On Chi-Squares for the Independence Model and Fit Measures in LISREL

Karl G Jöreskog

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LISREL computes many fit measures for the estimated model. Most of these, *e.g.*, RMSEA, ECVI, and AIC, depend on chi-square for the model. Some others, *e.g.*, NFI, NNFI, CFI, IFI, and RFI, depend on chi-square for the independence model as well. Things become complicated because there are up to four different chi-squares (C1, C2, C3, and C4, explained in the next section) computed for the model and, in principle, there are also four different chi-squares (C1i, C2i, C3i, and C4i) for the independence model. Which chi-square and combination of chi-squares should be used to compute the fit measures? Some of the chi-squares are valid under non-normality and some are valid only under normality (to be precise this should be multivariate normality). Things get even more complicated because the chi-squares depend also on the method of estimation used to fit the model to the data. As LISREL has at least five estimation methods (ULS, GLS, ML, WLS, and DWLS), there is a variety of chi-squares that can be used, and hence, many fit measures that can be computed from them.

Previous versions of LISREL sometimes use C1, sometimes C2, and sometimes C3. For example, with ML, LISREL uses C3 to compute RMSEA and C2 and C2i to compute most other fit measures. The worst problem is with ULS and DWLS where LISREL sometimes uses C1 which does not have an asymptotic chi-square distribution.

In LISREL 8.70 we have corrected these anomalies so that C2 and C2i are used under normality, *i.e.*, if no asymptotic covariance matrix is provided, and C3 and C3i are used under non-normality, *i.e.*, if an asymptotic covariance matrix is provided. Furthermore, LISREL 8.70 provides an additional new table of fit measures where users can "see" (as in a spread sheet) how the fit measures depend on (C1,C1i), (C2,C2i), (C3,C3i), and (C4,C4i). Previously this was not possible because C3i and C4i were not available within the program[1].

The choice of C2 and C2i instead of C1 and C1i is not based on the belief that C2 and C2i are better chi-squares than C1 and C1i. Rather it is because C2 and C2i have asymptotic chi-squares for all methods of estimation, which is not the case with C1 and C1i. On the other hand, the choice of C3 and C3i instead of C4 and C4i is based on the belief that C3 and C3i are better chi-squares than C4 and C4i unless the sample size is huge, see *e.g.*, Hu, Bentler, & Kano (1992).

In this note I explain what the independence model is and I outline how the four chi-squares C1i, C2i, C3i, and C4i for the independence model can be computed for each method of estimation. In this description I use some material published in Chapter 4 and Appendix A of Jöreskog *et al.* (2003).

[1]One could of course obtain all four chi-squares for the independence model by running the independence model as the model to be estimated. However, new in LISREL 8.70 is that these chi-squares are computed internally in LISREL for any single group model, and they can therefore be used to compute all fit measures.

The objective of this note *is not* to discuss the advantages and disadvantages of various fit measures. The formulas for the fit measures and references to the original papers where they were first proposed are given in Chapter 4 of Jöreskog & Sörbom (2002). Readers are referred to these original sources and other papers for a discussion of the pros and cons of the various fit measures. A comprehensive simulation study of their performances in different situations has been performed by Hammervold (1998).

1 The four different chi-squares

The four different chi-squares are denoted C1, C2, C3, C4. Which ones are obtained in different situations is seen in the following table, where $\bullet$ means obtained and $\circ$ means not obtained ($\star$ means that C2 will be obtained only if the asymptotic variances are provided).

Asymptotic Covariance Matrix not Provided

	ULS	GLS	ML	WLS	DWLS
C1	○	●	●	○	○
C2	●	●	●	○	⋆
C3	○	○	○	○	○
C4	○	○	○	○	○

Asymptotic Covariance Matrix Provided

	ULS	GLS	ML	WLS	DWLS
C1	○	●	●	●	○
C2	●	●	●	○	●
C3	●	●	●	○	●
C4	●	●	●	○	●

Let N be the sample size.

