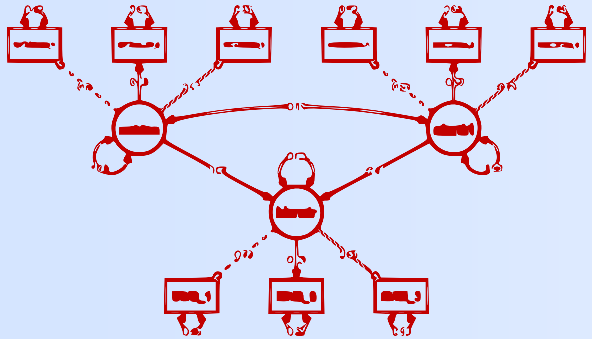
TALLER Introducción a los modelos de ecuaciones estructurales en R



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Mayo 2021

UNIVERSIDAD DE MURCIA

UMUR

gauss.inf.um.es/umur/

MODELOS DE ECUACIONES ESTRUCTURALES

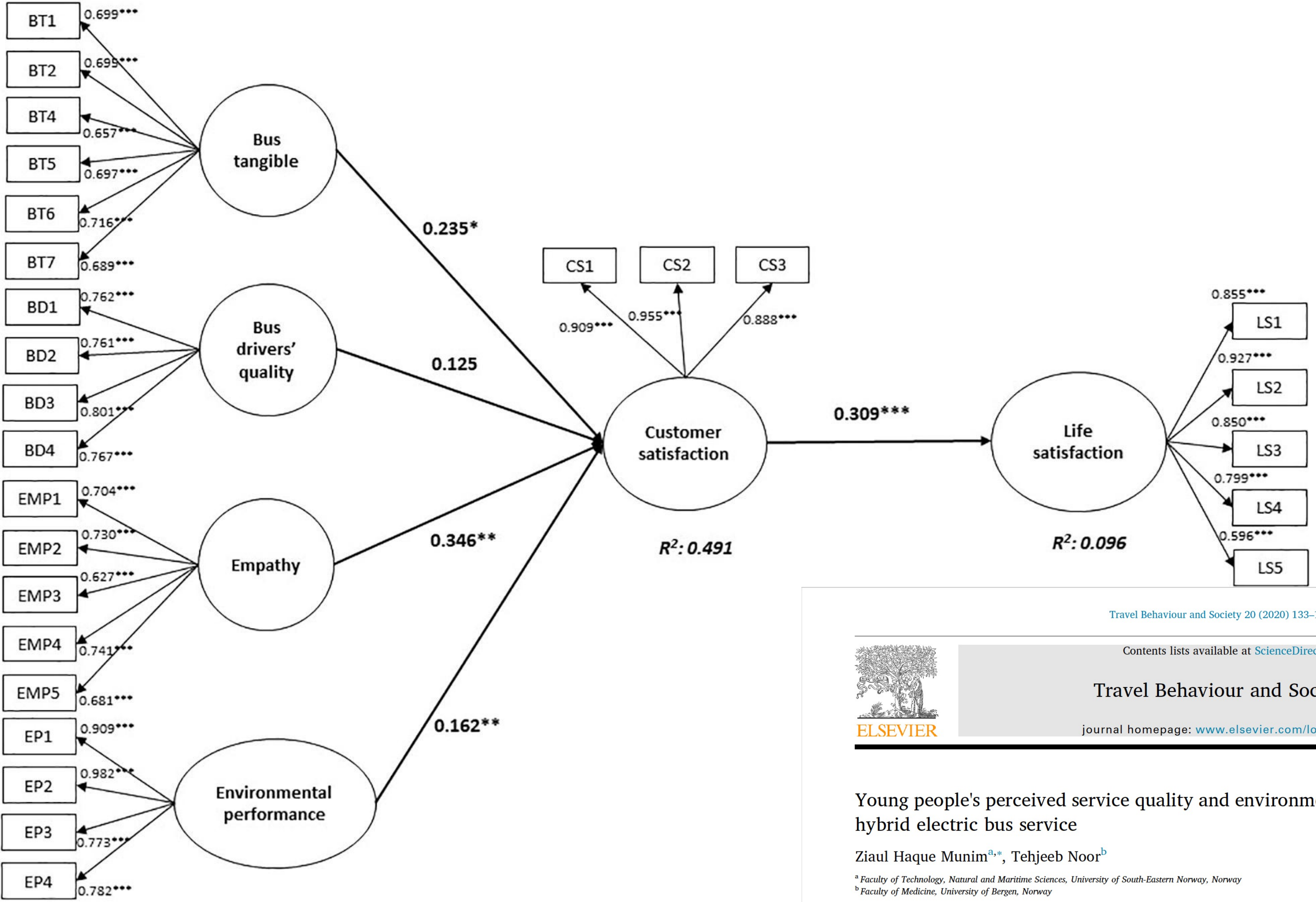
- "Los modelos de ecuaciones estructurales puede definirse como una clase de metodologías que busca representar hipótesis sobre las medias, varianzas y covarianzas de los datos observados en términos de un número número de parámetros 'estructurales' definidos por un modelo conceptual o teórico subyacente".

(Kaplan, 2001, p. 15215)

- Metodología más usada: Modelos de estructuras de covarianza (CB-SEM)

VENTAJAS

- Permite contrastar hipótesis de relaciones entre variables (modelo)
- Permite utilizar variables latentes medidas a través de variables observadas (escalas)
- Los modelos se representan con diagramas que permiten una visión global del bloque de relaciones planteado
- Permite estimar efectos directos e indirectos
- Permite comparaciones multigrupo
- etc.



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Young people's perceived service quality and environmental performance of hybrid electric bus service

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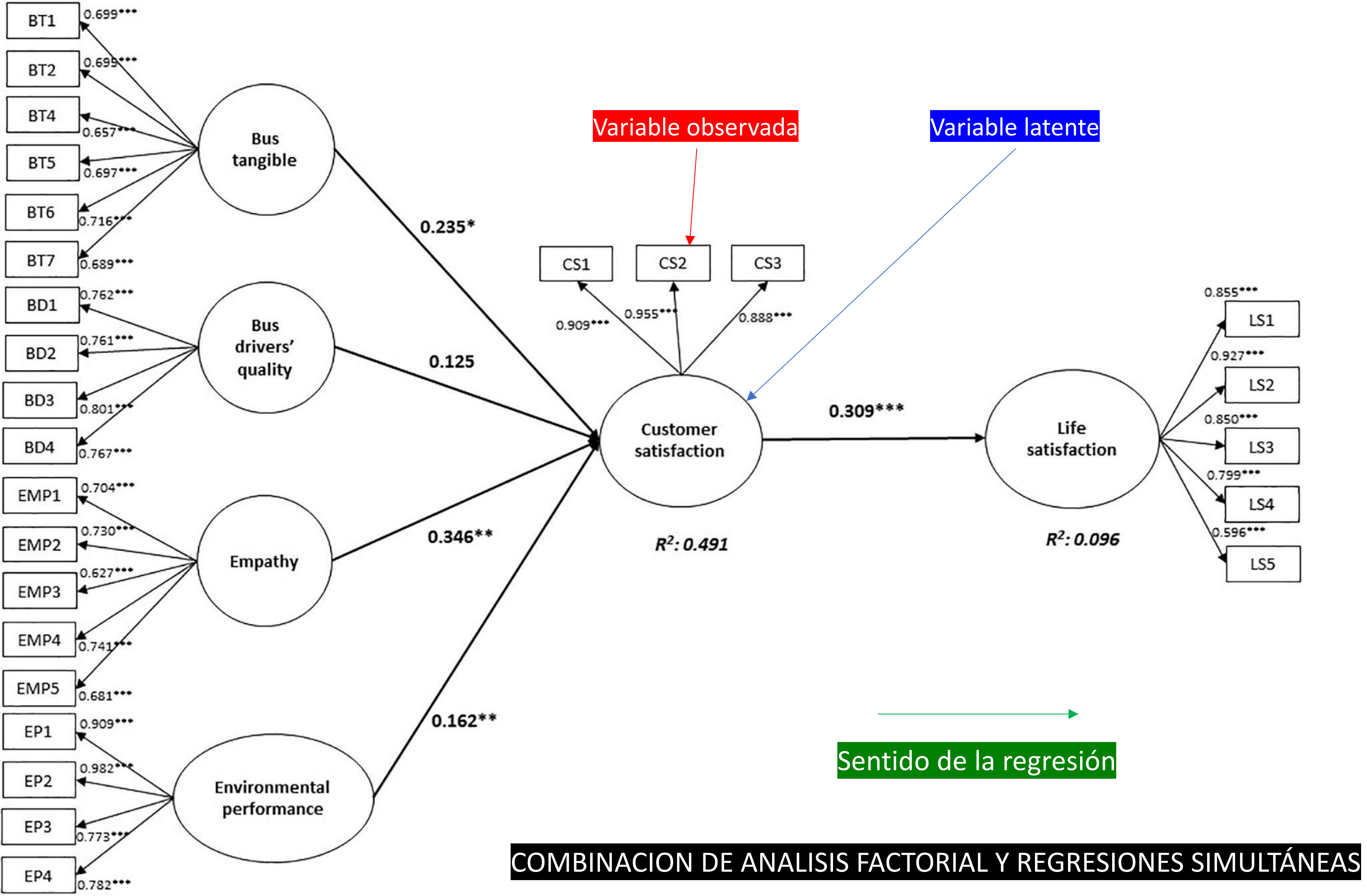
[b] Faculty of Medicine, University of Bergen, Norway



