

Grace and Steiner Supplementary Material 2

Grace JB, Steiner M (2021) A protocol for modeling generalized biological responses using latent variables in structural equation models. *One Ecosystem*.

```
### load libraries
library(lavaan)
library(AICcmodavg)
```

Covariance Matrices for Paper

```
# Covariance matrix for input (Chasselas)
input.cov1 <- '
  2.602
-1.187  1.896
  1.038 -0.781  2.536
  1.270 -0.726  0.559  1.688
-0.592  0.451  0.147 -0.219  1.670
  0.821 -0.364 -0.455  0.578  -0.864  1.366'

# Create input covariance matrix and name variables
Chass.dat <- getCov(input.cov1, names = c("N", "Sugars", "Tart", "Malic", "Nfixers", "Mgt"))

# Covariance matrix for input (Pinot)
input.cov2 <- '
  2.111
-0.583  1.548
  1.024 -0.583  1.799
  0.838 -0.388  0.698  2.029
  0.341  0.155  0.410  0.184  0.903
  0.470 -0.169  0.324  0.322  -0.328  0.871'

# Create input covariance matrix and name variables
Pinot.dat <- getCov(input.cov2, names = c("N", "Sugars", "Tart", "Malic", "Nfixers", "Mgt"))
```

Confirmatory Factor Analysis

• Table S2.1. Fit statistics and Parameter Estimates for Latent Response Model.

```
# CFA1 model
cfa1 <- '
GrapeQual =~ lambda1*N +lambda2*Sugars +lambda3*Tart +lambda4*Malic'

# Estimate model
cfa1.fit <- sem(cfa1, sample.cov = Chass.dat, sample.nobs = 50)

# Get Full Summary of Results
summary(cfa1.fit, fit.measures=T, rsq=T)
```

```

## lavaan 0.6-8 ended normally after 25 iterations
##
##      Estimator                      ML
##      Optimization method          NLMINB
##      Number of model parameters      8
##
##      Number of observations          50
##
## Model Test User Model:
##
##      Test statistic                0.808
##      Degrees of freedom              2
##      P-value (Chi-square)           0.668
##
## Model Test Baseline Model:
##
##      Test statistic                51.040
##      Degrees of freedom              6
##      P-value                        0.000
##
## User Model versus Baseline Model:
##
##      Comparative Fit Index (CFI)    1.000
##      Tucker-Lewis Index (TLI)      1.079
##
## Loglikelihood and Information Criteria:
##
##      Loglikelihood user model (H0)  -332.906
##      Loglikelihood unrestricted model (H1) -332.501
##
##      Akaike (AIC)                  681.811
##      Bayesian (BIC)                 697.107
##      Sample-size adjusted Bayesian (BIC) 671.997
##
## Root Mean Square Error of Approximation:
##
##      RMSEA                        0.000
##      90 Percent confidence interval - lower 0.000
##      90 Percent confidence interval - upper 0.215
##      P-value RMSEA <= 0.05          0.700
##
## Standardized Root Mean Square Residual:
##
##      SRMR                        0.027
##
## Parameter Estimates:
##
##      Standard errors              Standard
##      Information                  Expected
##      Information saturated (h1) model  Structured
##
## Latent Variables:
##      Estimate Std.Err z-value P(>|z|)

```

```
## GrapeQual =~
##      N      (lmb1)      1.000
##      Sugars (lmb2)    -0.592      0.156    -3.805      0.000
##      Tart   (lmb3)      0.516      0.175      2.952      0.003
##      Malic  (lmb4)      0.616      0.151      4.073      0.000
##
## Variances:
##              Estimate Std.Err  z-value  P(>|z|)
##      .N              0.557    0.392    1.421    0.155
##      .Sugars          1.159    0.273    4.249    0.000
##      .Tart            1.954    0.415    4.708    0.000
##      .Malic           0.898    0.234    3.845    0.000
##      GrapeQual        1.992    0.624    3.194    0.001
##
## R-Square:
##              Estimate
##      N              0.781
##      Sugars          0.376
##      Tart            0.214
##      Malic           0.457
```