- C1 is $N - 1$ times the minimum value of the fit function.
- C2 is $N-1$ times the minimum value of the WLS fit function using a weight matrix estimated under multivariate normality.
- C3 is the Satorra-Bentler scaled chi-square statistic (Satorra & Bentler, 1988, equation 4.1).
- C4 is $N-1$ times the minimum value of the WLS fit function using a weight matrix estimated under multivariate non-normality (as provided by PRELIS). C4 is computed from equation (2.20a) in Browne (1984).

A unified presentation of these chi-squares is given in Appendix A in Jöreskog *et al.* (2003).

Under multivariate normality of the observed variables, C1 and C2, whenever provided, are asymptotically equivalent and have an asymptotic chi-square distribution if the model holds exactly and an asymptotic non-central chi-square distribution if the model holds approximately. The same holds for C4 under the more general assumption that the observed variables have a multivariate distribution with finite moments up to order four. C3 is a correction to C2 which makes C3 have the correct asymptotic mean even under non-normality. For more information, see Chapter 4 and Appendix A of Jöreskog *et al.* (2003).

In the output for LISREL, the four chi-squares are recognized by the following text.

```
C1  Minimum Fit Function Chi-Square
C2  Normal Theory Weighted Least Squares Chi-Square
C3  Satorra-Bentler Scaled Chi-Square
C4  Chi-Square Corrected for Non-Normality
```

2 Chi-squares for Independence Model

The formulas for the four chi-squares are quite complicated for a general model. They are given in equations (A.28) - (A.32) in Appendix A of Jöreskog *et al.* (2003). However, for the independence model, they can be considerably simplified. In this section I outline how they can be computed.

The independence model is the model which specifies that the covariance matrix $\mathbf{\Sigma}$ of the observed variables is diagonal, and hence that all observed variables are uncorrelated. It is called independence model because if the observed variables are multivariate normal they would be independent. However, this model can also be considered under non-normality.

Why would anyone be interested in the independence model? There are only two reasons:

- Before a genuine LISREL model is estimated it is recommended that the independence model is tested. If the independence model is not rejected by the data, one has no business in structural equation modeling because all the variables may be uncorrelated.
- The chi-square for the independence model is used as a baseline chi-square for computing some fit measures, notably NFI, NNFI, CFI, IFI, and RFI.

It is for the second reason I am writing this note.

If $\mathbf{\Sigma}$ is diagonal, it seems "natural" to estimate its diagonal elements by the diagonal elements of $\mathbf{S}$, the covariance matrix of the observed variables estimated from the sample. Indeed, it can be shown that these estimates are ML, ULS, and DWLS estimates, *i.e.*, these methods of fitting the independence model give the same estimate, namely $\hat{\mathbf{\Sigma}} = diag(\mathbf{S})$. However, $\hat{\mathbf{\Sigma}} = diag(\mathbf{S})$ *is not* a GLS estimate, *nor* a WLS estimate. Nevertheless, GLS and WLS estimates can be obtained explicitly by exploiting the fact that the independence model is a specific special case of a linear covariance structure. The GLS and WLS estimates are functions of *all* the elements of $\mathbf{S}$.

Once the estimate of $\hat{\mathbf{\Sigma}}$ has been obtained the chi-squares C2i, C3i, and C4i can be computed by noting that $\mathbf{\Delta}'_c(\mathbf{s} - \hat{\boldsymbol{\sigma}})$ in (A.29) and (A.32) is simply a vector of the off-diagonal elements of $\mathbf{S}$, and $\mathbf{\Delta}'_c\mathbf{W}\mathbf{\Delta}_c$ is the asymptotic covariance matrix of the off-diagonal elements of $\mathbf{S}$.

3 Example

To illustrate the chi-squares for the independence model and the new table of fit measures I use the data on nine psychological variables from 145 school children of the Grant-White School described on pp 147–148 in Jöreskog *et al.* (2003). The data are available in files **NPV.RAW**

Table 1: Parameter Estimates for Independence Model

Variable	ULS	GLS	ML	WLS	DWLS
VIS PERC	47.801	24.924	47.801	22.351	47.801
CUBES	19.758	14.243	19.758	17.547	19.758
LOZENGES	69.172	38.301	69.172	50.678	69.172
PAR COMP	11.393	2.916	11.393	2.280	11.393
SEN COMP	21.616	6.676	21.616	3.951	21.616
WORDMEAN	63.163	20.415	63.163	13.649	63.163
ADDITION	556.590	144.807	556.590	365.882	556.590
COUNTDOT	440.790	160.835	440.790	109.396	440.790
S-C CAPS	1371.600	607.907	1371.600	561.439	1371.600