BT1
BT2
BT4
BT5
BT6
BT7
BD1
BD2
BD3
BD4
EMP1
EMP2
EMP3
EMP4
EMP5
EP1
EP2
EP3
EP4
0.699***
0.699***
0.657***
0.697***
0.716***
0.689***
0.762***
0.761***
0.801***
0.767***
0.704***
0.730***
0.627***
0.741***
0.681***
0.909***
0.982***
0.773***
0.782***
Bus tangible
Bus drivers' quality
Empathy
Environmental performance
0.235*
0.125
0.346**
0.162**
Variable observada
Variable latente
CS1
CS2
CS3
0.909***
0.955***
0.888***
Customer satisfaction
R^2: 0.491
0.309***
Life satisfaction
R^2: 0.096
LS1
LS2
LS3
LS4
LS5
0.855***
0.927***
0.850***
0.799***
0.596***
Sentido de la regresión
COMBINACION DE ANALISIS FACTORIAL Y REGRESIONES SIMULTÁNEAS

PROCEDIMIENTO

- ESPECIFICACIÓN DEL MODELO (sobre la base de la teoría y las hipótesis planteadas)
- ESTIMACIÓN DEL MODELO DE MEDIDA
- EVALUACIÓN DEL MODELO DE MEDIDA
- FIABILIDAD Y VALIDEZ
- ESTIMACIÓN DEL MODELO ESTRUCTURAL
- EVALUACIÓN DEL MODELO ESTRUCTURAL

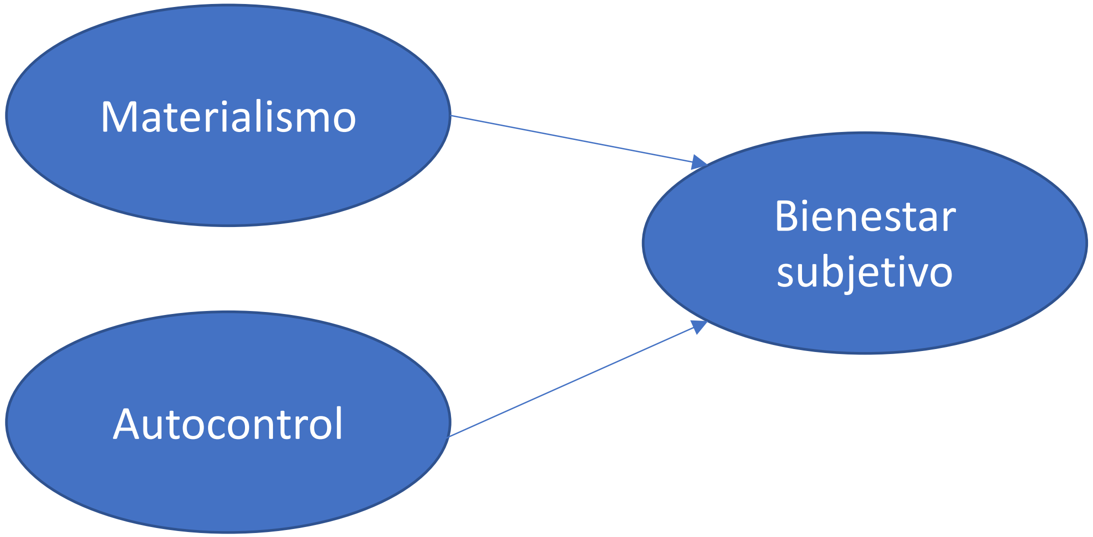
Veamos un ejemplo

PROCEDIMIENTO

- ESPECIFICACIÓN DEL MODELO (sobre la base de la teoría y las hipótesis planteadas)

PROCEDIMIENTO: ESPECIFICACION DEL MODELO (sobre la base de la teoría y las hipótesis planteadas)

- Encuesta de bienestar financiero
- https://www.consumerfinance.gov/data-research/financial-well-being-survey-data/
- Hipotesis: los rasgos de personalidad afectan al bienestar financiero del individuo



PROCEDIMIENTO: ESTIMACIÓN DEL MODELO DE MEDIDA

- Bienestar subjetivo: 3 items (1 = muy en desacuerdo, 7= muy de acuerdo)
  - Ejemplo: estoy satisfecho/a con mi vida
- Materialismo: 3 items (1 = muy en desacuerdo, 7= muy de acuerdo)
  - Ejemplo: admire a la gente que tiene casas, coches y ropa cara
- Bienestar subjetivo: 3 items (1 = muy en desacuerdo, 7= muy de acuerdo)
  - Ejemplo: A menudo actuo sin considerar todas las alternativas

PROCEDIMIENTO

- ESPECIFICACIÓN DEL MODELO (sobre la base de la teoría y las hipótesis planteadas)
- ESTIMACIÓN DEL MODELO DE MEDIDA

PROCEDIMIENTO: ESTIMACIÓN DEL MODELO DE MEDIDA

- Mediante ANALISIS FACTORIAL CONFIRMATORIO (AFC)

```
library(lavaan)
```

lavaan: Latent Variable Analysis

Fit a variety of latent variable models, including confirmatory factor analysis, structural equation modeling and latent growth curve models.

Version:	0.6-8
Depends:	R (≥ 3.4)
Imports:	methods, stats4, stats, utils, graphics, MASS, mnormt, pbivnorm, numDeriv
Published:	2021-03-10
Author:	Yves Rosseel [aut, cre], Terrence D. Jorgensen [aut], Nicholas Rockwood [aut], Daniel Oberski [ctb], Jarrett Byrnes [ctb], Leonard Vanbrabant [ctb], Victoria Savalei [ctb], Ed Merkle [ctb], Michael Hallquist [ctb], Mijke Rhemtulla [ctb], Myrsini Katsikatsou [ctb], Mariska Barendse [ctb], Florian Scharf [ctb], Han Du [ctb]
Maintainer:	Yves Rosseel <Yves.Rosseel at UGent.be>
License:	GPL-2 | GPL-3 [expanded from: GPL (≥ 2)]
URL:	https://lavaan.ugent.be
NeedsCompilation:	no
Citation:	lavaan citation info
Materials:	README
In views:	Econometrics, MissingData, OfficialStatistics, Psychometrics
CRAN checks:	lavaan results

PROCEDIMIENTO: ESTIMACIÓN DEL MODELO DE MEDIDA

- Mediante ANALISIS FACTORIAL CONFIRMATORIO (AFC)

```
modeloAFC <- '
# modelo de medida
swb =~ SWB_1 + SWB_2 + SWB_3
mat =~ MATERIALISM_1 + MATERIALISM_2 + MATERIALISM_3
selfc =~ SELFCONTROL_1 + SELFCONTROL_2 + SELFCONTROL_3
'
```

PROCEDIMIENTO: ESTIMACIÓN DEL MODELO DE MEDIDA

- Mediante ANALISIS FACTORIAL CONFIRMATORIO (AFC)

```
fitAFC <- cfa(modeloAFC, data = mydata, estimator = "MLM")
summary(fitAFC, fit.measures = TRUE)
fitMeasures(fitAFC)
inspect (fitAFC, "cor.lv")
inspect (fitAFC, "cor.ov")
standardizedSolution(fitAFC)
MI <- modificationIndices(fitAFC)
subset(MI, mi > 4)
```

Estimación de los parámetros del modelo:
Redución de la discrepancia entre la matriz de covarianzas observada y la derivada del modelo estimado.