Net Effect Model

Table S2.2. Results for initial Net Effect Model.

```
### Initial net effect model
LVNet1 <- '
# declare latent variables
GrapeQual =~ lambda1*N +lambda2*Sugars +lambda3*Tart +lambda4*Malic
ManInten  =~ lambda5*Mgt

# structural relations
GrapeQual ~ gamma1*ManInten'

# Estimate model
LVNet1.fit <- sem(LVNet1, sample.cov = Chass.dat, sample.nobs = 50)

# Examine fit
show(LVNet1.fit); fitMeasures(LVNet1.fit, "cfi")
```

```
## lavaan 0.6-8 ended normally after 24 iterations
##
##      Estimator                      ML
##      Optimization method          NLMINB
##      Number of model parameters    10
##
##      Number of observations        50
##
## Model Test User Model:
##
##      Test statistic                19.638
##      Degrees of freedom            5
##      P-value (Chi-square)          0.001
```

```
##      cfi
## 0.789
```

```
# Mod indices
subset(modindices(LVNet1.fit), mi>3)
```

```
##      lhs op  rhs      mi      epc sepc.lv sepc.all sepc.nox
## 17 ManInten =~ Tart 15.021 -0.794 -0.918 -0.583 -0.583
## 27      Tart ~~ Mgt 15.021 -0.852 -0.852      NA      NA
```

```
#### Revised net effect model
LVNet2 <- '
# declare latent variables
GrapeQual =~ lambda1*N +lambda2*Sugars +lambda3*Tart +lambda4*Malic
ManInten  =~ lambda5*Mgt

# structural relations
GrapeQual ~ gamma1*ManInten
Tart      ~ gamma3*ManInten'

# Estimate model
LVNet2.fit <- sem(LVNet2, sample.cov = Chass.dat, sample.nobs = 50)

# Examine fit
show(LVNet2.fit); fitMeasures(LVNet2.fit, "cfi")
```

```
## lavaan 0.6-8 ended normally after 23 iterations
##
##      Estimator                      ML
##      Optimization method          NLMINB
##      Number of model parameters    11
##
##      Number of observations        50
##
## Model Test User Model:
##
##      Test statistic                1.014
##      Degrees of freedom            4
##      P-value (Chi-square)          0.908
```

```
## cfi
## 1
```

Mediation Model

Table S2.3. Results for initial Mediated Effect Model.

```
### Initial partial mediation model
LVmed1 <- '
# declare latent variables
GrapeQual =~ lambda1*N +lambda2*Sugars +lambda3*Tart +lambda4*Malic
ManInten  =~ lambda5*Mgt
NonCrop   =~ lambda6*Nfixers

# structural relations
GrapeQual ~ gamma1*ManInten + beta1*NonCrop
NonCrop    ~ gamma2*ManInten'

# Estimate model
LVmed1.fit <- sem(LVmed1, sample.cov = Chass.dat, sample.nobs = 50)

# Examine fit
show(LVmed1.fit); fitMeasures(LVmed1.fit, "cfi")
```

```
## lavaan 0.6-8 ended normally after 36 iterations
##
##      Estimator                      ML
##      Optimization method          NLMINB
##      Number of model parameters    13
##
##      Number of observations        50
##
## Model Test User Model:
##
##      Test statistic                22.828
##      Degrees of freedom            8
##      P-value (Chi-square)          0.004
```

```
## cfi
## 0.83
```

```
# Mod indices
subset(modindices(LVmed1.fit), mi>3)
```

```
##      lhs op  rhs      mi      epc sepc.lv sepc.all sepc.nox
## 23 ManInten =~ Tart 15.024 -0.794 -0.918 -0.582 -0.582
## 41      Tart ~~ Mgt 12.306 -0.652 -0.652      NA      NA
```

```
#### Revised partial mediation model
LVmed2 <- '
# declare latent variables
GrapeQual =~ lambda1*N +lambda2*Sugars +lambda3*Tart +lambda4*Malic
ManInten  =~ lambda5*Mgt
NonCrop   =~ lambda6*Nfixers

# structural relations
GrapeQual ~ gamma1*ManInten + beta1*NonCrop
NonCrop    ~ gamma2*ManInten
Tart       ~ gamma3*ManInten'

# Estimate model
LVmed2.fit <- sem(LVmed2, sample.cov = Chass.dat, sample.nobs = 50)

# Examine fit
show(LVmed2.fit); fitMeasures(LVmed2.fit, "cfi")
```

```
## lavaan 0.6-8 ended normally after 34 iterations
##
##      Estimator                      ML
##      Optimization method          NLMINB
##      Number of model parameters      14
##
##      Number of observations          50
##
## Model Test User Model:
##
##      Test statistic                4.175
##      Degrees of freedom              7
##      P-value (Chi-square)           0.759
```

```
## cfi
##    1
```