Table 2: Chi-squares for Independence Model

Method	C1i	C2i	C3i	C4i
ULS		670.583	535.055	202.665
GLS	138.332	5031.350	613.716	202.665
ML	502.292	670.583	535.055	202.665
WLS	202.665			
DWLS		670.583	535.055	202.665

and **NPV.PSF** in the subfolder **LIS870EX**. The model I use is the confirmatory factor analysis model shown in Figure 1.15 on p. 25 in Jöreskog & Sörbom (2002).

Before I estimate the confirmatory factor analysis model, I report the results for the independence model.

The independence model gives estimates $\hat{\sigma}_{ii}$ of the variances of the observed variables. These variances estimated with different methods are given in Table 1.

Note that the parameter estimates are the same for methods ULS, ML, and DWLS. For these methods the estimates are equal to s_{ii}, the diagonal elements of the sample covariance matrix $\mathbf{S}$. For GLS and WLS the estimates are considerably smaller. For example, for SEN COMP the WLS variance estimate is 3.951 whereas the sample variance is 21.616.

Table 2 gives the four chi-squares associated with each method of estimation.

Note the following

- C1i is not given for ULS and DWLS. The reason is that for these methods, $N-1$ times the minimum fit function value (C1) does not have an asymptotic chi-square distribution.
- Only C1i is given for WLS. The reason is that it does not make sense to estimate C2i and C3i in this case. Note that C1i for WLS is the same as C4i for the other methods.
- C4i is the same for the methods ULS, GLS, ML, and DWLS. The reason for this is that, as stated previously, in the special case of the independence model, C4i is only a function of the off-diagonal elements of $\mathbf{S}$, and hence, independent of the parameter estimates.

- C2i and C3i are the same for ULS, ML, and DWLS. This is because these methods use the same parameter estimates.
- C1i for GLS is much smaller than C1i for the other methods and C2i is much larger than C2i for the other methods.

To proceed with the estimation of the confirmatory factor analysis model, I will use PRELIS and LISREL syntax files. Alternatively, one can perform these steps interactively, see Du Toit & Du Toit (2001).

To obtain the new table of fit measures, put `FT` on a `OU` line in a LISREL command file, or on a `Options` line or a `LISREL Output` line in a SIMPLIS command file. This will produce a file with fit measures with the same name as the input file but with the suffix **.FTB**.

I begin by constructing a DSF file, see Jöreskog *et al.* (2003) pp 169–170. This can be done in several ways. I use the following PRELIS syntax file, **NPV.PR2**, say.

```
SY=NPV.PSF
OU MA=CM AC=NPV.ACC
```

This produces a file **NPV.DSF** containing all the information about the data that LISREL needs, including a pointer to the asymptotic covariance matrix **NPV.ACC**.

A SIMPLIS command file **NinePV1.SPL**, say, for estimating the model by ML under non-normality assumptions is

```
Confirmatory Factor Analysis Model
SY=NPV.DSF
Latent Variables: Visual Verbal Speed
Relationships:
   'VIS PERC' - LOZENGES = Visual
   'PAR COMP' - WORDMEAN = Verbal
    ADDITION - 'S-C CAPS' = Speed
Path Diagram
Options: ME=ML FT
End of Problem
```

A LISREL command file **NinePV2.LS8**, say, for doing the same thing is

```
Confirmatory Factor Analysis Model
SY=NPV.DSF
MO NX=9 NK=3
LK
Visual Verbal Speed
PA LX
3(1 0 0) 3(0 1 0) 3(0 0 1)
PD
OU ME=ML FT
```

The SIMPLIS command file will produce a separate output file called **NinePV1.FTB**. The LISREL command file produces an identical file called **NinePV2.FTB**.