PROCEDIMIENTO: ESTIMACIÓN DEL MODELO DE MEDIDA

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```

Estimators

If all data is continuous, the default estimator in the lavaan package is maximum likelihood (`estimator = "ML"`). Alternative estimators available in lavaan are:

- `"GLS"`: generalized least squares. For complete data only.
- `"WLS"`: weighted least squares (sometimes called ADF estimation). For complete data only.
- `"DWLS"`: diagonally weighted least squares
- `"ULS"`: unweighted least squares
- `"DLS"`: distributionally-weighted least squares
- `"PML"`: pairwise maximum likelihood

Many estimators have 'robust' variants, meaning that they provide robust standard errors and a scaled test statistic. For example, for the maximum likelihood estimator, lavaan provides the following robust variants:

- `"MLM"`: maximum likelihood estimation with robust standard errors and a Satorra-Bentler scaled test statistic. For complete data only.
- `"MLMVS"`: maximum likelihood estimation with robust standard errors and a mean- and variance adjusted test statistic (aka the Satterthwaite approach). For complete data only.
- `"MLMV"`: maximum likelihood estimation with robust standard errors and a mean- and variance adjusted test statistic (using a scale-shifted approach). For complete data only.
- `"MLF"`: for maximum likelihood estimation with standard errors based on the first-order derivatives, and a conventional test statistic. For both complete and incomplete data.
- `"MLR"`: maximum likelihood estimation with robust (Huber-White) standard errors and a scaled test statistic that is (asymptotically) equal to the Yuan-Bentler test statistic. For both complete and incomplete data.

PROCEDIMIENTO: ESTIMACIÓN DEL MODELO DE MEDIDA

- Mediante ANALISIS FACTORIAL CONFIRMATORIO (AFC)

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inspect (fitAFC, "cor.lv")
inspect (fitAFC, "cor.ov")
standardizedSolution(fitAFC)
MI <- modificationIndices(fitAFC)
subset(MI, mi > 4)
```

Correlación entre las variables latentes

Correlación entre las variables observadas

Cálculo de los índices de modificacions

Mostrar mayores que 4:

```
> pchisq(3.84, df =  1)
[1] 0.9499565
```

PROCEDIMIENTO

- ESPECIFICACIÓN DEL MODELO (sobre la base de la teoría y las hipótesis planteadas)
- ESTIMACIÓN DEL MODELO DE MEDIDA
- EVALUACIÓN DEL MODELO DE MEDIDA

```
> summary(fitAFC, fit.measures = TRUE)
lavaan 0.6-8 ended normally after 45 iterations

  Estimator                                         ML
  Optimization method                           NLMINB
  Number of model parameters                        21

                                                  Used       Total
  Number of observations                          6107        6394

Model Test User Model:
                                              Standard      Robust
  Test Statistic                               575.657     482.508
  Degrees of freedom                                24          24
  P-value (Chi-square)                           0.000       0.000
  Scaling correction factor                                  1.193
       Satorra-Bentler correction

Model Test Baseline Model:

  Test statistic                             13734.840   10649.457
  Degrees of freedom                                36          36
  P-value                                        0.000       0.000
  Scaling correction factor                                  1.290

User Model versus Baseline Model:

  Comparative Fit Index (CFI)                    0.960       0.957
  Tucker-Lewis Index (TLI)                       0.940       0.935

  Robust Comparative Fit Index (CFI)                         0.960
  Robust Tucker-Lewis Index (TLI)                            0.940

Loglikelihood and Information Criteria:

  Loglikelihood user model (H0)             -72698.477  -72698.477
  Loglikelihood unrestricted model (H1)     -72410.648  -72410.648

  Akaike (AIC)                              145438.954  145438.954
  Bayesian (BIC)                            145580.015  145580.015
  Sample-size adjusted Bayesian (BIC)       145513.282  145513.282

Root Mean Square Error of Approximation:

  RMSEA                                          0.061       0.056
  90 Percent confidence interval - lower         0.057       0.052
  90 Percent confidence interval - upper         0.066       0.060
  P-value RMSEA <= 0.05                          0.000       0.007

  Robust RMSEA                                               0.061
  90 Percent confidence interval - lower                     0.056
  90 Percent confidence interval - upper                     0.066

Standardized Root Mean Square Residual:

  SRMR                                           0.048       0.048
```

Table 1

Recommendations for Model Evaluation: Some Rules of Thumb

Fit Measure	Good Fit	Acceptable Fit
χ^2	$0 \le \chi^2 \le 2df$	$2df < \chi^2 \le 3df$
p value	$.05 < p \le 1.00$	$.01 \le p \le .05$
χ^2/df	$0 \le \chi^2/df \le 2$	$2 < \chi^2/df \le 3$
RMSEA	$0 \le RMSEA \le .05$	$.05 < RMSEA \le .08$
p value for test of close fit ($RMSEA < .05$)	$.10 < p \le 1.00$	$.05 \le p \le .10$
Confidence interval (CI)	close to *RMSEA*, left boundary of CI = .00	close to *RMSEA*
SRMR	$0 \le SRMR \le .05$	$.05 < SRMR \le .10$
NFI	$.95 \le NFI \le 1.00$[a]	$.90 \le NFI < .95$
NNFI	$.97 \le NNFI \le 1.00$[b]	$.95 \le NNFI < .97$[c]
CFI	$.97 \le CFI \le 1.00$	$.95 \le CFI < .97$[c]
GFI	$.95 \le GFI \le 1.00$	$.90 \le GFI < .95$
AGFI	$.90 \le AGFI \le 1.00$, close to *GFI*	$.85 \le AGFI < .90$, close to *GFI*
AIC	smaller than *AIC* for comparison model	
CAIC	smaller than *CAIC* for comparison model	
ECVI	smaller than *ECVI* for comparison model	

Note. *AGFI* = Adjusted Goodness-of-Fit-Index, *AIC* = Akaike Information Criterion, *CAIC* = Consistent *AIC*, *CFI* = Comparative Fit Index, *ECVI* = Expected Cross Validation Index, *GFI* = Goodness-of-Fit Index, *NFI* = Normed Fit Index, *NNFI* = Nonnormed Fit Index, *RMSEA* = Root Mean Square Error of Approximation, *SRMR* = Standardized Root Mean Square Residual.

[a]*NFI* may not reach 1.0 even if the specified model is correct, especially in smaller samples (Bentler, 1990). [b]As *NNFI* is not normed, values can sometimes be outside the 0-1 range. [c]*NNFI* and *CFI* values of .97 seem to be more realistic than the often reported cutoff criterion of .95 for a good model fit.

Schermelleh-Engel et al (2003)

```
Latent Variables:
                   Estimate  Std.Err  z-value  P(>|z|)
  swb =~
    SWB_1             1.000
    SWB_2             1.200    0.028   42.310    0.000
    SWB_3             0.918    0.025   37.248    0.000
  mat =~
    MATERIALISM_1     1.000
    MATERIALISM_2     0.766    0.020   37.892    0.000
    MATERIALISM_3     1.025    0.026   39.000    0.000
  selfc =~
    SELFCONTROL_1     1.000
    SELFCONTROL_2    -1.795    0.121  -14.789    0.000
    SELFCONTROL_3    -2.148    0.152  -14.160    0.000

Covariances:
                   Estimate  Std.Err  z-value  P(>|z|)
  swb ~~
    mat               0.010    0.014    0.694    0.488
    selfc            -0.107    0.009  -12.301    0.000
  mat ~~
    selfc             0.023    0.004    5.489    0.000

Variances:
                   Estimate  Std.Err  z-value  P(>|z|)
   .SWB_1             0.948    0.037   25.587    0.000
   .SWB_2             0.437    0.041   10.651    0.000
   .SWB_3             1.263    0.041   30.613    0.000
   .MATERIALISM_1     0.466    0.019   24.823    0.000
   .MATERIALISM_2     0.646    0.016   40.968    0.000
   .MATERIALISM_3     0.379    0.019   19.825    0.000
   .SELFCONTROL_1     0.591    0.013   47.097    0.000
   .SELFCONTROL_2     0.305    0.011   28.984    0.000
   .SELFCONTROL_3     0.214    0.012   17.516    0.000
    swb               1.103    0.045   24.482    0.000
    mat               0.635    0.023   27.880    0.000
    selfc             0.054    0.007    8.116    0.000
```

Indicador de problemas en la fiabilidad de la escala