Table S2.4. Parameter estimates for revised Mediated Effect Model (LVmed2).

```
# Examine results
summary(LVmed2.fit, standardized=T, rsq=T)
```

```

## lavaan 0.6-8 ended normally after 34 iterations
##
##      Estimator                      ML
##      Optimization method          NLMINB
##      Number of model parameters    14
##
##      Number of observations        50
##
## Model Test User Model:
##
##      Test statistic                4.175
##      Degrees of freedom            7
##      P-value (Chi-square)          0.759
##
## Parameter Estimates:
##
##      Standard errors              Standard
##      Information                  Expected
##      Information saturated (h1) model Structured
##
## Latent Variables:
##      Estimate Std.Err z-value P(>|z|) Std.lv Std.all
##      GrapeQual =~
##      N      (lmb1)  1.000          1.411  0.883
##      Sugars (lmb2) -0.585  0.135 -4.322  0.000 -0.826 -0.606
##      Tart   (lmb3)  0.857  0.192  4.469  0.000  1.209  0.767
##      Malic  (lmb4)  0.622  0.126  4.956  0.000  0.878  0.682
##      ManInten =~
##      Mgt     (lmb5)  1.000          1.157  1.000
##      NonCrop =~
##      Nfixers (lmb6)  1.000          1.279  1.000
##
## Regressions:
##      Estimate Std.Err z-value P(>|z|) Std.lv Std.all
##      GrapeQual ~
##      ManIntn (gmm1)  0.555  0.206  2.695  0.007  0.456  0.456
##      NonCrop (bet1) -0.067  0.182 -0.368  0.713 -0.061 -0.061
##      NonCrop ~
##      ManIntn (gmm2) -0.633  0.128 -4.932  0.000 -0.572 -0.572
##      Tart ~
##      ManIntn (gmm3) -0.845  0.185 -4.573  0.000 -0.978 -0.620
##
## Variances:
##      Estimate Std.Err z-value P(>|z|) Std.lv Std.all
##      .N        0.560  0.270  2.070  0.038  0.560  0.219
##      .Sugars    1.177  0.260  4.524  0.000  1.177  0.633
##      .Tart      1.227  0.319  3.845  0.000  1.227  0.494
##      .Malic     0.884  0.208  4.255  0.000  0.884  0.534
##      .Mgt       0.000          0.000  0.000
##      .Nfixers   0.000          0.000  0.000
##      .GrapeQual 1.507  0.450  3.347  0.001  0.757  0.757
##      ManInten   1.339  0.268  5.000  0.000  1.000  1.000
##      .NonCrop   1.101  0.220  5.000  0.000  0.673  0.673

```



```
##
## R-Square:
##           Estimate
##      N           0.781
##    Sugars         0.367
##      Tart         0.506
##     Malic         0.466
##      Mgt          1.000
##    Nfixers        1.000
##   GrapeQual       0.243
##    NonCrop        0.327
```

Multi-group Analyses

syntax from [<https://groups.google.com/g/lavaan/c/PWh2TAniWbM?pli=1>]
(<https://groups.google.com/g/lavaan/c/PWh2TAniWbM?pli=1>)]