All the results in the output file from LISREL are written with 2 decimals by default. The **FTB** file also uses 2 decimals by default. However, one can request more decimals by putting `ND=n` on the `OU` line or `Options` line, where n is the required number of decimals, $0 \leq n \leq 8$.

```
Method of Estimation:  Maximum Likelihood (ML)

                                                      C1        C2        C3        C4
Chi-Square for Model (CM)                            51.19     48.61     47.22     64.20
Degrees of Freedom for Model (DFM)                  24        24        24        24
Chi-Square for Independence Model (CI)              502.28    670.57    535.05    202.66
Degrees of Freedom for Independence Model (DFI)     36        36        36        36
CM/DFM                                                2.13      2.03      1.97      2.68
CI/DFI                                               13.95     18.63     14.86      5.63
Estimated Non-Centrality Parameter (NCP)             27.19     24.61     23.22     40.20
Population Discrepancy Function Value (F0)            0.19      0.17      0.16      0.28
Root Mean Square Error of Approximation (RMSEA)       0.09      0.08      0.08      0.11
Expected Cross-Validation Index (ECVI)                0.65      0.63      0.62      0.74
Model AIC (AIC)                                      93.19     90.61     89.22    106.20
Model CAIC (CAIC)                                   176.70    174.13    172.73    189.71
Normed Fit Index (NFI)                                0.90      0.93      0.91      0.68
Non-Normed Fit Index (NNFI)                           0.91      0.94      0.93      0.64
Parsimony Normed Fit Index (PNFI)                     0.60      0.62      0.61      0.46
Comparative Fit Index (CFI)                           0.94      0.96      0.95      0.76
Incremental Fit Index (IFI)                           0.94      0.96      0.95      0.77
Relative Fit Index (RFI)                              0.85      0.89      0.87      0.52
Goodness of Fit Index (GFI)                           0.93      0.93      0.93      0.93
Adjusted Goodness of Fit Index (AGFI)                 0.87      0.87      0.87      0.87
Parsimony Goodness of Fit Index (PGFI)                0.50      0.50      0.50      0.50
```

This can be compared with some fit measures given in the output file. Some of these fit measures are also given in the file **NinePV1.FIT**. The **FIT** file is only produced if a path diagram is requested and the **FTB** file is only produced if `FT` is requested on the `Options` or `OU` line. The **NinePV1.FIT** is

```
                          Degrees of Freedom = 24
             Minimum Fit Function Chi-Square = 51.19 (P = 0.00100)
     Normal Theory Weighted Least Squares Chi-Square = 48.61 (P = 0.0021)
             Satorra-Bentler Scaled Chi-Square = 47.22 (P = 0.0032)
          Chi-Square Corrected for Non-Normality = 64.20 (P = 0.00)
            Estimated Non-centrality Parameter (NCP) = 23.22
          90 Percent Confidence Interval for NCP = (7.47 ; 46.74)
                     Minimum Fit Function Value = 0.36
           Population Discrepancy Function Value (F0) = 0.16
          90 Percent Confidence Interval for F0 = (0.052 ; 0.32)
         Root Mean Square Error of Approximation (RMSEA) = 0.082
        90 Percent Confidence Interval for RMSEA = (0.046 ; 0.12)
           P-Value for Test of Close Fit (RMSEA < 0.05) = 0.066
              Expected Cross-Validation Index (ECVI) = 0.62
          90 Percent Confidence Interval for ECVI = (0.51 ; 0.78)
                     ECVI for Saturated Model = 0.62
                    ECVI for Independence Model = 3.84
   Chi-Square for Independence Model with 36 Degrees of Freedom = 535.05
                        Independence AIC = 553.05
                           Model AIC = 89.22
                         Saturated AIC = 90.00
                        Independence CAIC = 588.84
                           Model CAIC = 172.73
```

```
Saturated CAIC = 268.95
Normed Fit Index (NFI) = 0.91
Non-Normed Fit Index (NNFI) = 0.93
Parsimony Normed Fit Index (PNFI) = 0.61
Comparative Fit Index (CFI) = 0.95
Incremental Fit Index (IFI) = 0.95
Relative Fit Index (RFI) = 0.87
Critical N (CN) = 132.08
Root Mean Square Residual (RMR) = 16.20
Standardized RMR = 0.072
Goodness of Fit Index (GFI) = 0.93
Adjusted Goodness of Fit Index (AGFI) = 0.87
Parsimony Goodness of Fit Index (PGFI) = 0.50
```