```
> fitMeasures(fitAFC)
                         npar                          fmin                         chisq 
                       21.000                         0.047                       575.657 
                           df                        pvalue                  chisq.scaled 
                       24.000                         0.000                       482.508 
                    df.scaled                 pvalue.scaled          chisq.scaling.factor 
                       24.000                         0.000                         1.193 
               baseline.chisq                   baseline.df               baseline.pvalue 
                    13734.840                        36.000                         0.000 
        baseline.chisq.scaled            baseline.df.scaled        baseline.pvalue.scaled 
                    10649.457                        36.000                         0.000 
baseline.chisq.scaling.factor                           cfi                           tli 
                        1.290                         0.960                         0.940 
                         nnfi                           rfi                           nfi 
                        0.940                         0.937                         0.958 
                         pnfi                           ifi                           rni 
                        0.639                         0.960                         0.960 
                   cfi.scaled                    tli.scaled                    cfi.robust 
                        0.957                         0.935                         0.960 
                   tli.robust                   nnfi.scaled                   nnfi.robust 
                        0.940                         0.935                         0.940 
                   rfi.scaled                    nfi.scaled                    ifi.scaled 
                        0.932                         0.955                         0.957 
                   rni.scaled                    rni.robust                          logl 
                        0.957                         0.960                    -72698.477 
            unrestricted.logl                           aic                           bic 
                   -72410.648                    145438.954                    145580.015 
                       ntotal                          bic2                         rmsea 
                     6107.000                    145513.282                         0.061 
               rmsea.ci.lower                rmsea.ci.upper                  rmsea.pvalue 
                        0.057                         0.066                         0.000 
                 rmsea.scaled         rmsea.ci.lower.scaled         rmsea.ci.upper.scaled 
                        0.056                         0.052                         0.060 
          rmsea.pvalue.scaled                  rmsea.robust         rmsea.ci.lower.robust 
                        0.007                         0.061                         0.056 
        rmsea.ci.upper.robust           rmsea.pvalue.robust                           rmr 
                        0.066                            NA                         0.051 
                   rmr_nomean                          srmr                  srmr_bentler 
                        0.051                         0.048                         0.048 
          srmr_bentler_nomean                          crmr                   crmr_nomean 
                        0.048                         0.054                         0.054 
                   srmr_mplus             srmr_mplus_nomean                         cn_05 
                        0.048                         0.048                       387.318 
                        cn_01                           gfi                          agfi 
                      456.962                         0.978                         0.960 
                         pgfi                           mfi                          ecvi 
                        0.522                         0.956                         0.101 
>
```

```
> inspect (fitAFC, "cor.lv")
      swb    mat    selfc
swb    1.000
mat    0.011  1.000
selfc -0.438  0.125  1.000
> inspect (fitAFC, "cor.ov")
              SWB_1  SWB_2  SWB_3  MATERIALISM_1 MATERIALISM_2 MATERIALISM_3 SELFCONTROL_1
SWB_1          1.000
SWB_2          0.650  1.000
SWB_3          0.478  0.577  1.000
MATERIALISM_1  0.006  0.008  0.006  1.000
MATERIALISM_2  0.005  0.006  0.005  0.459         1.000
MATERIALISM_3  0.007  0.008  0.006  0.606         0.483         1.000
SELFCONTROL_1 -0.093 -0.112 -0.082  0.028         0.022         0.029         1.000
SELFCONTROL_2  0.193  0.234  0.172 -0.057        -0.046        -0.060        -0.174
SELFCONTROL_3  0.235  0.284  0.209 -0.070        -0.056        -0.073        -0.212
              SELFCONTROL_2 SELFCONTROL_3
SWB_1
SWB_2
SWB_3
MATERIALISM_1
MATERIALISM_2
MATERIALISM_3
SELFCONTROL_1
SELFCONTROL_2  1.000
SELFCONTROL_3  0.441         1.000
```

Indicador de regresión: se lee como "está medido por"

Indicador de varianza/covarianza

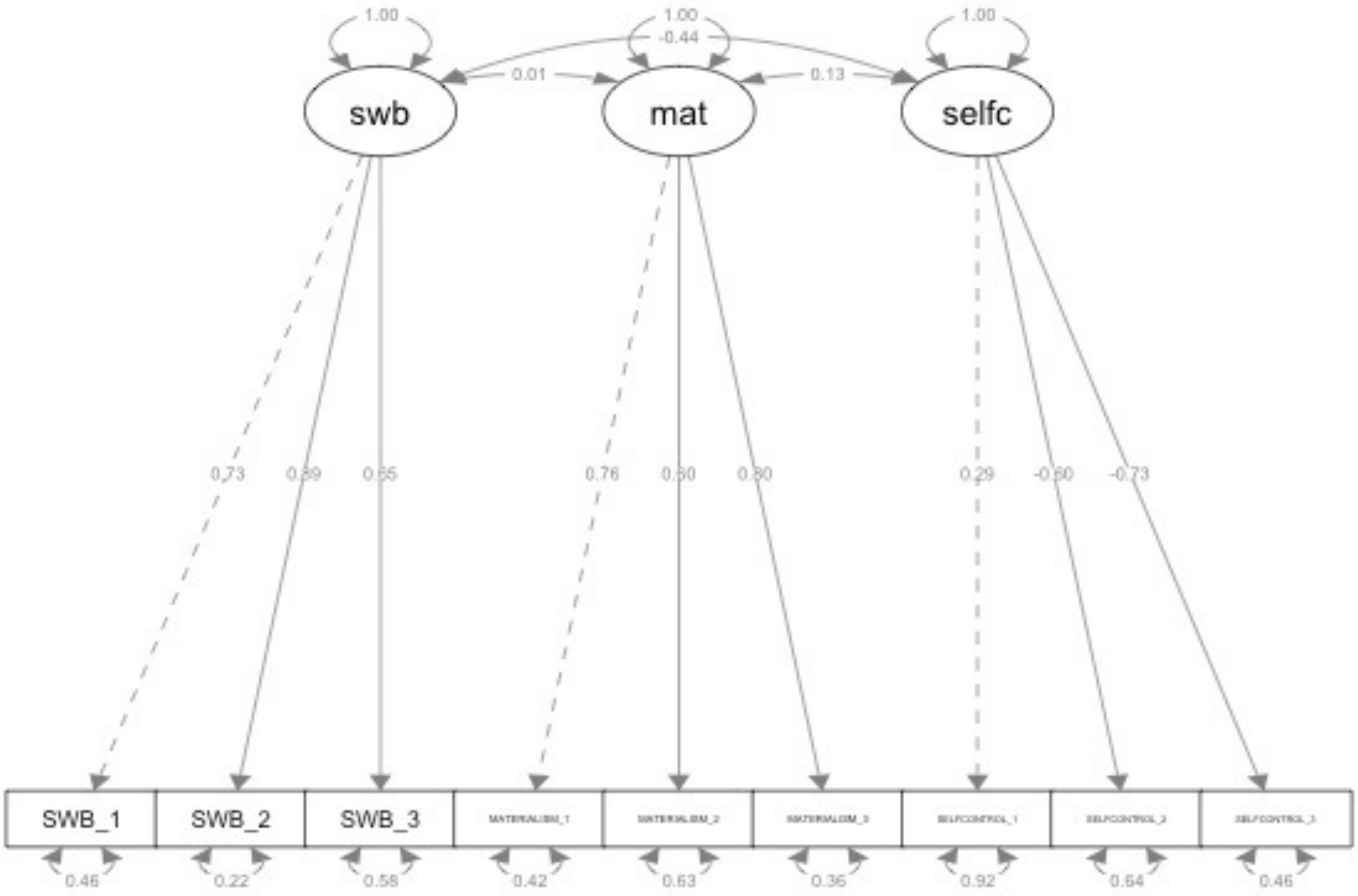
Indicador de problemas en la fiabilidad de la escala

