

# Structural Equation Models

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## Introduction

- Structural-equation models (SEMs) are multiple-equation regression models in which the response variable in one regression equation can appear as an explanatory variable in another equation. Indeed, two variables in an SEM can even effect one-another reciprocally, either directly, or indirectly through a “feedback” loop.
- Structural-equation models can include variables that are not measured directly, but rather indirectly through their effects (called indicators).
- Unmeasured variables are variously termed latent variables, constructs, or factors.

## Confirmatory factor analysis

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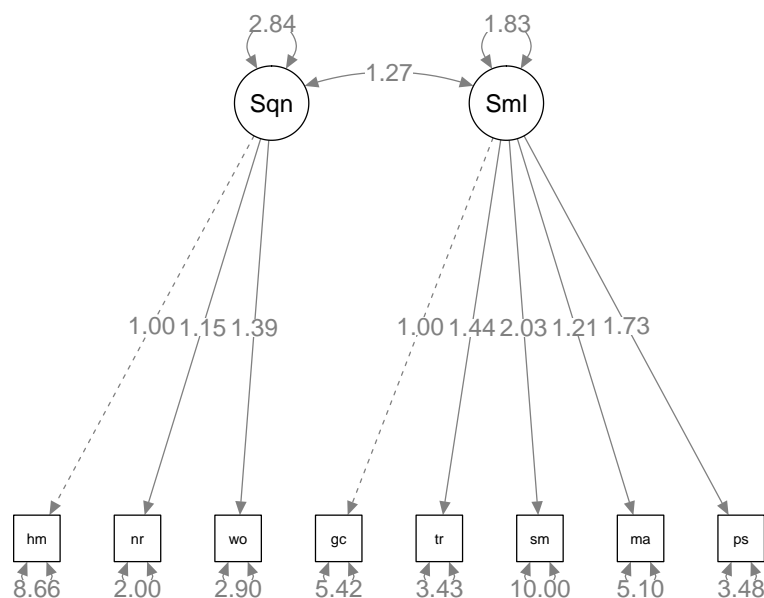
- Confirmatory factor analysis, as the name implies, involves specifying a theoretically motivated model of relationships among variables and factors and carrying out statistical tests to confirm that this model provides an adequate fit to the observed data.
- We can use different assumptions to those standard in exploratory factor analysis.
- Is a special case of Structural Equation Models.
- You can also think of CFA as being “one half” of SEMs, what is often called the *measurement model*.

## CFA example

The Kaufman Assessment Battery for Children is an individually administered cognitive ability test for children. The eight items are claimed to be measures of two factors: sequential processing and simultaneous processing. The former require correct recall of auditory stimuli (nr: Number Recall, wo: Word Order) or visual stimuli (hm: Hand Movements) in a particular order. The latter are intended to measure more holistic, less order-dependent reasoning (gc: Gestalt Closure, tr: Triangles, sm: Spatial Memory, ma: Matrix Analogies, ps: Photo Series). We will perform a CFA using these tests on 200 children aged 10. The covariance matrix is:

	hm	nr	wo	gc	tr	sm	ma	ps
hm	11.56	3.182	3.45	1.928	2.94	5.71	3.71	3.98
nr	3.18	5.760	4.66	0.713	1.75	2.92	2.15	2.09
wo	3.45	4.663	8.41	1.253	2.27	3.41	2.44	3.22
gc	1.93	0.713	1.25	7.290	2.77	3.40	2.34	3.40
tr	2.94	1.750	2.27	2.770	7.29	5.33	3.18	4.70
sm	5.71	2.923	3.41	3.402	5.33	17.64	4.82	6.43
ma	3.71	2.150	2.44	2.344	3.18	4.82	7.84	3.53
ps	3.98	2.088	3.22	3.402	4.70	6.43	3.53	9.00

## CFA with two factors



- Unlike EFA, it is conventional not to assume variance of unobserved factors = 1, but rather to constrain one regression parameter from each factor to = 1. [Additional homework exercise: try constraining variances of unobserved factors to be 1 and freeing all regression parameters. Model fit should be the same.]
- Can do hypothesis tests on regression parameters; all of these are statistically significant.
- Can obtain standardized results if we prefer; these are a closer equivalent to the EFA loadings.
- Also no need to assume no correlation between unobserved factors.
- But it is conventional to assume no correlation between error terms (although this can be relaxed).

