrees of freedom                               171         171
##   P-value                                        0.000       0.000
##   Scaling correction factor                                  1.227
##
## User Model versus Baseline Model:
##
##   Comparative Fit Index (CFI)                    0.964       0.982
##   Tucker-Lewis Index (TLI)                       0.958       0.979
##
##   Robust Comparative Fit Index (CFI)                         0.981
##   Robust Tucker-Lewis Index (TLI)                            0.978
##
## Loglikelihood and Information Criteria:
##
##   Loglikelihood user model (H0)              -3472.850   -3472.850
##   Loglikelihood unrestricted model (H1)      -3351.128   -3351.128
##
##   Akaike (AIC)                                7029.700    7029.700
##   Bayesian (BIC)                              7157.252    7157.252
##   Sample-size adjusted Bayesian (BIC)         7024.315    7024.315
##
## Root Mean Square Error of Approximation:
```

```
##
##   RMSEA                                          0.065       0.041
##   90 Percent confidence interval - lower         0.050       0.021
##   90 Percent confidence interval - upper         0.079       0.056
##   P-value RMSEA <= 0.05                          0.052       0.832
##
##   Robust RMSEA                                               0.047
##   90 Percent confidence interval - lower                     0.020
##   90 Percent confidence interval - upper                     0.066
##
## Standardized Root Mean Square Residual:
##
##   SRMR                                           0.045       0.045
##
## Parameter Estimates:
##
##   Information                                 Expected
##   Information saturated (h1) model          Structured
##   Standard errors                           Robust.sem
##
## Latent Variables:
##                    Estimate  Std.Err  z-value  P(>|z|)
##   TE =~
##     TE1               0.356    0.067    5.289    0.000
##     TE2               0.364    0.065    5.554    0.000
##     TE3               0.299    0.059    5.056    0.000
##     TE4               0.323    0.058    5.605    0.000
##     TE5               0.338    0.065    5.198    0.000
##   OE =~
##     OE1               0.641    0.074    8.642    0.000
##     OE2               0.616    0.060   10.334    0.000
##     OE3               0.630    0.066    9.523    0.000
##     OE4               0.647    0.064   10.078    0.000
##   LV =~
##     LVA1              0.442    0.056    7.836    0.000
##     LVA2              0.457    0.059    7.751    0.000
##     LVA3              0.427    0.059    7.286    0.000
##     LVA4              0.460    0.056    8.258    0.000
##   EM =~
##     EM1               0.509    0.069    7.394    0.000
##     EM2               0.462    0.066    7.018    0.000
##     EM3               0.517    0.074    6.955    0.000
##     EM4               0.483    0.067    7.179    0.000
##     EM5               0.535    0.069    7.756    0.000
##     EM6               0.595    0.080    7.430    0.000
##   cost =~
##     TE                2.914    0.595    4.894    0.000
##     OE                1.223    0.155    7.880    0.000
##     LV                1.951    0.281    6.933    0.000
##     EM                1.900    0.327    5.809    0.000
```

```
##
## Variances:
##                    Estimate  Std.Err  z-value  P(>|z|)
##    .TE1               0.321    0.063    5.081    0.000
##    .TE2               0.473    0.069    6.837    0.000
##    .TE3               0.531    0.100    5.289    0.000
##    .TE4               0.398    0.073    5.494    0.000
##    .TE5               0.418    0.070    5.935    0.000
##    .OE1               0.531    0.099    5.353    0.000
##    .OE2               0.440    0.081    5.428    0.000
##    .OE3               0.495    0.099    5.001    0.000
##    .OE4               0.315    0.055    5.719    0.000
##    .LVA1              0.443    0.081    5.466    0.000
##    .LVA2              0.170    0.035    4.851    0.000
##    .LVA3              0.412    0.064    6.473    0.000
##    .LVA4              0.533    0.090    5.945    0.000
##    .EM1               0.637    0.085    7.508    0.000
##    .EM2               0.367    0.062    5.872    0.000
##    .EM3               0.493    0.075    6.564    0.000
##    .EM4               0.387    0.064    6.017    0.000
##    .EM5               0.315    0.062    5.059    0.000
##    .EM6               0.554    0.085    6.515    0.000
##    .TE                1.000
##    .OE                1.000
##    .LV                1.000
##    .EM                1.000
##     cost              1.000
```

**Obtain omega-ho for the PCS total score as a measure of the 'psychological cost' higher-order factor:**

