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lavaan: An Open Source Structural Equation Modeling Package Using the R System for Statistical Modeling

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By Dr. Rich Herrington, Research and Statistical Support Consultant

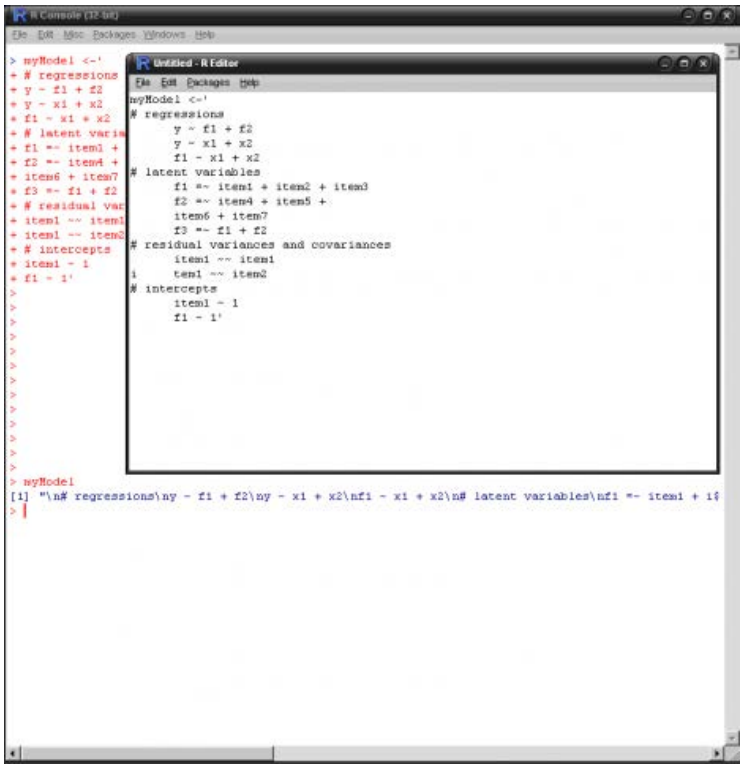
In a previous article, Dr. Starkweather covered implementing structural equations models (SEM) within the R statistical system. Specifically, the R packages ***sem*** and ***lavaan*** were used in the article's R script examples. In this article, we highlight some of the capabilities, and recent changes, to the R package ***lavaan***.

The web page for the lavaan package can be found at http://www.lavaan.org. The corresponding CRAN website for this package is found at: http://cran.r-project.org/web/packages/lavaan/index.html . Recently, a review article covering package ***lavaan***, has appeared in the Journal of Statistical Software: http://www.jstatsoft.org/v48/i02/paper .

One of the authors primary reasons for developing ***lavaan*** was to provide *"access to an easy-to-use, but complete, SEM program that is inexpensive to install in a computer classroom"* (1). This ease of use extends to the model syntax that has been chosen for **lavvan**. The author chose to emulate the syntax of the well known SEM software Mplus. Additionally, ***lavaan*** provides a "mimic" option for output formatting. If ***mimic="Mplus"***, ***lavaan*** produces output that resembles the output of ***Mplus*** (similar mimic options exist for emulating ***LISREL*** and ***EQS*** output). Similar to ***Mplus***, the conventions adopted in ***lavaan*** follow the following nomenclature (table taken from reference 1.):

Formula type	Operator	Mnemonic
Latent variable	=~	is manifested by
Regression	~	is regressed on
(Residual) (co)variance	~~	is correlated with
Intercept	~ 1	intercept
Defined parameter	:=	is defined as
Equality constraint	==	is equal to
Inequality constraint	<	is smaller than
Inequality constraint	>	is larger than

An example of the prototypical R code necessary to declare a ***lavaan*** model in R appears as follows:



Note that lines with "#" are comment lines and do not effect the evaluation of the script. The R code above assigns a character string to the model object "myModel". An example taken from the help pages of ***lavaan*** include a famous model and data set, included in many articles and texts covering SEM methodology:

lavaan SEM R script:

```
#  lavaan SEM R script

library(lavaan)

# The Holzinger and Swineford (1939) example

HS.model <- ' visual  =~ x1 + x2 + x3
              textual =~ x4 + x5 + x6
              speed   =~ x7 + x8 + x9 '

fit <- lavaan(HS.model, data=HolzingerSwineford1939,
              auto.var=TRUE, auto.fix.first=TRUE,
              auto.cov.lv.x=TRUE)

summary(fit, fit.measures=TRUE)
```

The resulting lavaan output:

Output Part 1:

```
# lavaan SEM output

lavaan (0.5-9) converged normally after  41 iterations

  Number of observations                           301

  Estimator                                         ML
  Minimum Function Chi-square                   85.306
  Degrees of freedom                                24
  P-value                                        0.000

Chi-square test baseline model:

  Minimum Function Chi-square                  918.852
  Degrees of freedom                                36
  P-value                                        0.000

Full model versus baseline model:

  Comparative Fit Index (CFI)                    0.931
  Tucker-Lewis Index (TLI)                       0.896

Loglikelihood and Information Criteria:

  Loglikelihood user model (H0)              -3737.745
  Loglikelihood unrestricted model (H1)      -3695.092

  Number of free parameters                         21
  Akaike (AIC)                                7517.490
  Bayesian (BIC)                              7595.339
  Sample-size adjusted Bayesian (BIC)         7528.739

Root Mean Square Error of Approximation:

  RMSEA                                          0.092
  90 Percent Confidence Interval          0.071  0.114
  P-value RMSEA <= 0.05                          0.001
```

Output Part 2:

```
Standardized Root Mean Square Residual:

  SRMR                                           0.065

Parameter estimates:

  Information                                 Expected
  Standard Errors                             Standard

                   Estimate  Std.err  Z-value  P(>|z|)
Latent variables:
  visual =~
    x1                1.000
    x2                0.553    0.100    5.554    0.000
    x3                0.729    0.109    6.685    0.000
  textual =~
    x4                1.000
    x5                1.113    0.065   17.014    0.000
    x6                0.926    0.055   16.703    0.000
  speed =~
    x7                1.000
    x8                1.180    0.165    7.152    0.000
    x9                1.082    0.151    7.155    0.000

Covariances:
  visual ~~
    textual           0.408    0.074    5.552    0.000
    speed             0.262    0.056    4.660    0.000
  textual ~~
    speed             0.173    0.049    3.518    0.000

Variances:
    x1                0.549    0.114
    x2                1.134    0.102
    x3                0.844    0.091
    x4                0.371    0.048
    x5                0.446    0.058
    x6                0.356    0.043
    x7                0.799    0.081
    x8                0.488    0.074
    x9                0.566    0.071
    visual            0.809    0.145
    textual           0.979    0.112
    speed             0.384    0.086
```

Some of the functionality available to users in the current version of lavaan (0.5.9) includes:

- Esitmators: ML, GLS, WLS, MLM, MLF, MLR
- Can use Bollen-Stine bootstrapping
- Provides full FIML missing value analysis for MCAR and MAR settings
- Can implement general nonlinear equality and inequality constraints
- Provides full support for mean structures with parameter restrictions across groups
- Provides modification indicies and expected parameter changes based on these indices

- Provides full support for categorical and ordinal data using three stage WLS: WLS, WLSM, & WLSMV

References:

(1) lavaan: An R Package for Structural Equation Modeling

Contact Us:

University Information Technology
1155 Union Circle #310709
Denton, TX 76203 USA
Voice: 940-565-4068
Fax: 940-565-4060

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