## Goodness of fit

- CFA (and more generally SEM) is fit using maximum likelihood estimation, so we obtain the log-likelihood that enable us to compare the relative fit of nested models. Here the log likelihood is -3779.041.
- We can compare that to the log likelihood that would be obtained from a model that reproduces the data perfectly. This is -3759.878. From these two figures, we can calculate the likelihood ratio  $\chi^2$ , which in this case is 38.325 with 19 degrees of freedom.
- The number of degrees of freedom is the number of estimated parameters fewer in the estimated model than there are observed moments in the data. There are always  $k(k+1)/2$  observed second-order moments (ie, variances and covariances), where  $k$  is the number of observed variables, so in this case that is  $8 \times 9 \div 2 = 36$ . There are 17 estimated parameters: 6 regression parameters, 8 variances of measured variables, 2 variances and 1 covariance of unobserved factors. That gives  $36 - 17 = 19$  degrees of freedom.
- Gives p-value of 0.005. That means we would have to conclude this model does not fit the data.

## Other GoF statistics

- **RMSEA** This is actually a “badness of fit” statistic, so we want values close to 0. Measures size of discrepancy from *close fit*, defined as  $\hat{\Delta}_{model} = \max(0, \chi^2_{model} - df_{model})$ . This is then standardized, to give the RMSEA statistic:

$$\hat{\epsilon} = \sqrt{\frac{\hat{\Delta}_{model}}{df_{model}(N - 1)}}.$$

- **CFI** Ranges from 0 to 1. Compares estimated model to null model, using the same  $\hat{\Delta}$  as before:

$$CFI = 1 - \frac{\hat{\Delta}_{model}}{\hat{\Delta}_{null}}.$$

Commonly cited rule is that  $CFI > 0.95$ , implying a fit that is 95% better than the null model. The TLI and NNFI are variants on this index.

- **SRMR** Standardised root mean square residual, where the residual is the difference between observed and fitted correlation matrices. Rule of thumb is that  $SRMR > 0.10$  may indicate a poor fit, but it is a good idea to look at the residual matrix itself.

## GoF statistics

npar	fmin	chisq
17.000	0.096	38.325
df	pvalue	baseline.chisq
19.000	0.005	498.336
baseline.df	baseline.pvalue	cfi
28.000	0.000	0.959
tli	nnfi	rfi
0.939	0.939	0.887
nfi	pnfi	ifi
0.923	0.626	0.960
rni	logl	unrestricted.logl
0.959	-3779.041	-3759.878
aic	bic	ntotal
7592.082	7648.153	200.000
bic2	rmsea	rmsea.ci.lower
7594.295	0.071	0.038
rmsea.ci.upper	rmsea.pvalue	rmr
0.104	0.132	0.767
rmr_nomean	srmr	srmr_bentler
0.767	0.072	0.072
srmr_bentler_nomean	srmr_bollen	srmr_bollen_nomean
0.072	0.072	0.072
srmr_mplus	srmr_mplus_nomean	cn_05
0.072	0.072	158.306
cn_01	gfi	agfi
189.864	0.956	0.917
pgfi	mfi	ecvi
0.505	0.953	0.362

# GoF rules of thumb

Statistic	Rule of thumb	Comments
$\chi^2$	Not significant (ie, p-value > .05)	Influenced by sample size.
CFI	More than 0.93	Compares model to the independence model. Relatively insensitive to sample size, but biased. Must lie between 0 and 1
RMSEA	Less than .08, ideally less than .05	Has no upper bound, so hard to interpret.
TLI	Greater than .9 or .95	Compares to null model, but controls for complexity. Relatively insensitive to sample size.
AIC		Only useful for comparing models. Controls for model complexity.
BIC		Similar to AIC, with greater penalty for complexity