```
> standardizedSolution(fitAFC)
              lhs op           rhs est.std    se       z pvalue ci.lower ci.upper
1             swb =~         SWB_1   0.733 0.012  63.602  0.000    0.711    0.756
2             swb =~         SWB_2   0.886 0.011  79.531  0.000    0.864    0.907
3             swb =~         SWB_3   0.651 0.013  51.233  0.000    0.626    0.676
4             mat =~ MATERIALISM_1   0.759 0.011  67.713  0.000    0.737    0.781
5             mat =~ MATERIALISM_2   0.605 0.012  50.170  0.000    0.581    0.629
6             mat =~ MATERIALISM_3   0.798 0.011  69.478  0.000    0.776    0.821
7           selfc =~ SELFCONTROL_1   0.289 0.018  16.137  0.000    0.254    0.324
8           selfc =~ SELFCONTROL_2  -0.602 0.017 -34.450  0.000   -0.637   -0.568
9           selfc =~ SELFCONTROL_3  -0.733 0.018 -41.501  0.000   -0.767   -0.698
10          SWB_1 ~~         SWB_1   0.462 0.017  27.323  0.000    0.429    0.495
11          SWB_2 ~~         SWB_2   0.216 0.020  10.934  0.000    0.177    0.254
12          SWB_3 ~~         SWB_3   0.576 0.017  34.801  0.000    0.544    0.608
13  MATERIALISM_1 ~~ MATERIALISM_1   0.423 0.017  24.844  0.000    0.390    0.457
14  MATERIALISM_2 ~~ MATERIALISM_2   0.634 0.015  43.450  0.000    0.605    0.663
15  MATERIALISM_3 ~~ MATERIALISM_3   0.362 0.018  19.751  0.000    0.327    0.398
16  SELFCONTROL_1 ~~ SELFCONTROL_1   0.916 0.010  88.517  0.000    0.896    0.937
17  SELFCONTROL_2 ~~ SELFCONTROL_2   0.637 0.021  30.242  0.000    0.596    0.678
18  SELFCONTROL_3 ~~ SELFCONTROL_3   0.463 0.026  17.883  0.000    0.412    0.514
19            swb ~~           swb   1.000 0.000      NA     NA    1.000    1.000
20            mat ~~           mat   1.000 0.000      NA     NA    1.000    1.000
21          selfc ~~         selfc   1.000 0.000      NA     NA    1.000    1.000
22            swb ~~           mat   0.011 0.017   0.694  0.488   -0.021    0.044
23            swb ~~         selfc  -0.438 0.018 -24.207  0.000   -0.473   -0.402
24            mat ~~         selfc   0.125 0.020   6.297  0.000    0.086    0.164
> 
```

```
> MI <- modificationIndices(fitAFC)
> subset(MI, mi > 4)
            lhs op           rhs      mi    epc sepc.lv sepc.all sepc.nox
25          swb =~ MATERIALISM_1   9.003 -0.034  -0.036   -0.034   -0.034
28          swb =~ SELFCONTROL_1   4.908  0.028   0.029    0.037    0.037
29          swb =~ SELFCONTROL_2 100.243 -0.155  -0.162   -0.235   -0.235
30          swb =~ SELFCONTROL_3 138.037  0.222   0.233    0.342    0.342
31          mat =~         SWB_1 106.440 -0.204  -0.163   -0.114   -0.114
32          mat =~         SWB_2   9.197  0.062   0.049    0.035    0.035
33          mat =~         SWB_3  66.274  0.178   0.142    0.096    0.096
34          mat =~ SELFCONTROL_1 184.733  0.196   0.157    0.195    0.195
35          mat =~ SELFCONTROL_2  14.945 -0.048  -0.038   -0.055   -0.055
36          mat =~ SELFCONTROL_3  99.739  0.143   0.114    0.167    0.167
37        selfc =~         SWB_1  53.671 -0.680  -0.158   -0.110   -0.110
38        selfc =~         SWB_2  63.610  0.792   0.184    0.129    0.129
40        selfc =~ MATERIALISM_1   6.526  0.150   0.035    0.033    0.033
41        selfc =~ MATERIALISM_2  20.016 -0.267  -0.062   -0.061   -0.061
43        SWB_1 ~~         SWB_2  12.947  0.209   0.209    0.325    0.325
44        SWB_1 ~~         SWB_3  56.263 -0.256  -0.256   -0.234   -0.234
45        SWB_1 ~~ MATERIALISM_1  27.673 -0.059  -0.059   -0.088   -0.088
47        SWB_1 ~~ MATERIALISM_3  18.727 -0.046  -0.046   -0.077   -0.077
48        SWB_1 ~~ SELFCONTROL_1   8.721 -0.032  -0.032   -0.042   -0.042
49        SWB_1 ~~ SELFCONTROL_2   8.057  0.024   0.024    0.045    0.045
50        SWB_1 ~~ SELFCONTROL_3   4.138  0.017   0.017    0.038    0.038
51        SWB_2 ~~         SWB_3  28.249  0.244   0.244    0.328    0.328
53        SWB_2 ~~ MATERIALISM_2   5.348 -0.025  -0.025   -0.047   -0.047
54        SWB_2 ~~ MATERIALISM_3  17.628  0.042   0.042    0.103    0.103
56        SWB_2 ~~ SELFCONTROL_2  47.378 -0.058  -0.058   -0.160   -0.160
58        SWB_3 ~~ MATERIALISM_1  28.222  0.066   0.066    0.086    0.086
61        SWB_3 ~~ SELFCONTROL_1  11.606  0.041   0.041    0.047    0.047
63        SWB_3 ~~ SELFCONTROL_3  25.112  0.046   0.046    0.088    0.088
64 MATERIALISM_1 ~~ MATERIALISM_2   4.161  0.120   0.120    0.219    0.219
65 MATERIALISM_1 ~~ MATERIALISM_3  16.531 -0.437  -0.437   -1.040   -1.040
66 MATERIALISM_1 ~~ SELFCONTROL_1  19.109  0.035   0.035    0.067    0.067
72 MATERIALISM_2 ~~ SELFCONTROL_3  15.102  0.025   0.025    0.068    0.068
73 MATERIALISM_3 ~~ SELFCONTROL_1  37.302  0.048   0.048    0.100    0.100
74 MATERIALISM_3 ~~ SELFCONTROL_2  28.079 -0.033  -0.033   -0.097   -0.097
75 MATERIALISM_3 ~~ SELFCONTROL_3  22.933  0.029   0.029    0.103    0.103
76 SELFCONTROL_1 ~~ SELFCONTROL_2  50.835 -0.053  -0.053   -0.126   -0.126
77 SELFCONTROL_1 ~~ SELFCONTROL_3  74.352  0.074   0.074    0.209    0.209
78 SELFCONTROL_2 ~~ SELFCONTROL_3   5.765  0.051   0.051    0.198    0.198
>
```

Relevancia limitada por los índices de ajuste del modelo

```
> library(semPlot)
> semPaths(fitAFC, "std", weighted = FALSE, nCharNodes = 7,
+          shapeMan = "rectangle", sizeMan = 8, sizeMan2 = 5)
```



PROCEDIMIENTO: EVALUACIÓN DEL MODELO DE MEDIDA

- Interpretación del modelo de medida
  - ¿Existen correlaciones superiores a la unidad?
  - ¿Existen cargas factorials estandarizadas fuera del interval -1, +1?
  - ¿Son los errores estándar anormalmente grandes o pequeños?
  - ¿Hay estimaciones negativas de las varianzas?
- Con respuestas positivas a estas preguntas hay problemas en el modelo (especificación, no normalidad, muestra demasiado pequeña, modelo no identificado o problema con los valores perdidos)

PROCEDIMIENTO

- ESPECIFICACIÓN DEL MODELO (sobre la base de la teoría y las hipótesis planteadas)
- ESTIMACIÓN DEL MODELO DE MEDIDA
- EVALUACIÓN DEL MODELO DE MEDIDA
- FIABILIDAD Y VALIDEZ

PROCEDIMIENTO: FIABILIDAD Y VALIDEZ

- Evaluar la calidad del modelo de medida Interpretación del modelo de medida
- Fiabilidad: aplicaciones repetidas del instrumento generan resultados consistentes
  - Alfa de Cronbach > 0.7
  - Fiabilidad compuesta > 0.7 a partir de resultados del AFC
- Validez
  - De contenido
  - Convergente: cargas factoriales > 0.6 ó 0.7 (√0.7 = 0.5)
  - Discriminante: test del intervalo de confianza (ver diapositiva 21), Fornell y Larcker (AVE > correlación al cuadrado)

Indicador de problemas en la fiabilidad de la escala

