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LISREL 8.54: A PROGRAM FOR STRUCTURAL EQUATION MODELLING WITH LATENT VARIABLES

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1. INTRODUCTION

LISREL 8.54 is a computer program originally designed for estimation of a general structural equation model developed by Karl Jöreskog in the early 1970s (Jöreskog, 1973). Its current version, LISREL 8.54, is an advanced statistical program for multivariate analysis of linear systems with latent or unobserved variables, econometric structural equation systems, and a variety of factor analytic methods and covariance structure models. Recent developments also include powerful procedures for analysis with non-metric variables including latent variable models with ordinal indicators.

The core code of the program is written in FORTRAN, but over the last decade its current vendor, Scientific Software International Inc. (SSI), developed an impressive interactive visual interface in C/C++ that made LISREL one of the most user-friendly multivariate analysis packages available. While preserving its raw power and flexibility, this multi-language architecture, however, contributed to instability problems associated with the 8.50/8.51 versions. Several subsequent upgrades have resulted in the 8.54 release that now more closely resembles the power and reliability of the earlier versions of this program.

The LISREL 8.54 program (LISWIN32.EXE) is a 32-bit Windows application which interfaces with several modules, the main two of which are LISREL (LISREL85.EXE) and PRELIS (PRELIS25.EXE).[1] PRELIS was developed later than LISREL with the main purpose of providing a pre-processor and data transformation front-end to LISREL.

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[1] Specifically, LISWIN32.EXE interfaces with the 32-bit applications LISREL85.EXE, PRELIS25.EXE, MULTILEV5.EXE, CATFIRM.EXE and CONFIRM.EXE. These are modules designed for specific statistical procedures such as estimation of multilevel structural equation models.

LISREL 8.54 is strongly flavoured by the structure and logic of Jöreskog's general structural equation model, which is often referred to simply as 'LISREL' in the literature.[2] The most important aspect of this model and of the overall modelling philosophy of LISREL 8.54 is its general nature, which encompasses most of the classical linear econometric and factor-analytic models as special cases. In fact, most of the experimental designs such as ANOVA, MANOVA, dummy variable regression, etc. can be specified as special cases of the general LISREL model (see e.g. Cziráky *et al*., 2003a).

The LISREL model is given by three matrix equations: the measurement model for the latent exogenous variables $\mathbf{x} = \mathbf{\Lambda}_x \xi + \delta$, the measurement model for the latent endogenous variables $\mathbf{y} = \mathbf{\Lambda}_y \eta + \varepsilon$, and the structural equation model $\eta = \mathbf{B}\eta + \mathbf{\Gamma}\xi + \zeta$. Here $\mathbf{\Lambda}_x$, $\mathbf{\Lambda}_y$, $\mathbf{B}$ and $\mathbf{\Gamma}$ are coefficient matrices, and δ, ε and ζ are vectors of latent errors. As I will explain shortly, much of modelling with LISREL centres around specifying various special cases of this general model by referring to the elements of the above matrices.

2. IMPLEMENTATION

LISREL 8.54 is distributed on a CD as a self-extracting installation file. The installation is a simple and short one-step process. Previous versions need to be updated with self-installing patch files, which can be downloaded for free from the distributor's web site. A free time-limited demo and student versions are available, as are rental versions and versions for other platforms (see Table I for details). The installation includes a large number of examples and an extensive interactive help facility. Included examples, which are selected from a variety of social science applications, are well suited for classroom use. Most examples are briefly discussed in the manuals but not in the otherwise excellent help facility, which is a drawback. The interactive help options are particularly usefully designed and allow the novice user to build complex models from scratch by following step-by-step on-screen instructions. An especially useful feature is that the help facility can be used while analysing the data without needing to switch between the help window and the command prompt. The online help file includes the user's guide to LISREL's user interface, new statistical features and syntax. Technical support is also excellent.