Note the following

- The fit measures reported in the **FIT** file correspond to those listed under the C3 column in the **FTB** file. The values in the **FIT** file differ from those produced by previous versions of LISREL for reasons stated earlier.
- The **FTB** file is not supposed to replace the **FIT** file. Rather they complement each other. In a sense the **FIT** file contains more information. For example, it gives confidence intervals for NCP, F0, RMSEA, and ECVI and it gives ECVI, AIC, and CAIC not only for the estimated model but also for the saturated and the independence model.
- The fit measures NFI, NNFI, PNFI, CFI, IFI, and RFI in the **FIT** file are now based on (C3, C3i). The **FTB** file is intended to answer such questions as "How will these fit measures change if (C2, C2i), say, were used instead?".

Note also that the values reported for GFI, AGFI, and PGFI in the **FTB** file are equal across all columns. LISREL computes GFI by the formula

$$\mathrm{GFI} = 1 - \frac{(\mathbf{s} - \hat{\boldsymbol{\sigma}})'\mathbf{V}(\mathbf{s} - \hat{\boldsymbol{\sigma}})}{\mathbf{s}'\mathbf{V}\mathbf{s}} , \tag{1}$$

where $\mathbf{V}$ is a weight matrix which is different for different methods of estimation, see Jöreskog *et al.* (2003) p. 194. GFI measures how much *better* the model fits as compared to no model at all. This should not be confused with NFI which measures how much *better* the model fits as compared to the independence model. For ML, the numerator $(\mathbf{s} - \hat{\boldsymbol{\sigma}})'\mathbf{V}(\mathbf{s} - \hat{\boldsymbol{\sigma}})$ in (1) is $1/(N-1)$ times C2 and for GLS and WLS it is $1/(N-1)$ times C1 but GFI does not depend on any chi-square for the independence model.

In the Appendix I list the **FTB** file for each method of estimation. These are obtained by replacing `ME=ML` by `ME=ULS`, `ME=GLS`, `ME=WLS`, and `ME=DWLS` in turn. Note that these **FTB** files contain different numbers of columns.

References

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Appendix

Method of Estimation: Unweighted Least Squares (ULS)

	C2	C3	C4
Chi-Square for Model (CM)	58.85	47.72	58.16
Degrees of Freedom for Model (DFM)	24	24	24
Chi-Square for Independence Model (CI)	670.57	535.05	202.66
Degrees of Freedom for Independence Model (DFI)	36	36	36
CM/DFM	2.45	1.99	2.42
CI/DFI	18.63	14.86	5.63
Estimated Non-Centrality Parameter (NCP)	34.85	23.72	34.16
Population Discrepancy Function Value (F0)	0.24	0.16	0.24
Root Mean Square Error of Approximation (RMSEA)	0.10	0.08	0.10
Expected Cross-Validation Index (ECVI)	0.70	0.62	0.70
Model AIC (AIC)	100.85	89.72	100.16
Model CAIC (CAIC)	184.36	173.23	183.67
Normed Fit Index (NFI)	0.91	0.91	0.71
Non-Normed Fit Index (NNFI)	0.92	0.93	0.69
Parsimony Normed Fit Index (PNFI)	0.61	0.61	0.48
Comparative Fit Index (CFI)	0.95	0.95	0.80
Incremental Fit Index (IFI)	0.95	0.95	0.81
Relative Fit Index (RFI)	0.87	0.87	0.57
Goodness of Fit Index (GFI)	0.99	0.99	0.99
Adjusted Goodness of Fit Index (AGFI)	0.99	0.99	0.99
Parsimony Goodness of Fit Index (PGFI)	0.53	0.53	0.53

Method of Estimation: Generalized Least Squares (GLS)