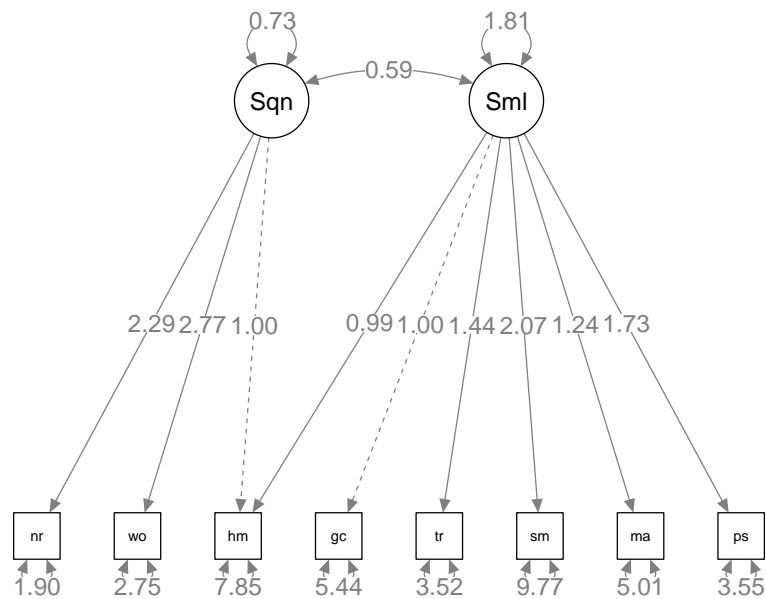
Not clear which measure is “best”, so good idea to look at more than one. There are many others that you might see used in articles, but these are the most common. In the example, most show inadequate fit.

## Modification indices

	lhs	op	rhs	mi	epc	sepc.lv	sepc.all	sepc.nox
25	Simultan	=~	hm	20.10	1.054	1.428	0.421	0.421
35	nr	~~	wo	20.10	4.741	4.741	0.685	0.685
26	Simultan	=~	nr	7.01	-0.510	-0.691	-0.289	-0.289
29	hm	~~	wo	7.01	-1.746	-1.746	-0.178	-0.178
32	hm	~~	sm	4.85	1.609	1.609	0.113	0.113
33	hm	~~	ma	3.80	0.995	0.995	0.105	0.105
23	Sequent	=~	ma	3.25	0.269	0.454	0.162	0.162
40	nr	~~	ps	3.15	-0.502	-0.502	-0.070	-0.070
20	Sequent	=~	gc	2.90	-0.254	-0.429	-0.159	-0.159
55	ma	~~	ps	2.73	-0.733	-0.733	-0.088	-0.088

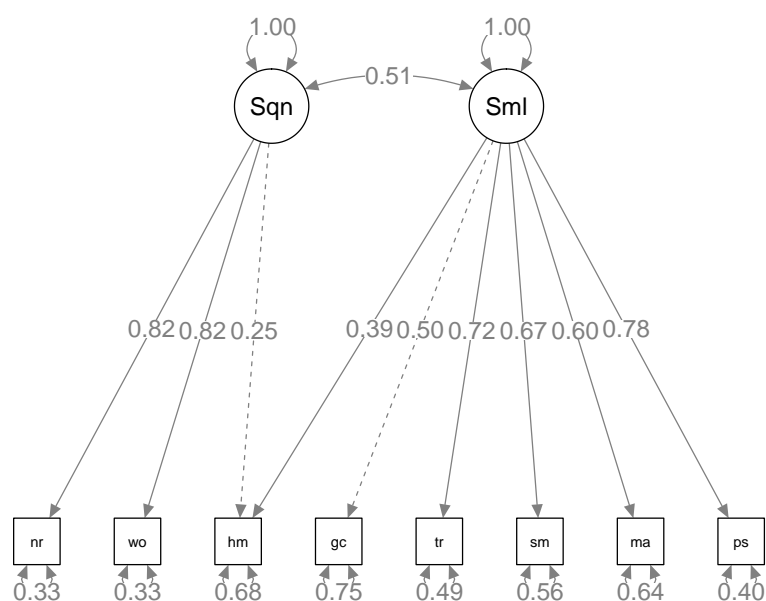
These show the effect of freeing a constrained parameter. We may then choose to modify our model accordingly.