3. DOCUMENTATION

A decent collection of manuals for LISREL 8.54 is available at extra cost. The manuals are extensive but not always helpful. The main LISREL manual (Jöreskog and Sörbom, 1996c) is an excellent reference manual for the LISREL command language. It provides lots of examples and a good overview of the statistical methods behind the program. This relatively old manual was amended with an addendum volume (Jöreskog *et al*., 2001). However, the two manuals were not integrated into a single volume. The second command language for LISREL 8.54, the SIMPLIS language, has a separate manual (Jöreskog and Sörbom, 1996b), which is however much less informative than the LISREL manual. Finally, recently developed interactive features are covered by Du Toit and Du Toit (2001), and the PRELIS module has a separate, relatively good manual

[2] To avoid confusion with the computer program, I refer to the statistical model as 'LISREL' and to the software package as 'LISREL 8.54'.

Table I. LISREL 8.54

Vendor:	Scientific Software International Inc., 7383 N. Lincoln Ave, Suite 100, Lincolnwood, IL 60712-1704, USA
Authors:	Karl Jöreskog, Dag Sörbom
Pricing:	PC individual licence: $445 Set of 5 manuals: $130
Student edition:	Free, limited to 12 variables
Trial & rental editions:	Free, fully-featured trial edition limited to 15 days, and 6- or 12-month rentals are available from www.e-academy.com
Tel:	800-247-6113, 847-675-0720
Fax:	847-675-2140
WWW:	http://www.ssicentral.com
Tech support:	techsupport@ssicentral.com
Hardware & software supported:	IBM PCs, AIX, Solaris and TRU64 on RISC hardware, Macintosh version will be released in Summer 2003, MS Windows (95/98/ME/NT/2000/XP), Linux, UNIX, Open VMS
Multivariate routines (partial listing):	IV/TSLS/ULS/GLS/ML/WLS/DWLS Estimation of Structural Equation Models with Latent Variables, Structural Modelling with Incomplete Data, Efficient FIML for Incomplete Data that are Missing at Random, Multilevel Structural Equation Modelling with Complete and Incomplete Data, Nonlinear Multilevel Modelling, EM/MCMC for Imputing Incomplete Data that are Missing at Random, Exploratory and Confirmatory Maximum Likelihood Factor Analysis, Latent Curve Modelling, Minimum Fit Function χ^2, Normal Theory Weighted
Fit statistics (partial listing):	Least Squares χ^2, Satorra–Bentler Scaled χ^2, χ^2 Corrected for Non-Normality, Population Discrepancy Function, Root Mean Square Error of Approximation, Expected Cross-Validation Index, Normed Fit Index, Non-Normed Fit Index, Parsimony Normed Fit Index, Comparative Fit Index, Incremental Fit Index, Relative Fit Index, Goodness of Fit Index

(Jöreskog and Sörbom, 1996a). Indexing of all manuals is very good with separate author and subject indices. Unfortunately, economic examples in the manuals are scarce and notably dated.

4. DATA MANIPULATION: PRELIS

PRELIS, an integral part of LISREL 8.54, is a pre-processor designed to perform data manipulation, transformations, data import/export, descriptive analysis and graphics. Upon importing data into PRELIS, the program transforms it into a 'PRELIS system file' (.psf) which stores information on the number of observations, number of variables, variable names, type of variables, category labels and missing value codes, as well as the raw data. PRELIS enables file import from over 80 different formats. However, file export options are only comma separated (.csv), tab delimited (.txt), ASCII (.dat) and SPSS (.sav) formats. PRELIS has its own command language (stored in files with extension .pr2) and a menu-driven user interface that enables interactive model specification. To give an example of the PRELIS syntax, the following code performs an instrumental variables regression, written by specifying a path to the file, with RG for 'regression' of variable 1 on variables 2, 3 and 4, using variables 5, 6, 7 and 8 as instruments. The numbers of the variables relate to their position in the data file, and the OU command specifies various output options:


```
SY='C:\....\FILE.PSF'
RG 1 ON 2 3 4 WITH 5 6 7 8
OU MA=CM XT XM
```