Latent Factor Model

Table S2.5. Model fit results for multigroup analysis

```
#### Stage I of our analysis examines the latent factor submodel by itself
## mg.mod0 - CFA independence model with distinct labels for each group
mg.mod0 <- '
GrapeQual =~ c("lambda1a","lambda1b")*N + c("lambda2a","lambda2b")*Sugars + c("lambda3a","lambda
3b")*Tart
              + c("lambda4a","lambda4b")*Malic'
# fit model
mg.mod0.fit <- sem(mg.mod0, sample.cov=list(Chass.dat,Pinot.dat), sample.nobs=list(50, 50))

show(mg.mod0.fit ); fitMeasures(mg.mod0.fit, "cfi")
```

```
## lavaan 0.6-8 ended normally after 47 iterations
##
##      Estimator                      ML
##    Optimization method              NLMINB
##    Number of model parameters        16
##
##    Number of observations per group:
##      Group 1                        50
##      Group 2                        50
##
## Model Test User Model:
##
##    Test statistic                      0.999
##    Degrees of freedom                  4
##    P-value (Chi-square)                0.910
##    Test statistic for each group:
##      Group 1                        0.808
##      Group 2                        0.191
```

```
## cfi
## 1
```

```
#subset(modindices(mg.mod0.fit), mi > 3)
#summary(mg.mod0.fit)

## mg.mod1 - CFA equal across groups with repeated labels for each group
mg.mod1 <- '
GrapeQual =~ c("lambda1","lambda1")*N + c("lambda2","lambda2")*Sugars + c("lambda3","lambda3")*T
art
          + c("lambda4","lambda4")*Malic'
# fit model
mg.mod1.fit <- sem(mg.mod1, sample.cov=list(Chass.dat,Pinot.dat), sample.nobs=list(50, 50))

show(mg.mod1.fit ); fitMeasures(mg.mod1.fit, "cfi")
```

```
## lavaan 0.6-8 ended normally after 39 iterations
##
##      Estimator                      ML
##      Optimization method          NLMINB
##      Number of model parameters      16
##      Number of equality constraints     3
##
##      Number of observations per group:
##      Group 1                        50
##      Group 2                        50
##
## Model Test User Model:
##
##      Test statistic                  3.220
##      Degrees of freedom              7
##      P-value (Chi-square)           0.864
##      Test statistic for each group:
##      Group 1                        1.783
##      Group 2                        1.437
```

```
## cfi
## 1
```

Multi-group Full Model

Table S2.6. Model specification and model fit results for final multigroup model (parameter estimates are in Table S2.7).

```
## mg.mod4 - test that Non-Crop Vegetation responds to Management Intensity the same in different groups
mg.mod4 <- '
# declare latent variables
GrapeQual =~ c("lambda1","lambda1")*N + c("lambda2","lambda2")*Sugars + c("lambda3","lambda3")*Tart
            + c("lambda4","lambda4")*Malic
ManInten =~ c("lambda5","lambda5")*Mgt
NonCrop =~ c("lambda6","lambda6")*Nfixers
# regressions
GrapeQual ~ c("gamma1a","gamma1b")*ManInten + c("beta1a","beta1b")*NonCrop
NonCrop ~ c("gamma2a","gamma2b")*ManInten
Tart ~ c("gamma3a","gamma3b")*ManInten
# set constraints
beta1a == 0
gamma3b == 0
gamma2a == gamma2b'
# fit model
mg.mod4.fit <- sem(mg.mod4, sample.cov=list(Chass.dat,Pinot.dat), sample.nobs=list(50, 50))
# results
show(mg.mod4.fit ); fitMeasures(mg.mod4.fit, "cfi")
```

```
## lavaan 0.6-8 ended normally after 49 iterations
##
##      Estimator                      ML
##      Optimization method          NLMINB
##      Number of model parameters      28
##      Number of equality constraints     6
##
##      Number of observations per group:
##      Group 1                        50
##      Group 2                        50
##
## Model Test User Model:
##
##      Test statistic                  17.521
##      Degrees of freedom              20
##      P-value (Chi-square)            0.619
##      Test statistic for each group:
##      Group 1                        5.497
##      Group 2                       12.024
```

```
## cfi
## 1
```

Table S2.7. Parameter estimates for multigroup analyses of final full model.

```
summary(mg.mod4.fit, standardized=T, rsq=T)
```

```

## lavaan 0.6-8 ended normally after 49 iterations
##
##      Estimator                      ML
##      Optimization method          NLMINB
##      Number of model parameters    28
##      Number of equality constraints  6
##
##      Number of observations per group:
##      Group 1                      50
##      Group 2                      50
##
## Model Test User Model:
##
##      Test statistic                17.521
##      Degrees of freedom            20
##      P-value (Chi-square)          0.619
##      Test statistic for each group:
##      Group 1                      5.497
##      Group 2                      12.024
##
## Parameter Estimates:
##
##      Standard errors              Standard
##      Information                  Expected
##      Information saturated (h1) model Structured
##
##
## Group 1 [Group 1]:
##
## Latent Variables:
##      Estimate Std.Err z-value P(>|z|) Std.lv Std.all
##      GrapeQual =~
##      N      (lmb1)  1.000          1.417  0.885
##      Sugars (lmb2) -0.521  0.109 -4.763  0.000 -0.739 -0.558
##      Tart   (lmb3)  0.871  0.144  6.034  0.000  1.234  0.777
##      Malic  (lmb4)  0.633  0.108  5.858  0.000  0.898  0.692
##      ManInten =~
##      Mgt     (lmb5)  1.000          1.157  1.000
##      NonCrop =~
##      Nfixers (lmb6)  1.000          1.212  1.000
##
## Regressions:
##      Estimate Std.Err z-value P(>|z|) Std.lv Std.all
##      GrapeQual ~
##      ManIntn (gmm1)  0.605  0.171  3.536  0.000  0.494  0.494
##      NonCrop (bet1)  0.000          0.000  0.000
##      NonCrop ~
##      ManIntn (gmm2) -0.510  0.093 -5.457  0.000 -0.487 -0.487
##      Tart ~
##      ManIntn (gmm3) -0.860  0.172 -5.015  0.000 -0.995 -0.626
##
## Variances:
##      Estimate Std.Err z-value P(>|z|) Std.lv Std.all