```
> library(semTools)

###############################################################################
This is semTools 0.5-4
All users of R (or SEM) are invited to submit functions or ideas for functions.
###############################################################################
> reliability(fitAFC)
             swb       mat       selfc
alpha  0.7938106 0.7626696 -0.02077786
omega  0.8020386 0.7684229  0.29598838
omega2 0.8020386 0.7684229  0.29598838
omega3 0.8054651 0.7681281  0.29831240
avevar 0.5777184 0.5290683  0.30015487
```

```
> inspect (fitAFC, "cor.lv")
      swb    mat    selfc
swb    1.000
mat    0.011  1.000
selfc -0.438  0.125  1.000
```

avevar > 0.5

PROCEDIMIENTO

- ESPECIFICACIÓN DEL MODELO (sobre la base de la teoría y las hipótesis planteadas)
- ESTIMACIÓN DEL MODELO DE MEDIDA
- EVALUACIÓN DEL MODELO DE MEDIDA
- FIABILIDAD Y VALIDEZ
- ESTIMACIÓN DEL MODELO ESTRUCTURAL

PROCEDIMIENTO: ESTIMACIÓN DEL MODELO ESTRUCTURAL

```
# SEM
modeloSEM <- '
# modelo de medida
swb =~ SWB_1 + SWB_2 + SWB_3
mat =~ MATERIALISM_1 + MATERIALISM_2 + MATERIALISM_3
selfc =~ SELFCONTROL_1 + SELFCONTROL_2 + SELFCONTROL_3

# regresiones
swb ~ mat + selfc
'
```

PROCEDIMIENTO: ESTIMACIÓN DEL MODELO ESTRUCTURAL

```
fitSEM <- sem(modeloSEM, data = mydata, estimator = "MLM")
summary(fitSEM, fit.measures = TRUE, standardized = TRUE, rsquare=TRUE)
parameterEstimates(fitSEM, boot.ci.type="bca.simple")
fitMeasures(fitSEM)
inspect (fitSEM, "cor.lv")
standardizedSolution(fitSEM)
MI <- modificationIndices(fitSEM)
subset(MI, mi > 4)
```

PROCEDIMIENTO

- ESPECIFICACIÓN DEL MODELO (sobre la base de la teoría y las hipótesis planteadas)
- ESTIMACIÓN DEL MODELO DE MEDIDA
- EVALUACIÓN DEL MODELO DE MEDIDA
- FIABILIDAD Y VALIDEZ
- ESTIMACIÓN DEL MODELO ESTRUCTURAL
- EVALUACIÓN DEL MODELO ESTRUCTURAL

```
> summary(fitSEM, fit.measures = TRUE, standardized = TRUE, rsquare=TRUE)
lavaan 0.6-8 ended normally after 49 iterations

  Estimator                                         ML
  Optimization method                           NLMINB
  Number of model parameters                        21

                                                  Used       Total
  Number of observations                          6107        6394

Model Test User Model:
                                              Standard      Robust
  Test Statistic                               575.657     482.508
  Degrees of freedom                                24          24
  P-value (Chi-square)                           0.000       0.000
  Scaling correction factor                                  1.193
       Satorra-Bentler correction

Model Test Baseline Model:

  Test statistic                             13734.840   10649.457
  Degrees of freedom                                36          36
  P-value                                        0.000       0.000
  Scaling correction factor                                  1.290

User Model versus Baseline Model:

  Comparative Fit Index (CFI)                    0.960       0.957
  Tucker-Lewis Index (TLI)                       0.940       0.935

  Robust Comparative Fit Index (CFI)                         0.960
  Robust Tucker-Lewis Index (TLI)                            0.940

Loglikelihood and Information Criteria:

  Loglikelihood user model (H0)             -72698.477  -72698.477
  Loglikelihood unrestricted model (H1)     -72410.648  -72410.648

  Akaike (AIC)                              145438.954  145438.954
  Bayesian (BIC)                            145580.015  145580.015
  Sample-size adjusted Bayesian (BIC)       145513.282  145513.282

Root Mean Square Error of Approximation:

  RMSEA                                          0.061       0.056
  90 Percent confidence interval - lower         0.057       0.052
  90 Percent confidence interval - upper         0.066       0.060
  P-value RMSEA <= 0.05                          0.000       0.007

  Robust RMSEA                                               0.061
  90 Percent confidence interval - lower                     0.056
  90 Percent confidence interval - upper                     0.066
```

```
  Robust RMSEA                                               0.061
  90 Percent confidence interval - lower                     0.056
  90 Percent confidence interval - upper                     0.066

Standardized Root Mean Square Residual:

  SRMR                                           0.048       0.048
```

```
Latent Variables:
                   Estimate  Std.Err  z-value  P(>|z|)   Std.lv  Std.all
  swb =~
    SWB_1             1.000                               1.050    0.733
    SWB_2             1.200    0.028   42.310    0.000    1.261    0.886
    SWB_3             0.918    0.025   37.248    0.000    0.964    0.651
  mat =~
    MATERIALISM_1     1.000                               0.797    0.759
    MATERIALISM_2     0.766    0.020   37.892    0.000    0.611    0.605
    MATERIALISM_3     1.025    0.026   39.000    0.000    0.817    0.798
  selfc =~
    SELFCONTROL_1     1.000                               0.232    0.289
    SELFCONTROL_2    -1.795    0.121  -14.789    0.000   -0.416   -0.602
    SELFCONTROL_3    -2.148    0.152  -14.160    0.000   -0.498   -0.733

Regressions:
                   Estimate  Std.Err  z-value  P(>|z|)   Std.lv  Std.all
  swb ~
    mat               0.089    0.021    4.280    0.000    0.067    0.067
    selfc            -2.021    0.146  -13.805    0.000   -0.446   -0.446

Covariances:
                   Estimate  Std.Err  z-value  P(>|z|)   Std.lv  Std.all
  mat ~~
    selfc             0.023    0.004    5.489    0.000    0.125    0.125

Variances:
                   Estimate  Std.Err  z-value  P(>|z|)   Std.lv  Std.all
   .SWB_1             0.948    0.037   25.587    0.000    0.948    0.462
   .SWB_2             0.437    0.041   10.651    0.000    0.437    0.216
   .SWB_3             1.263    0.041   30.613    0.000    1.263    0.576
   .MATERIALISM_1     0.466    0.019   24.823    0.000    0.466    0.423
   .MATERIALISM_2     0.646    0.016   40.968    0.000    0.646    0.634
   .MATERIALISM_3     0.379    0.019   19.825    0.000    0.379    0.362
   .SELFCONTROL_1     0.591    0.013   47.097    0.000    0.591    0.916
   .SELFCONTROL_2     0.305    0.011   28.985    0.000    0.305    0.637
   .SELFCONTROL_3     0.214    0.012   17.516    0.000    0.214    0.463
   .swb               0.887    0.040   22.290    0.000    0.804    0.804
    mat               0.635    0.023   27.880    0.000    1.000    1.000
    selfc             0.054    0.007    8.116    0.000    1.000    1.000

R-Square:
                   Estimate
    SWB_1             0.538
    SWB_2             0.784
    SWB_3             0.424
    MATERIALISM_1     0.577
    MATERIALISM_2     0.366
    MATERIALISM_3     0.638
    SELFCONTROL_1     0.084
    SELFCONTROL_2     0.363
    SELFCONTROL_3     0.537
    swb               0.196
```

Indicador de problemas en la fiabilidad de la escala

Indicador de problemas en la fiabilidad de la escala