```r
reliabilityL2(fitHo, 'cost')
```

```
##        omegaL1        omegaL2 partialOmegaL1
##      0.9088176      0.9410190      0.9734520
```

**Obtain omega estimates for the subscale scores as measures of the lower-order factors:**

```r
reliability(fitHo)
```

```
## Higher-order factors were ignored.
```

```
##               TE        OE        LV        EM
## alpha  0.9250420 0.8992820 0.9052459 0.9405882
## omega  0.9260209 0.9000548 0.9077522 0.9415490
## omega2 0.9260209 0.9000548 0.9077522 0.9415490
## omega3 0.9256773 0.9014397 0.9125259 0.9404921
## avevar 0.7155347 0.6925123 0.7111716 0.7299181
```

---

## Obtaining omega-h and omega-h-ss from a bifactor model for the Psychological Cost Scale

**Specify and estimate the bifactor model for the PCS items:**

```
modBf <- 'gen =~ TE1 + TE2 + TE3 + TE4 + TE5 + OE1 + OE2 + OE3 + OE4
              + LVA1 + LVA2 + LVA3 + LVA4 + EM1 + EM2 + EM3 + EM4 + EM5 + EM6
            s1 =~ TE1 + TE2 + TE3 + TE4 + TE5
            s2 =~ OE1 + OE2 + OE3 + OE4
            s3 =~ LVA1 + LVA2 + LVA3 + LVA4
            s4 =~ EM1 + EM2 + EM3 + EM4 + EM5 + EM6
                        '
fitBf <- cfa(modBf, data=pcs, std.lv=T, estimator='MLR', orthogonal=T)
summary(fitBf, fit.measures=T)
```

```
## lavaan 0.6-5 ended normally after 36 iterations
##
##   Estimator                                         ML
##   Optimization method                           NLMINB
##   Number of free parameters                         57
##
##                                                   Used       Total
##   Number of observations                           154         172
##
## Model Test User Model:
##                                               Standard      Robust
##   Test Statistic                               211.382     182.509
##   Degrees of freedom                               133         133
##   P-value (Chi-square)                           0.000       0.003
##   Scaling correction factor                                  1.158
##     for the Yuan-Bentler correction (Mplus variant)
##
## Model Test Baseline Model:
##
##   Test statistic                              2799.877    2260.239
##   Degrees of freedom                               171         171
##   P-value                                        0.000       0.000
##   Scaling correction factor                                  1.239
##
## User Model versus Baseline Model:
##
##   Comparative Fit Index (CFI)                    0.970       0.976
##   Tucker-Lewis Index (TLI)                       0.962       0.970
##
##   Robust Comparative Fit Index (CFI)                         0.978
##   Robust Tucker-Lewis Index (TLI)                            0.972
##
## Loglikelihood and Information Criteria:
##
##   Loglikelihood user model (H0)              -3456.819   -3456.819
```

```
##   Scaling correction factor                                  1.269
##       for the MLR correction
##   Loglikelihood unrestricted model (H1)      -3351.128   -3351.128
##   Scaling correction factor                                  1.191
##       for the MLR correction
##
##   Akaike (AIC)                                7027.638    7027.638
##   Bayesian (BIC)                              7200.744    7200.744
##   Sample-size adjusted Bayesian (BIC)         7020.331    7020.331
##
## Root Mean Square Error of Approximation:
##
##   RMSEA                                          0.062       0.049
##   90 Percent confidence interval - lower         0.046       0.031
##   90 Percent confidence interval - upper         0.077       0.065
##   P-value RMSEA <= 0.05                          0.108       0.520
##
##   Robust RMSEA                                               0.053
##   90 Percent confidence interval - lower                     0.032
##   90 Percent confidence interval - upper                     0.071
##
## Standardized Root Mean Square Residual:
##
##   SRMR                                           0.038       0.038
##
## Parameter Estimates:
##
##   Information                                 Observed
##   Observed information based on                Hessian
##   Standard errors                   Robust.huber.white
##
## Latent Variables:
##                    Estimate  Std.Err  z-value  P(>|z|)
##   gen =~
##     TE1               1.041    0.071   14.715    0.000
##     TE2               1.045    0.084   12.430    0.000
##     TE3               0.848    0.090    9.392    0.000
##     TE4               0.984    0.075   13.097    0.000
##     TE5               1.004    0.082   12.264    0.000
##     OE1               0.787    0.083    9.537    0.000
##     OE2               0.819    0.080   10.207    0.000
##     OE3               0.738    0.089    8.319    0.000
##     OE4               0.742    0.087    8.512    0.000
##     LVA1              0.937    0.084   11.180    0.000
##     LVA2              0.863    0.071   12.205    0.000
##     LVA3              0.816    0.085    9.649    0.000
##     LVA4              0.865    0.098    8.802    0.000
##     EM1               0.968    0.095   10.215    0.000
##     EM2               0.930    0.078   11.957    0.000
##     EM3               0.959    0.091   10.542    0.000
```