# Modified model



chisq	df	pvalue	cfi	rmsea	gfi	tli
18.108	18.000	0.449	1.000	0.005	0.977	1.000

# Standardized results



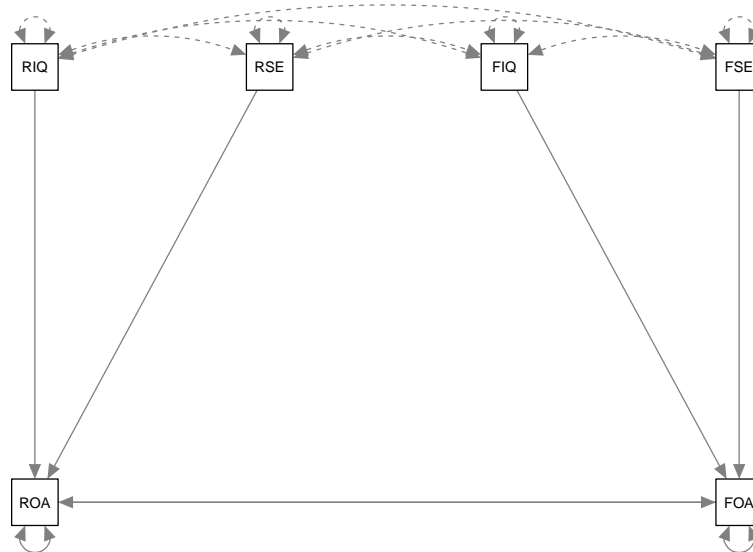
## Path models

## Path models

Path models have only observed variables, but they differ from the regression models we've seen so far in that they allow us to model indirect and reciprocal effects as well as direct effects. Models with reciprocal effects are known as *nonrecursive* models. The following example is Duncan, Haller, and Portes's (nonrecursive) peer-influences model. It is based on a sample of Michigan high school students. It is an example of a general class of peer influence models that acknowledge that if I am influencing my peers (e.g., my best friend), then he or she could be influencing me.



# Path diagram



Duncan, Haller, and Portes's (nonrecursive) peer-influences model: RIQ: respondent's IQ; RSE: respondent's family SES; FSE: best friend's family SES; FIQ: best friend's IQ; ROA: respondent's occupational aspiration; FOA: best friend's occupational aspiration.

## Results

lavaan (0.5-23.1097) converged normally after 14 iterations

Number of observations	329
Estimator	ML
Minimum Function Test Statistic	20.620
Degrees of freedom	3
P-value (Chi-square)	0.000

Parameter Estimates:

Information	Expected
Standard Errors	Standard

Regressions:

	Estimate	Std.Err	z-value	P(> z )
ROccAsp ~				
RIQ	0.315	0.051	6.226	0.000
RSES	0.200	0.050	3.999	0.000
FOccAsp	0.176	0.077	2.304	0.021
FOccAsp ~				
FIQ	0.437	0.049	8.862	0.000
FSES	0.283	0.048	5.920	0.000
ROccAsp	-0.003	0.074	-0.038	0.970

Variances:

	Estimate	Std.Err	z-value	P(> z )
.ROccAsp	0.746	0.058	12.826	0.000
.FOccAsp	0.657	0.054	12.161	0.000

cfi	rmsea	srmr
0.928	0.134	0.046

# Add covariance between the two error terms

lavaan (0.5-23.1097) converged normally after 24 iterations

Number of observations	329
Estimator	ML
Minimum Function Test Statistic	2.820
Degrees of freedom	2
P-value (Chi-square)	0.244

Parameter Estimates:

Information	Expected
Standard Errors	Standard

Regressions:

	Estimate	Std.Err	z-value	P(> z )
R0ccAsp ~				
RIQ	0.237	0.053	4.480	0.000
RSES	0.176	0.047	3.728	0.000
F0ccAsp	0.398	0.104	3.816	0.000
F0ccAsp ~				
FIQ	0.311	0.056	5.598	0.000
FSES	0.219	0.047	4.689	0.000
R0ccAsp	0.422	0.131	3.215	0.001

Covariances:

	Estimate	Std.Err	z-value	P(> z )
.R0ccAsp ~~				
.F0ccAsp	-0.494	0.136	-3.634	0.000

Variances:

	Estimate	Std.Err	z-value	P(> z )
.R0ccAsp	0.790	0.074	10.749	0.000
.F0ccAsp	0.715	0.086	8.272	0.000

cfi rmsea srmr  
0.997 0.035 0.013

## Structural equation models

# Types of variables

Several classes of variables appear in SEMs:

- Endogenous variables are the response variables of the model.
  - There is one structural equation (regression equation) for each endogenous variable.
  - An endogenous variable may, however, also appear as an explanatory variable in other structural equations.
  - For the kinds of models that we will consider, the endogenous variables are (as in the single-equation linear model) quantitative continuous variables.
- Exogenous variables appear only as explanatory variables in the structural equations.
  - The values of exogenous variable are therefore determined outside of the model (hence the term).

## Types of variables 2

- Structural errors (or disturbances) represent the aggregated omitted causes of the endogenous variables, along with measurement error (and possibly intrinsic randomness) in the endogenous variables.
  - There is one error variable for each endogenous variable (and hence for each structural equation).
  - The errors are assumed to have zero expectations and to be independent of (or at least uncorrelated with) the exogenous variables.
  - The errors for different observations are assumed to be independent of one another, but (depending upon the form of the model) different errors for the same observation may be related.