PRELIS includes a data transformation calculator capable of performing most standard transformations. An exceptionally useful feature is the ability to perform normal score transforms. Together with univariate and multivariate normality tests, this makes PRELIS an excellent environment for preliminary analysis when modelling aims to proceed in the Gaussian multivariate framework. Descriptive analysis of an entire data set can be performed with a single mouse click, which results in detailed and informative output. The output file appears in a separate window, originally as a text file, but it can be automatically converted into RTF, HTML and TEX formats. The formatted output appears in a new window and can be copied on the clipboard or directly inserted into a word processor or a LATEX compiler. The output conversion generally works well if the output was not edited before conversion. The RTF output will save hours of typing to the users of commercial word processors, as it produces formatted tables that can easily be edited by any major word processing software. This additional editing is necessary because the PRELIS-formatted output is still short of being publication quality, and larger tables get broken into several smaller ones, all of which requires additional editing. The conversion of output into TEX format is merely a way to print slightly nicer-looking output, and it should be further improved.

5. MODELLING AND ESTIMATION: LISREL

The modelling philosophy of LISREL 8.54 is rather different from that of most standard econometric packages. With each release, this package includes more of the standard procedures as part of the interactive (and batch) implementation of PRELIS. However, its main flavour can be summarized by saying that if a model can be formulated as a special case of Jöreskog's general structural model, it can be estimated with LISREL 8.54. This generally holds whether the variables one wishes to use are continuous, ordinal or binary. Naturally, standard conditions such as identification of the model, convergence criteria and admissibility of the solution apply. However, some of these aspects are under the control of the user, e.g. convergence and admissibility can be user-defined or, in the case of admissibility, switched off. For simple applications, formulating the model within the LISREL framework would take far more effort than using a general-purpose package like E-Views or SPSS, especially if the LISREL batch language is used. However, for more complex structural equation models, particularly models including latent variables, the LISREL approach is advantageous.

As an example, the LISREL syntax for maximum likelihood estimation of a structural equation model with nine observed and four latent variables from Cziráky *et al*. (2003b, pp. 12–13)[3] can be written as:

```
DA NI=9 NO=192
LA
y1 y2 y3 y4 x1 x2 y5 y6 y7
SE
```

[3] This example is a regional development model for Slovenia where observations are 192 municipalities and latent variables are economic, structural, social and demographic development factors.


```
1 2 3 4 7 8 9 5 6/
CM=SLO.CM
MO NX=2 NY=7 NK=1 NE=3 BE=FU PS=DI TE=SY
LE
Eta1 Eta2 Eta3
LK
Ksi1
FR LY(3,1) LY(3,2) LY(4,2) LY(4,3)
FR LY(5,1) LY(5,3) LY(7,1) LX(1,1) LX(2,1)
FR BE(1,2) BE(1,3) BE(2,3)
FR TE(4,2)
VA 1 LY(1,1) LY(2,2) LY(6,3)
OU RS ND=3
```

The principal feature of the LISREL command language is the necessity to specify individual elements of the 'LISREL matrices' that should be estimated, although built-in defaults can be used to simplify the syntax. Alternatively, it is possible to use a simpler but less flexible command language, SIMPLIS. The above LISREL code can be written equivalently in the SIMPLIS command language as:

```
Observed variables: y1 y2 y3 y4 x1 x2 y5 y6 y7
Covariance Matrix From File SLO.CM
Sample size: 192
Latent variables: Eta1 Eta2 Eta3 Ksi1
Equations:
y1=1*Eta1
y3 y5 y7=Eta1
y2=1*Eta2
y3 y4=Eta2
y6=1*Eta3
y4 y5=Eta3
x1 x2=Ksi1
Eta1 Eta2 Eta3=Ksi1
Eta1 Eta2=Eta3
Eta1=Eta2
Set the Variance of Ksi1 to 1.00
Set the Error Covariance of y4 and y2 Free
LISREL output: ME=ML RS ND=3
```