```
> parameterEstimates(fitSEM, boot.ci.type="bca.simple")
           lhs op           rhs    est    se       z pvalue ci.lower ci.upper
1          swb =~         SWB_1  1.000 0.000      NA     NA    1.000    1.000
2          swb =~         SWB_2  1.200 0.028  42.310      0    1.145    1.256
3          swb =~         SWB_3  0.918 0.025  37.248      0    0.869    0.966
4          mat =~ MATERIALISM_1  1.000 0.000      NA     NA    1.000    1.000
5          mat =~ MATERIALISM_2  0.766 0.020  37.892      0    0.726    0.806
6          mat =~ MATERIALISM_3  1.025 0.026  39.000      0    0.973    1.076
7        selfc =~ SELFCONTROL_1  1.000 0.000      NA     NA    1.000    1.000
8        selfc =~ SELFCONTROL_2 -1.795 0.121 -14.789      0   -2.033   -1.557
9        selfc =~ SELFCONTROL_3 -2.148 0.152 -14.160      0   -2.446   -1.851
10         swb  ~           mat  0.089 0.021   4.280      0    0.048    0.130
11         swb  ~         selfc -2.021 0.146 -13.805      0   -2.308   -1.734
12       SWB_1 ~~         SWB_1  0.948 0.037  25.587      0    0.875    1.021
13       SWB_2 ~~         SWB_2  0.437 0.041  10.651      0    0.357    0.517
14       SWB_3 ~~         SWB_3  1.263 0.041  30.613      0    1.182    1.343
15 MATERIALISM_1 ~~ MATERIALISM_1  0.466 0.019  24.823      0    0.429    0.503
16 MATERIALISM_2 ~~ MATERIALISM_2  0.646 0.016  40.968      0    0.615    0.677
17 MATERIALISM_3 ~~ MATERIALISM_3  0.379 0.019  19.825      0    0.342    0.417
18 SELFCONTROL_1 ~~ SELFCONTROL_1  0.591 0.013  47.097      0    0.566    0.615
19 SELFCONTROL_2 ~~ SELFCONTROL_2  0.305 0.011  28.985      0    0.284    0.325
20 SELFCONTROL_3 ~~ SELFCONTROL_3  0.214 0.012  17.516      0    0.190    0.238
21         swb ~~           swb  0.887 0.040  22.290      0    0.809    0.965
22         mat ~~           mat  0.635 0.023  27.880      0    0.591    0.680
23       selfc ~~         selfc  0.054 0.007   8.116      0    0.041    0.067
24         mat ~~         selfc  0.023 0.004   5.489      0    0.015    0.031
```

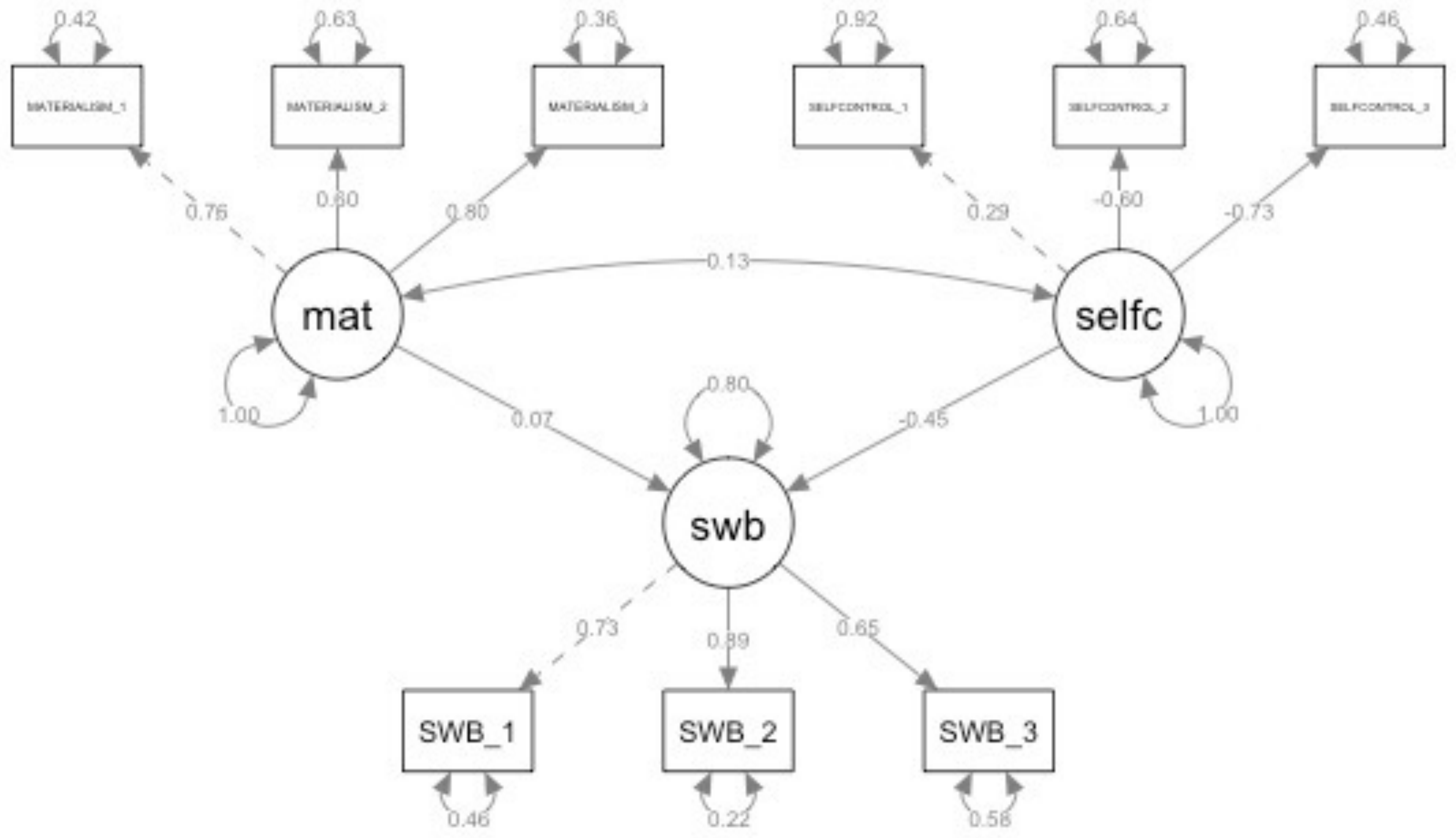
```
> fitMeasures(fitSEM)
                         npar                          fmin                         chisq 
                       21.000                         0.047                       575.657 
                           df                        pvalue                  chisq.scaled 
                       24.000                         0.000                       482.508 
                    df.scaled                 pvalue.scaled          chisq.scaling.factor 
                       24.000                         0.000                         1.193 
               baseline.chisq                   baseline.df               baseline.pvalue 
                    13734.840                        36.000                         0.000 
        baseline.chisq.scaled            baseline.df.scaled        baseline.pvalue.scaled 
                    10649.457                        36.000                         0.000 
baseline.chisq.scaling.factor                           cfi                           tli 
                        1.290                         0.960                         0.940 
                         nnfi                           rfi                           nfi 
                        0.940                         0.937                         0.958 
                         pnfi                           ifi                           rni 
                        0.639                         0.960                         0.960 
                   cfi.scaled                    tli.scaled                    cfi.robust 
                        0.957                         0.935                         0.960 
                   tli.robust                   nnfi.scaled                   nnfi.robust 
                        0.940                         0.935                         0.940 
                   rfi.scaled                    nfi.scaled                    ifi.scaled 
                        0.932                         0.955                         0.957 
                   rni.scaled                    rni.robust                          logl 
                        0.957                         0.960                    -72698.477 
            unrestricted.logl                           aic                           bic 
                   -72410.648                    145438.954                    145580.015 
                       ntotal                          bic2                         rmsea 
                     6107.000                    145513.282                         0.061 
               rmsea.ci.lower                rmsea.ci.upper                  rmsea.pvalue 
                        0.057                         0.066                         0.000 
                 rmsea.scaled         rmsea.ci.lower.scaled         rmsea.ci.upper.scaled 
                        0.056                         0.052                         0.060 
          rmsea.pvalue.scaled                  rmsea.robust         rmsea.ci.lower.robust 
                        0.007                         0.061                         0.056 
        rmsea.ci.upper.robust           rmsea.pvalue.robust                           rmr 
                        0.066                            NA                         0.051 
                   rmr_nomean                          srmr                  srmr_bentler 
                        0.051                         0.048                         0.048 
          srmr_bentler_nomean                          crmr                   crmr_nomean 
                        0.048                         0.054                         0.054 
                   srmr_mplus             srmr_mplus_nomean                         cn_05 
                        0.048                         0.048                       387.318 
                        cn_01                           gfi                          agfi 
                      456.962                         0.978                         0.960 
                         pgfi                           mfi                          ecvi 
                        0.522                         0.956                         0.101 
>
```