That is, a structural equation model can contain some or all of the following:

- Exogenous concepts (unobserved);
- Endogenous concepts (unobserved);
- Indicators of exogenous concepts;
- Indicators of endogenous concepts;
- Structural errors;
- Measurement errors;
- Structural parameters
- Covariances

## LISREL

There are three basic equations in a SEM. These are shown using the notation that is standard in LISREL, the first and most well-known computer software for analysing these models:

$$\eta = \beta\eta + \Gamma\xi + \zeta$$

$$y = \Lambda_y\eta + \epsilon$$

$$x = \Lambda_x\xi + \delta$$

# Meanings

These terms have the following meaning:

- $\eta$ : Endogenous concepts.
- $\beta$ : Structural coefficients for the relationships among endogenous concepts.
- $\xi$ : Exogenous concepts.
- $\Gamma$ : Structural coefficients for the relationships between exogenous and endogenous concepts.
- $\zeta$ : Structural errors.
- $x$  and  $y$ : Observed exogeneous and endogenous indicators, respectively.
- $\Lambda_y$ : Structural coefficients relating indicators to endogenous concepts.
- $\epsilon$  and  $\delta$ : Measurement errors.
- $\Lambda_x$ : Structural coefficients relating indicators to exogenous concepts.

# Covariance matrices

In addition, the following covariance matrices are defined:

- $\Phi$ : Covariances among the concepts.
- $\Psi$ : Covariances among the structural errors.
- $\Theta_\epsilon$ : Covariances among the  $\epsilon$  measurement errors.
- $\Theta_\delta$ : Covariances among the  $\delta$  measurement errors.

# Assumptions of general SEM

- The measurement errors,  $\delta$  and  $\epsilon$ ,
  - have expectations of 0;
  - are each multivariately-normally distributed;
  - are independent of each other;
  - are independent of the latent exogenous variables ( $\xi$ ), latent endogenous variables ( $\eta$ ), and structural disturbances ( $\zeta$ ).
- The N observations are independently sampled.
- The latent exogenous variables,  $\xi$ , are multivariate normal.
- This assumption is unnecessary for exogenous variables that are measured without error.

## Assumptions 2

- The structural disturbances,  $\zeta$ 
  - have expectation 0;
  - are multivariately-normally distributed;
  - are independent of the latent exogenous variables ( $\xi$ 's).
- Under these assumptions, the observable indicators,  $x$  and  $y$ , have a multivariate-normal distribution.

$$\begin{bmatrix} X_i \\ Y_i \end{bmatrix} \sim N_{q+p}(\mathbf{0}, \Sigma)$$

where  $\Sigma$  represents the population covariance matrix of the indicators.

# Identification of SEMs

Identification of models with latent variables is a complex problem without a simple general solution.

- A global necessary condition for identification is that the number of free parameters in the model can be no larger than the number of variances and covariances among observed variables,

$$\frac{(k)(k + 1)}{2}$$

- This condition is insufficiently restrictive to give us any confidence that a model that meets the condition is identified.
- That is, it is easy to meet this condition and still have an underidentified model.

## Useful rule

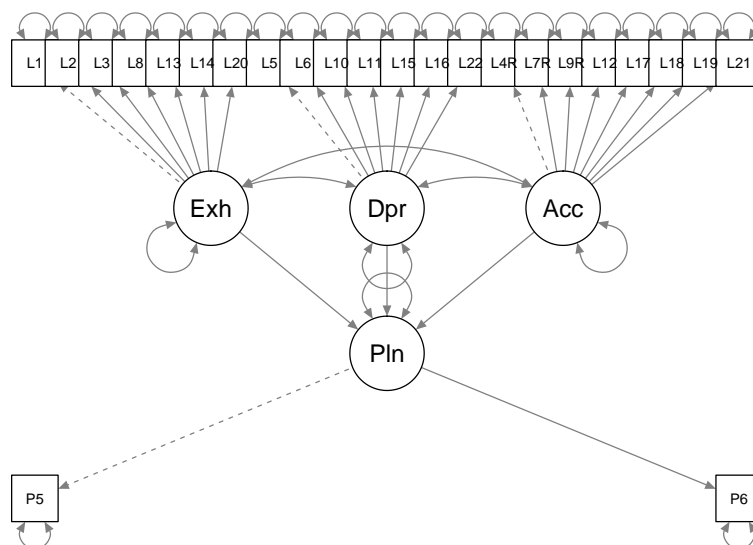
A useful rule that sometimes helps is that a model is identified if:

- 1 all of the measurement errors in the model are uncorrelated with one another;
- 2 there are at least two unique indicators for each latent variable, or if there is only one indicator for a latent variable, it is measured without error;
- 3 the structural sub model would be identified were it an observed variable model

The variances and covariances of the observed variables ( $\Sigma$ ) are functions of the parameters of the SEM ( $\beta$ ,  $\Gamma$ ,  $\Lambda_x$ ,  $\Lambda_y$ ,  $\Phi$ ,  $\Theta_\delta$ ,  $\Theta_\epsilon$ , and  $\Psi$ ).

- In any particular model, there will be restrictions on many of the elements of the parameter matrices.
- Most commonly, these restrictions are exclusions: certain parameters are prespecified to be 0.
- The  $\Lambda$  matrices (or the  $\Psi$  matrix) must contain normalizing restrictions to set the metrics of the latent variables.
- If the restrictions on the model are sufficient to identify it, then MLEs of the parameters can be found.

## SEM example





## Model explained

- There are three exogenous latent variables ( $\xi$ ); these are the three components of burnout as measured by the Maslach Burnout Inventory.
- Each exogenous latent variable has a number of exogenous indicators ( $x$ ), 22 in all.
- Each indicator has a path with a coefficient ( $\Lambda_x$ ). One per latent variable is fixed to 1, so there are  $22 - 3 = 19$  free parameters.
- Each of the exogenous indicators has an error ( $\delta$ ).
- There is one endogenous latent variable ( $\eta$ ), the career plans of a nurse.
- There is a path between each exogenous latent variable and the endogenous latent variable ( $\Gamma$ )

## Continued

- The endogenous latent variable has a structural error ( $\zeta$ ).
- The endogenous latent variable has two indicators ( $y$ ).
- The endogenous indicators have error terms ( $\epsilon$ ).
- Each indicator has a path with a coefficient ( $\Lambda_y$ ), one of which will be set to one, so there is 1 free parameter.
- There are 3 covariances between the exogenous concepts and 3 variances ( $\Phi$ ), so 6 free parameters.
- Covariances among the  $\delta$  measurement errors are zero (that is,  $\Theta_\delta$  is a diagonal matrix with 22 free parameters).
- Covariances among the  $\epsilon$  measurement errors are zero (that is,  $\Theta_\epsilon$  is a diagonal matrix with 2 free parameters).
- There is only one structural error, so  $\Psi$  is just a single free parameter.

# Specification

There are 24 observed variables, and hence there are  $24 \times 25 \div 2 = 300$  observed variances and covariances. There are 54 free parameters to be estimated. Therefore there are  $300 - 54 = 246$  degrees of freedom.

```
mas_mod <- ' Exhaust =~ L1 + L2 + L3 + L8 + L13 + L14 + L20
Depers =~ L5 + L6 + L10 + L11 + L15 + L16 + L22
Accomp =~ L4R + L7R + L9R + L12R + L17R + L18R + L19R + L21R
Plans =~ P5 + P6
Plans ~ Exhaust + Depers + Accomp '
```

# Results

lhs	op	rhs	est	se
Exhaust	=~	L1	1.000	0.000
Exhaust	=~	L2	0.938	0.044
Exhaust	=~	L3	1.214	0.056
Exhaust	=~	L8	1.322	0.055
Exhaust	=~	L13	0.997	0.055
Exhaust	=~	L14	1.011	0.058
Exhaust	=~	L20	0.799	0.053
Depers	=~	L5	1.000	0.000
Depers	=~	L6	0.855	0.070
Depers	=~	L10	1.565	0.091
Depers	=~	L11	1.531	0.089
Depers	=~	L15	0.544	0.045
Depers	=~	L16	0.456	0.043
Depers	=~	L22	0.910	0.082
Accomp	=~	L4R	1.000	0.000
Accomp	=~	L7R	1.435	0.128
Accomp	=~	L9R	1.740	0.150
Accomp	=~	L12R	1.404	0.148
Accomp	=~	L17R	1.561	0.142
Accomp	=~	L18R	1.828	0.167
Accomp	=~	L19R	1.869	0.157
Accomp	=~	L21R	1.585	0.146
Plans	=~	P5	1.000	0.000
Plans	=~	P6	1.571	0.125
Plans	~	Exhaust	-0.151	0.022
Plans	~	Depers	-0.131	0.033
Plans	~	Accomp	-0.138	0.043