	C1	C2	C3	C4
Chi-Square for Model (CM)	42.58	85.04	59.18	60.45
Degrees of Freedom for Model (DFM)	24	24	24	24
Chi-Square for Independence Model (CI)	138.33	5031.04	613.72	202.66
Degrees of Freedom for Independence Model (DFI)	36	36	36	36
CM/DFM	1.77	3.54	2.47	2.52
CI/DFI	3.84	139.75	17.05	5.63
Estimated Non-Centrality Parameter (NCP)	18.58	61.04	35.18	36.45
Population Discrepancy Function Value (F0)	0.13	0.42	0.24	0.25
Root Mean Square Error of Approximation (RMSEA)	0.07	0.13	0.10	0.10
Expected Cross-Validation Index (ECVI)	0.59	0.88	0.70	0.71
Model AIC (AIC)	84.58	127.04	101.18	102.45
Model CAIC (CAIC)	168.09	210.55	184.69	185.96
Normed Fit Index (NFI)	0.69	0.98	0.90	0.70
Non-Normed Fit Index (NNFI)	0.73	0.98	0.91	0.67
Parsimony Normed Fit Index (PNFI)	0.46	0.66	0.60	0.47
Comparative Fit Index (CFI)	0.82	0.99	0.94	0.78
Incremental Fit Index (IFI)	0.84	0.99	0.94	0.80
Relative Fit Index (RFI)	0.54	0.97	0.86	0.55
Goodness of Fit Index (GFI)	0.88	0.88	0.88	0.88
Adjusted Goodness of Fit Index (AGFI)	0.77	0.77	0.77	0.77
Parsimony Goodness of Fit Index (PGFI)	0.47	0.47	0.47	0.47

Method of Estimation: Weighted Least Squares (WLS)

	C1
Chi-Square for Model (CM)	57.92
Degrees of Freedom for Model (DFM)	24
Chi-Square for Independence Model (CI)	202.66
Degrees of Freedom for Independence Model (DFI)	36
CM/DFM	2.41
CI/DFI	5.63
Estimated Non-Centrality Parameter (NCP)	33.92
Population Discrepancy Function Value (F0)	0.24
Root Mean Square Error of Approximation (RMSEA)	0.10
Expected Cross-Validation Index (ECVI)	0.69
Model AIC (AIC)	99.92
Model CAIC (CAIC)	183.43
Normed Fit Index (NFI)	0.71
Non-Normed Fit Index (NNFI)	0.69
Parsimony Normed Fit Index (PNFI)	0.48
Comparative Fit Index (CFI)	0.80
Incremental Fit Index (IFI)	0.81
Relative Fit Index (RFI)	0.57
Goodness of Fit Index (GFI)	0.93
Adjusted Goodness of Fit Index (AGFI)	0.87
Parsimony Goodness of Fit Index (PGFI)	0.50

Method of Estimation: Diagonally Weighted Least Squares (DWLS)

	C2	C3	C4
Chi-Square for Model (CM)	48.11	44.83	60.14
Degrees of Freedom for Model (DFM)	24	24	24
Chi-Square for Independence Model (CI)	670.57	535.05	202.66
Degrees of Freedom for Independence Model (DFI)	36	36	36
CM/DFM	2.00	1.87	2.51
CI/DFI	18.63	14.86	5.63
Estimated Non-Centrality Parameter (NCP)	24.11	20.83	36.14
Population Discrepancy Function Value (F0)	0.17	0.14	0.25
Root Mean Square Error of Approximation (RMSEA)	0.08	0.08	0.10
Expected Cross-Validation Index (ECVI)	0.63	0.60	0.71
Model AIC (AIC)	90.11	86.83	102.14
Model CAIC (CAIC)	173.63	170.34	185.65
Normed Fit Index (NFI)	0.93	0.92	0.70
Non-Normed Fit Index (NNFI)	0.94	0.94	0.67
Parsimony Normed Fit Index (PNFI)	0.62	0.61	0.47
Comparative Fit Index (CFI)	0.96	0.96	0.78
Incremental Fit Index (IFI)	0.96	0.96	0.80
Relative Fit Index (RFI)	0.89	0.87	0.55
Goodness of Fit Index (GFI)	0.98	0.98	0.98
Adjusted Goodness of Fit Index (AGFI)	0.95	0.95	0.95
Parsimony Goodness of Fit Index (PGFI)	0.52	0.52	0.52