```
##     EM4                 0.885    0.091    9.679    0.000
##     EM5                 1.043    0.086   12.121    0.000
##     EM6                 1.108    0.100   11.054    0.000
##   s1 =~
##     TE1                 0.351    0.114    3.071    0.002
##     TE2                 0.451    0.144    3.142    0.002
##     TE3                 0.402    0.170    2.360    0.018
##     TE4                 0.162    0.111    1.457    0.145
##     TE5                 0.269    0.154    1.747    0.081
##   s2 =~
##     OE1                 0.626    0.107    5.860    0.000
##     OE2                 0.516    0.096    5.399    0.000
##     OE3                 0.673    0.107    6.291    0.000
##     OE4                 0.739    0.085    8.738    0.000
##   s3 =~
##     LVA1                0.253    0.107    2.357    0.018
##     LVA2                0.573    0.081    7.081    0.000
##     LVA3                0.422    0.104    4.051    0.000
##     LVA4                0.528    0.104    5.074    0.000
##   s4 =~
##     EM1                 0.506    0.152    3.324    0.001
##     EM2                 0.346    0.086    4.026    0.000
##     EM3                 0.567    0.121    4.682    0.000
##     EM4                 0.562    0.098    5.707    0.000
##     EM5                 0.479    0.097    4.930    0.000
##     EM6                 0.651    0.148    4.403    0.000
##
## Covariances:
##                      Estimate  Std.Err  z-value  P(>|z|)
##   gen ~~
##     s1                  0.000
##     s2                  0.000
##     s3                  0.000
##     s4                  0.000
##   s1 ~~
##     s2                  0.000
##     s3                  0.000
##     s4                  0.000
##   s2 ~~
##     s3                  0.000
##     s4                  0.000
##   s3 ~~
##     s4                  0.000
##
## Variances:
##                      Estimate  Std.Err  z-value  P(>|z|)
##    .TE1                 0.318    0.067    4.777    0.000
##    .TE2                 0.434    0.088    4.913    0.000
##    .TE3                 0.501    0.104    4.827    0.000
##    .TE4                 0.397    0.066    5.987    0.000
```

```
##    .TE5                 0.421    0.073    5.799    0.000
##    .OE1                 0.546    0.106    5.129    0.000
##    .OE2                 0.451    0.075    6.003    0.000
##    .OE3                 0.490    0.117    4.183    0.000
##    .OE4                 0.263    0.071    3.718    0.000
##    .LVA1                0.442    0.064    6.873    0.000
##    .LVA2                0.100    0.062    1.607    0.108
##    .LVA3                0.443    0.075    5.892    0.000
##    .LVA4                0.523    0.088    5.954    0.000
##    .EM1                 0.639    0.100    6.388    0.000
##    .EM2                 0.365    0.060    6.049    0.000
##    .EM3                 0.482    0.090    5.383    0.000
##    .EM4                 0.364    0.083    4.395    0.000
##    .EM5                 0.318    0.063    5.032    0.000
##    .EM6                 0.534    0.117    4.564    0.000
##     gen                 1.000
##     s1                  1.000
##     s2                  1.000
##     s3                  1.000
##     s4                  1.000
```

**Obtain omega-h-ss for the PCS subscale scores as measures of constructs orthogonal to the general factor, and omega-h as for the PCS total score as a measure of a general 'psychological cost' construct:**