## Results, continued

	lhs	op	rhs	est	se
28	L1	~~	L1	1.674	0.086
29	L2	~~	L2	1.005	0.055
30	L3	~~	L3	1.495	0.083
31	L8	~~	L8	0.853	0.061
32	L13	~~	L13	2.231	0.111
33	L14	~~	L14	2.600	0.129
34	L20	~~	L20	2.585	0.124
35	L5	~~	L5	1.475	0.075
36	L6	~~	L6	1.763	0.086
37	L10	~~	L10	0.956	0.068
38	L11	~~	L11	0.963	0.067
39	L15	~~	L15	0.751	0.036
40	L16	~~	L16	0.791	0.038
41	L22	~~	L22	2.738	0.131
42	L4R	~~	L4R	1.165	0.058
43	L7R	~~	L7R	1.291	0.069
44	L9R	~~	L9R	1.519	0.084
45	L12R	~~	L12R	2.725	0.134
46	L17R	~~	L17R	1.690	0.088
47	L18R	~~	L18R	2.434	0.127
48	L19R	~~	L19R	1.387	0.081
49	L21R	~~	L21R	1.880	0.097
50	P5	~~	P5	0.355	0.029
51	P6	~~	P6	0.255	0.062
52	Exhaust	~~	Exhaust	1.562	0.133
53	Depers	~~	Depers	0.747	0.083
54	Accomp	~~	Accomp	0.316	0.047
55	Plans	~~	Plans	0.254	0.027
56	Exhaust	~~	Depers	0.548	0.055
57	Exhaust	~~	Accomp	0.069	0.028
58	Depers	~~	Accomp	0.143	0.023

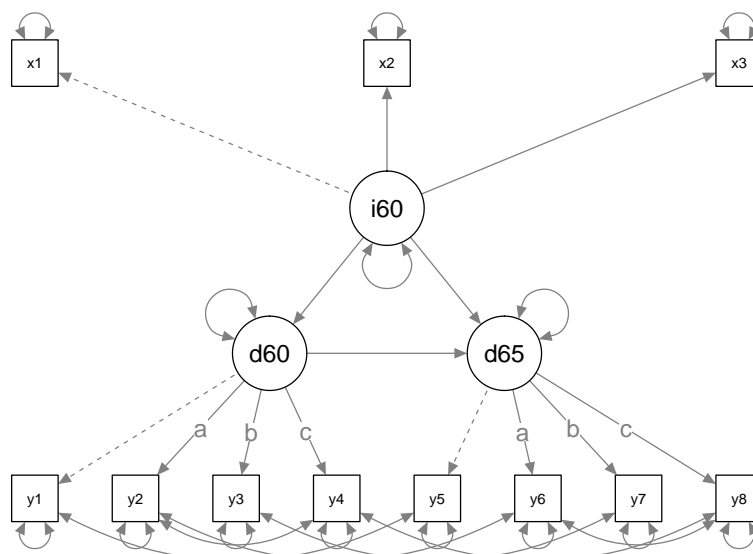
## Interpretation

High numbers of the 'Plans' variable mean more likely to stay in nursing, so the interpretation of these results is that each component of burnout reduces the chances that a nurse will remain in nursing. All those parameter estimates are statistically significant.

chisq	df	pvalue	cfi	rmsea	srmr
1301.136	246.000	0.000	0.860	0.067	0.074

	lhs	op	rhs	mi	epc	sepc.lv	sepc.all	sepc.nox
302	L10	~~	L11	124.0	0.786	0.786	0.286	0.286
69	Exhaust	==	L12R	116.8	0.509	0.636	0.348	0.348
362	L4R	~~	L7R	116.0	0.489	0.489	0.288	0.288
290	L6	~~	L16	104.1	0.413	0.413	0.279	0.279
131	L1	~~	L2	57.2	0.381	0.381	0.137	0.137
86	Depers	==	L12R	47.0	0.509	0.440	0.241	0.241
95	Accomp	==	L3	43.1	0.580	0.326	0.167	0.167
158	L2	~~	L20	38.8	-0.368	-0.368	-0.126	-0.126
80	Depers	==	L13	38.4	0.481	0.416	0.214	0.214
225	L13	~~	L22	34.7	0.500	0.500	0.140	0.140

# Political Democracy example



## Note

- Data from 75 countries
- Two endogenous concepts ( $\eta$ ), Democracy in 1960 and in 1965.
- Each  $\eta$  has four indicators ( $y$ ); press freedom, freedom of political opposition, fairness of elections, effectiveness of elected legislature
- One exogenous concept ( $\xi$ ), Industrialisation in 1960.
- This has three indicators ( $x$ ): GNP per capita, energy consumption per capita, percentage of labour force in industry.
- One  $\beta$  parameter and two  $\Gamma$  parameters.
- This model specifies some correlations between error terms (ie,  $\Lambda_\epsilon$  is *not* a diagonal matrix).
- This model constrains some parameters in the measurement model to be equal.
- There are 66 observed moments and 28 parameters to be estimated, so 38 degrees of freedom.