```
> inspect (fitSEM, "cor.lv")
         swb    mat    selfc
swb     1.000
mat     0.011  1.000
selfc -0.438  0.125  1.000
> standardizedSolution(fitSEM)
             lhs op            rhs est.std    se       z pvalue ci.lower ci.upper
1            swb =~          SWB_1   0.733 0.012  63.602      0    0.711    0.756
2            swb =~          SWB_2   0.886 0.011  79.531      0    0.864    0.907
3            swb =~          SWB_3   0.651 0.013  51.233      0    0.626    0.676
4            mat =~  MATERIALISM_1   0.759 0.011  67.713      0    0.737    0.781
5            mat =~  MATERIALISM_2   0.605 0.012  50.170      0    0.581    0.629
6            mat =~  MATERIALISM_3   0.798 0.011  69.478      0    0.776    0.821
7          selfc =~  SELFCONTROL_1   0.289 0.018  16.137      0    0.254    0.324
8          selfc =~  SELFCONTROL_2  -0.602 0.017 -34.450      0   -0.637   -0.568
9          selfc =~  SELFCONTROL_3  -0.733 0.018 -41.501      0   -0.767   -0.698
10           swb  ~            mat   0.067 0.016   4.288      0    0.037    0.098
11           swb  ~          selfc  -0.446 0.018 -24.437      0   -0.482   -0.411
12         SWB_1 ~~          SWB_1   0.462 0.017  27.323      0    0.429    0.495
13         SWB_2 ~~          SWB_2   0.216 0.020  10.934      0    0.177    0.254
14         SWB_3 ~~          SWB_3   0.576 0.017  34.801      0    0.544    0.608
15 MATERIALISM_1 ~~  MATERIALISM_1   0.423 0.017  24.844      0    0.390    0.457
16 MATERIALISM_2 ~~  MATERIALISM_2   0.634 0.015  43.450      0    0.605    0.663
17 MATERIALISM_3 ~~  MATERIALISM_3   0.362 0.018  19.751      0    0.327    0.398
18 SELFCONTROL_1 ~~  SELFCONTROL_1   0.916 0.010  88.517      0    0.896    0.937
19 SELFCONTROL_2 ~~  SELFCONTROL_2   0.637 0.021  30.242      0    0.596    0.678
20 SELFCONTROL_3 ~~  SELFCONTROL_3   0.463 0.026  17.883      0    0.412    0.514
21           swb ~~            swb   0.804 0.016  50.190      0    0.772    0.835
22           mat ~~            mat   1.000 0.000      NA     NA    1.000    1.000
23         selfc ~~          selfc   1.000 0.000      NA     NA    1.000    1.000
24           mat ~~          selfc   0.125 0.020   6.297      0    0.086    0.164
```

Indicador de problemas en la fiabilidad de la escala

```
> MI <- modificationIndices(fitSEM)
> subset(MI, mi > 4)
             lhs op           rhs      mi    epc sepc.lv sepc.all sepc.nox
25           swb =~ MATERIALISM_1   9.003 -0.034  -0.036   -0.034   -0.034
28           swb =~ SELFCONTROL_1   4.908  0.028   0.029    0.037    0.037
29           swb =~ SELFCONTROL_2 100.243 -0.155  -0.162   -0.235   -0.235
30           swb =~ SELFCONTROL_3 138.037  0.222   0.233    0.342    0.342
31           mat =~         SWB_1 106.440 -0.204  -0.163   -0.114   -0.114
32           mat =~         SWB_2   9.197  0.062   0.049    0.035    0.035
33           mat =~         SWB_3  66.274  0.178   0.142    0.096    0.096
34           mat =~ SELFCONTROL_1 184.733  0.196   0.157    0.195    0.195
35           mat =~ SELFCONTROL_2  14.945 -0.048  -0.038   -0.055   -0.055
36           mat =~ SELFCONTROL_3  99.740  0.143   0.114    0.167    0.167
37         selfc =~         SWB_1  53.671 -0.680  -0.158   -0.110   -0.110
38         selfc =~         SWB_2  63.610  0.792   0.184    0.129    0.129
40         selfc =~ MATERIALISM_1   6.526  0.150   0.035    0.033    0.033
41         selfc =~ MATERIALISM_2  20.016 -0.267  -0.062   -0.061   -0.061
43         SWB_1 ~~         SWB_2  12.947  0.209   0.209    0.325    0.325
44         SWB_1 ~~         SWB_3  56.263 -0.256  -0.256   -0.234   -0.234
45         SWB_1 ~~ MATERIALISM_1  27.673 -0.059  -0.059   -0.088   -0.088
47         SWB_1 ~~ MATERIALISM_3  18.727 -0.046  -0.046   -0.077   -0.077
48         SWB_1 ~~ SELFCONTROL_1   8.721 -0.032  -0.032   -0.042   -0.042
49         SWB_1 ~~ SELFCONTROL_2   8.057  0.024   0.024    0.045    0.045
50         SWB_1 ~~ SELFCONTROL_3   4.138  0.017   0.017    0.038    0.038
51         SWB_2 ~~         SWB_3  28.249  0.244   0.244    0.328    0.328
53         SWB_2 ~~ MATERIALISM_2   5.348 -0.025  -0.025   -0.047   -0.047
54         SWB_2 ~~ MATERIALISM_3  17.628  0.042   0.042    0.103    0.103
56         SWB_2 ~~ SELFCONTROL_2  47.378 -0.058  -0.058   -0.160   -0.160
58         SWB_3 ~~ MATERIALISM_1  28.222  0.066   0.066    0.086    0.086
61         SWB_3 ~~ SELFCONTROL_1  11.606  0.041   0.041    0.047    0.047
63         SWB_3 ~~ SELFCONTROL_3  25.112  0.046   0.046    0.088    0.088
64 MATERIALISM_1 ~~ MATERIALISM_2   4.161  0.120   0.120    0.219    0.219
65 MATERIALISM_1 ~~ MATERIALISM_3  16.532 -0.438  -0.438   -1.040   -1.040
66 MATERIALISM_1 ~~ SELFCONTROL_1  19.109  0.035   0.035    0.067    0.067
72 MATERIALISM_2 ~~ SELFCONTROL_3  15.102  0.025   0.025    0.068    0.068
73 MATERIALISM_3 ~~ SELFCONTROL_1  37.302  0.048   0.048    0.100    0.100
74 MATERIALISM_3 ~~ SELFCONTROL_2  28.079 -0.033  -0.033   -0.097   -0.097
75 MATERIALISM_3 ~~ SELFCONTROL_3  22.933  0.029   0.029    0.103    0.103
76 SELFCONTROL_1 ~~ SELFCONTROL_2  50.835 -0.053  -0.053   -0.126   -0.126
77 SELFCONTROL_1 ~~ SELFCONTROL_3  74.353  0.074   0.074    0.209    0.209
78 SELFCONTROL_2 ~~ SELFCONTROL_3   5.765  0.051   0.051    0.198    0.198
```

```
> semPaths(fitSEM, "std", layout = "tree2", weighted = FALSE, nCharNodes = 7,
+          shapeMan = "rectangle", sizeMan = 8, sizeMan2 = 5)
```



PROCEDIMIENTO: EVALUACIÓN DEL MODELO ESTRUCTURAL

- Interpretación del modelo estructural
  - Interpretacion de los parámetros estimados
  - Bondad del ajuste
  - Otros efectos: indirectos, multigrupo.

PROCEDIMIENTO

- ESPECIFICACIÓN DEL MODELO (sobre la base de la teoría y las hipótesis planteadas)
- ESTIMACIÓN DEL MODELO DE MEDIDA
- EVALUACIÓN DEL MODELO DE MEDIDA
- FIABILIDAD Y VALIDEZ
- ESTIMACIÓN DEL MODELO ESTRUCTURAL
- EVALUACIÓN DEL MODELO ESTRUCTURAL

EJERCICIO

- Estimar los modelos con script y comentar los resultados

Referencias

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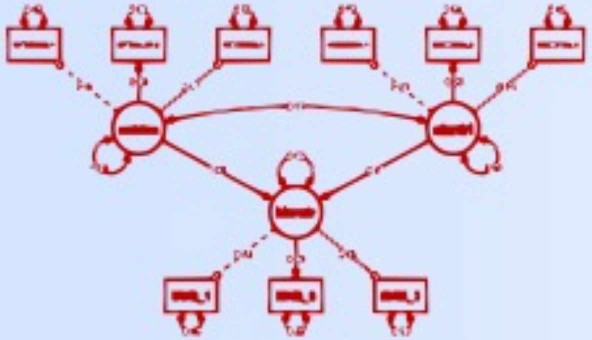

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