```

```

##      .N                0.554    0.256    2.164    0.030    0.554    0.216
##      .Sugars           1.208    0.260    4.654    0.000    1.208    0.689
##      .Tart             1.224    0.313    3.916    0.000    1.224    0.485
##      .Malic            0.875    0.206    4.246    0.000    0.875    0.521
##      .Mgt              0.000                0.000    0.000
##      .Nfixers          0.000                0.000    0.000
##      .GrapeQual       1.519    0.427    3.558    0.000    0.756    0.756
##      ManInten         1.339    0.268    5.000    0.000    1.000    1.000
##      .NonCrop         1.121    0.224    5.000    0.000    0.763    0.763
##
## R-Square:
##      Estimate
##      N                0.784
##      Sugars           0.311
##      Tart             0.515
##      Malic            0.479
##      Mgt              1.000
##      Nfixers          1.000
##      GrapeQual       0.244
##      NonCrop         0.237
##
##
## Group 2 [Group 2]:
##
## Latent Variables:
##      Estimate Std.Err z-value P(>|z|) Std.lv Std.all
## GrapeQual =~
##      N      (lmb1)  1.000                1.068    0.757
##      Sugars (lmb2) -0.521    0.109   -4.763    0.000   -0.557   -0.438
##      Tart   (lmb3)  0.871    0.144    6.034    0.000    0.930    0.715
##      Malic  (lmb4)  0.633    0.108    5.858    0.000    0.676    0.488
## ManInten =~
##      Mgt     (lmb5)  1.000                0.924    1.000
## NonCrop =~
##      Nfixers (lmb6)  1.000                1.001    1.000
##
## Regressions:
##      Estimate Std.Err z-value P(>|z|) Std.lv Std.all
## GrapeQual ~
##      ManIntn (gmm1)  0.728    0.188    3.869    0.000    0.630    0.630
##      NonCrop (bt1b)  0.630    0.173    3.645    0.000    0.590    0.590
## NonCrop ~
##      ManIntn (gmm2) -0.510    0.093   -5.457    0.000   -0.471   -0.471
## Tart ~
##      ManIntn (gmm3)  0.000         NA         0.000    0.000
##
## Variances:
##      Estimate Std.Err z-value P(>|z|) Std.lv Std.all
##      .N        0.850    0.262    3.246    0.001    0.850    0.427
##      .Sugars    1.304    0.277    4.714    0.000    1.304    0.808
##      .Tart      0.828    0.229    3.612    0.000    0.828    0.489
##      .Malic     1.463    0.316    4.628    0.000    1.463    0.762
##      .Mgt       0.000                0.000    0.000
##      .Nfixers   0.000                0.000    0.000

```

```

##      .GrapeQual      0.690    0.250    2.760    0.006    0.605    0.605
##      ManInten        0.854    0.171    5.000    0.000    1.000    1.000
##      .NonCrop        0.779    0.156    5.000    0.000    0.778    0.778
##
## R-Square:
##           Estimate
##      N           0.573
##      Sugars       0.192
##      Tart         0.511
##      Malic        0.238
##      Mgt          1.000
##      Nfixers      1.000
##      GrapeQual    0.395
##      NonCrop      0.222
##
## Constraints:
##                                     |Slack|
##      beta1a - 0                      0.000
##      gamma3b - 0                     0.000
##      gamma2a - (gamma2b)             0.000

```