# Results

lhs	op	rhs	label	est	se
ind60	=~	x1		1.000	0.000
ind60	=~	x2		2.180	0.138
ind60	=~	x3		1.818	0.152
dem60	=~	y1		1.000	0.000
dem60	=~	y2	a	1.191	0.139
dem60	=~	y3	b	1.175	0.120
dem60	=~	y4	c	1.251	0.117
dem65	=~	y5		1.000	0.000
dem65	=~	y6	a	1.191	0.139
dem65	=~	y7	b	1.175	0.120
dem65	=~	y8	c	1.251	0.117
dem60	~	ind60		1.471	0.392
dem65	~	ind60		0.600	0.226
dem65	~	dem60		0.865	0.075
y1	~~	y5		0.583	0.356
y2	~~	y4		1.440	0.689
y2	~~	y6		2.183	0.737
y3	~~	y7		0.712	0.611
y4	~~	y8		0.363	0.444
y6	~~	y8		1.372	0.577
x1	~~	x1		0.081	0.019
x2	~~	x2		0.120	0.070
x3	~~	x3		0.467	0.090
y1	~~	y1		1.855	0.433
y2	~~	y2		7.581	1.366
y3	~~	y3		4.956	0.956
y4	~~	y4		3.225	0.723
y5	~~	y5		2.313	0.479
y6	~~	y6		4.968	0.921
y7	~~	y7		3.560	0.710
y8	~~	y8		3.308	0.704
ind60	~~	ind60		0.449	0.087
dem60	~~	dem60		3.875	0.866
dem65	~~	dem65		0.164	0.227

# Goodness of fit

npar	fmin	chisq
28.000	0.268	40.179
df	pvalue	baseline.chisq
38.000	0.374	730.654
baseline.df	baseline.pvalue	cfi
55.000	0.000	0.997
tli	nnfi	rfi
0.995	0.995	0.920
nfi	pnfi	ifi
0.945	0.653	0.997
rni	logl	unrestricted.logl
0.997	-1548.818	-1528.728
aic	bic	ntotal
3153.636	3218.526	75.000
bic2	rmsea	rmsea.ci.lower
3130.277	0.028	0.000
rmsea.ci.upper	rmsea.pvalue	rmr
0.087	0.665	0.477
rmr_nomean	srmr	srmr_bentler
0.477	0.056	0.056
srmr_bentler_nomean	srmr_bollen	srmr_bollen_nomean
0.056	0.047	0.047
srmr_mplus	srmr_mplus_nomean	cn_05
0.050	0.050	100.647
cn_01	gfi	agfi
115.167	0.920	0.861
pgfi	mfi	ecvi
0.530	0.986	1.282

## Extras

## Definitions of GoF statistics

Statistic	Definition	Criterion
GFI	$1 - [\chi^2_{model} / \chi^2_{null}]$	$> 0.9$
NFI	$[\chi^2_{null} - \chi^2_{model}] / \chi^2_{null}$	$> 0.95$
RFI	$1 - [(\chi^2_{model} / df_{model}) / (\chi^2_{null} / df_{null})]$	
IFI	$(\chi^2_{null} - \chi^2_{model}) / (\chi^2_{null} - df_{model})$	
TLI	$[(\chi^2_{null} / df_{null}) - (\chi^2_{model} / df_{model})] / [(\chi^2_{null} / df_{null}) - 1]$	
CFI	$1 - [(\chi^2_{model} - df_{model}) / (\chi^2_{null} - df_{null})]$	$> 0.95$
Model AIC	$\chi^2_{model} + 2q(\text{number of free parameters})$	
Null AIC	$\chi^2_{null} + 2q(\text{number of free parameters})$	
RMSEA	$\sqrt{[\chi^2_{model} - df_{model}] / [(N - 1)df_{model}]}$	$< 0.07$