```
reliability(fitBf)
```

```
##              gen         s1        s2        s3        s4
## alpha  0.9638781 0.92504205 0.8992820 0.9052459 0.9405882
## omega  0.9741033 0.56377307 0.7884791 0.6766430 0.7816839
## omega2 0.9094893 0.09237594 0.3666293 0.1880759 0.2054075
## omega3 0.9077636 0.09240479 0.3666634 0.1878380 0.2053012
## avevar        NA         NA        NA        NA        NA
```

---

## Using the psych package to calculate omega estimates

**Use the 'omega' function to estimate omega-h based on an exploratory bifactor model of the PCS items (this bifactor model is based on the Schmid-Leiman transformation, and so the resulting omega-h is equivalent to omega-ho obtained from an exploratory higher-order model):*

```
omega(pcs, nfactors = 4, plot = F)
```

```
## Loading required namespace: GPArotation
```

```
## Omega
## Call: omega(m = pcs, nfactors = 4, plot = F)
## Alpha:                 0.96
## G.6:                   0.98
```

```
## Omega Hierarchical:    0.85
## Omega H asymptotic:    0.88
## Omega Total            0.98
##
## Schmid Leiman Factor loadings greater than  0.2
##         g   F1*   F2*   F3*   F4*   h2   u2   p2
## TE1  0.81             0.39       0.81 0.19 0.80
## TE2  0.76             0.40       0.75 0.25 0.77
## TE3  0.70             0.35       0.62 0.38 0.80
## TE4  0.78             0.29       0.72 0.28 0.84
## TE5  0.77             0.34       0.74 0.26 0.80
## OE1  0.61       0.55             0.67 0.33 0.56
## OE2  0.67       0.46             0.66 0.34 0.68
## OE3  0.61       0.54             0.68 0.32 0.54
## OE4  0.63       0.62             0.80 0.20 0.50
## LVA1 0.75                   0.28 0.67 0.33 0.85
## LVA2 0.80                   0.48 0.87 0.13 0.73
## LVA3 0.71       0.20        0.37 0.71 0.29 0.72
## LVA4 0.70                   0.43 0.67 0.33 0.72
## EM1  0.69  0.39                  0.66 0.34 0.73
## EM2  0.76  0.38                  0.75 0.25 0.77
## EM3  0.72  0.47                  0.73 0.27 0.71
## EM4  0.72  0.48                  0.74 0.26 0.70
## EM5  0.78  0.43                  0.81 0.19 0.76
## EM6  0.73  0.48                  0.78 0.22 0.68
##
## With eigenvalues of:
##    g  F1*  F2*  F3*  F4*
## 9.95 1.21 1.29 0.70 0.68
##
## general/max  7.74   max/min =   1.88
## mean percent general =  0.72    with sd =  0.1 and cv of  0.13
## Explained Common Variance of the general factor =  0.72
##
## The degrees of freedom are 101  and the fit is  1
## The number of observations was  172  with Chi Square =  161.11  with prob
<  0.00013
## The root mean square of the residuals is  0.02
## The df corrected root mean square of the residuals is  0.03
## RMSEA index =  0.064  and the 10 % confidence intervals are  0.041 0.076
## BIC =  -358.79
##
## Compare this with the adequacy of just a general factor and no group
factors
## The degrees of freedom for just the general factor are 152  and the fit is
4.49
## The number of observations was  172  with Chi Square =  732.57  with prob
<  8.2e-77
## The root mean square of the residuals is  0.1
## The df corrected root mean square of the residuals is  0.11
```

```
##
## RMSEA index =  0.154  and the 10 % confidence intervals are  0.139 0.16
## BIC =  -49.85
##
## Measures of factor score adequacy
##                                                  g  F1*  F2*  F3*  F4*
## Correlation of scores with factors            0.93 0.79 0.86 0.72 0.77
## Multiple R square of scores with factors      0.86 0.63 0.73 0.52 0.59
## Minimum correlation of factor score estimates 0.73 0.26 0.47 0.04 0.18
##
##  Total, General and Subset omega for each subset
##                                                  g  F1*  F2*  F3* F4*
## Omega total for total scores and subscales    0.98 0.94 0.90 0.92 0.9
## Omega general for total scores and subscales  0.85 0.69 0.52 0.76 0.7
## Omega group for total scores and subscales    0.08 0.25 0.38 0.16 0.2
```