Both sets of commands produce the same output. In addition, an interactive path diagram can be built automatically by including a 'path diagram' command in SIMPLIS code or a 'PD' command in LISREL code. Once such a path diagram, or graphical representation of the model, is obtained, a built-in translator can be used to convert it into either SIMPLIS or LISREL syntax. However, this translation is frequently imperfect. In this particular example, an attempt to generate LISREL code results in misspecification of the Θ_ε matrix (the covariance matrix of the latent errors from the endogenous measurement model), which erroneously gets specified as diagonal. That is, the TE = SY command on the MO line, and the line FR TE(4, 2) are omitted. This tends to happen

with models that have correlated errors, and it primarily occurs with the covariance matrices of the latent errors, Θ_ε and Θ_δ. If syntax translation is used only for quick generation of the basic syntax, the level of translation accuracy is generally sufficient.

The LISREL data input can be either in the form of raw data (or PRELIS system file) or in the form of a covariance/correlation matrix (with or without means). In the above example, a covariance matrix from file SLOV.CM was used for estimation. A model-implied covariance structure can be postulated and its coefficients can be estimated from the covariance or correlation matrix calculated directly from data. This means that estimation can be based only on covariance or correlation matrices, except when using the full information maximum likelihood (FIML) method for data with missing values and multilevel structural equation modelling.

Numerical algorithms can be controlled in terms of specifying convergence criteria (i.e. number of steps and admissibility of solution) and significantly improved by a careful application of starting values. LISREL 8.54 is surprisingly fast in estimating complex models, but care must be taken when complicated non-linear covariance structures are estimated. Initial estimates are computed automatically using a 2SLS procedure (if not provided by the user), but experimentation with different starting values might help avoid local minima and misleading solutions.

The LISREL output depends on the syntax used. It can be either in equation format (SIMPLIS) or in matrix format (LISREL). In each case, by default, a large number of fit statistics are printed at the end of the output (see Table I). Since the main evaluation statistics are in the form of the overall fit measures, diagnostics related to raw data should be calculated before LISREL analysis by using PRELIS. The emphasis on fit statistics is a logical inheritance from covariance structure analysis, but there is a notable lack of diagnostic tests, most notably tests for heteroskedasticity, which is a major deficiency given the cross-sectional focus of this package.

6. GRAPHICS

LISREL graphics include path diagrams (i.e. graphical representations of structural equation models) and various descriptive univariate and multivariate plots. The path diagrams are interactive and, in principle, enable estimation of most LISREL models interactively. Path diagrams can be printed and exported in .wmf and .gif formats. Unfortunately, there is no option to save files in PostScript format. The path diagrams can be edited on screen, which is generally necessary since model estimation often generates badly formatted diagrams. The graphical quality of path diagrams should be further improved, especially if the aim of the software is to produce publication-quality output. Quality of the other plots and graphs is relatively good, but still inferior in comparison with graphics produced by packages such as Statistica or PcGive.

7. CONCLUSION

LISREL 8.54 is an advanced package for structural equation modelling that incorporates a number of procedures of high value to applied econometricians. Since its main focus is on cross-sectional models, its usefulness for time-series analysis is currently quite limited.

In view of recent developments such as Bai (2003), which suggest that dynamic latent variable models are gaining in popularity, modelling time-series data is something that should be seriously considered in future development of this package. In particular, economic applications of latent variable models, such as Aasness *et al.* (1993), where LISREL is used for estimation, should be

discussed in the manuals or included among the examples. While applicability of the existing estimation methods to time-series data requires extensive theoretical investigation, some minor improvements, such as commands for creating lagged values and time-series diagnostic tests, might be straightforwardly included. This would significantly improve LISREL's usefulness to economics researchers.

Another current limitation is that the models LISREL can handle are primarily linear. Otherwise, the class of models that can be formulated and estimated with this package is exceptionally rich. Finally, the reliability of version 8.54 is good enough to pass demanding tests. This is a significant improvement over previous releases, especially the very crash-prone 8.50 and 8.51.

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