lavaan.survey: An R package for complex survey analysis of structural equation models

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Journal of Statistical Software

March 2014, Volume 57, Issue 1. *http://www.jstatsoft.org/*

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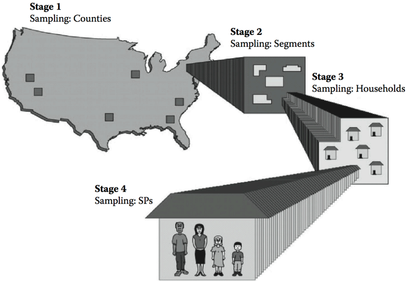
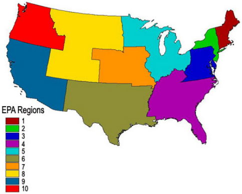
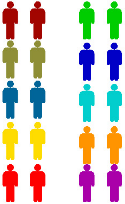
What is "complex" about a sample survey?

1. Clustering

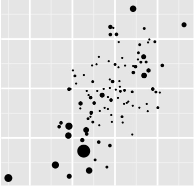


2. Stratification





3. Weighting



Why account for complex sampling in structural equation modeling?

- Clustering, stratification, and weighting all affect the **standard errors**.
- Weighting affects the **point estimates**;

(Skinner, Holt & Smith 1989; Pfefferman 1993; Muthén & Satorra 1995; Asparouhov 2005; Asparouhov, & Muthén 2005; Stapleton 2006; Asparouhov & Muthén 2007; Fuller 2009; Bollen, Tueller, & Oberski 2013)

`lavaan.survey`

Input:

1. A `lavaan` fit object (SEM analysis)
2. A `survey` design object (complex sample design)

Output:

A `lavaan` fit object (SEM analysis),
accounting for the complex sample design

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`lavaan.survey`

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Output:

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accounting for the complex sample design

Example call:

```
lavaan.survey(lavaan.fit, survey.design)
```

How to fit a structural equation model accounting for complex sampling using `lavaan.survey` in 3 steps:

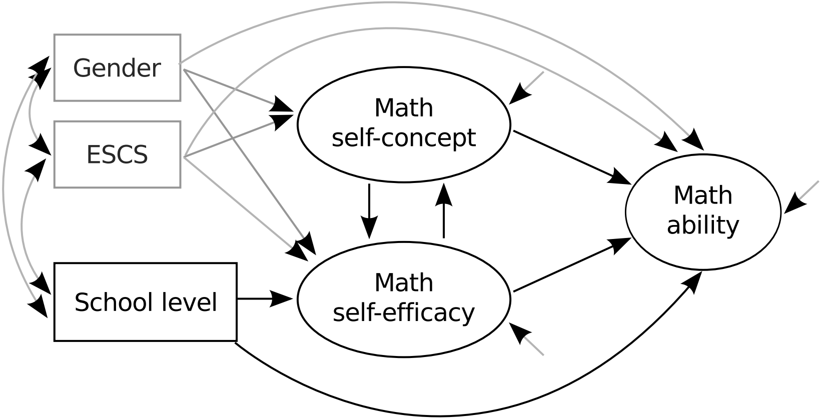
1. **Fit** the SEM using `lavaan` as you normally would
   → `lavaan` fit object;
2. **Define** the complex sampling design to the `survey` package
   → `svydesign` or `svrepdesign` object;
3. **Call** `lavaan.survey` with the two objects obtained in (1) and (2).
   → corrected `lavaan` fit object.

Afterwards, usual `lavaan` apparatus available.

Example complex sample SEM analysis from the literature

Ferla, Valcke & Cai (2009). Academic self-efficacy and academic self-concept: Reconsidering structural relationships. *Learning and Individual Differences*, 19 (4).

Structural equation model of Belgian PISA data

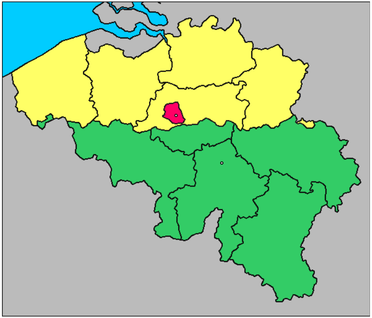


PISA data in the lavaan.survey package

```
load("pisa.be.2003.rda")

> head(pisa.be.2003, 5)[,1:20]
  PV1MATH1 PV1MATH2 PV1MATH3 PV1MATH4 ST31Q01 ST31Q02 ST31Q03 ST31Q04
1    1.160     1.26     1.19    1.190       2       1       2       2
2    1.293     1.27     1.22    1.247       1       1       1       1
3    1.383     1.44     1.37    1.347       2       1       1       1
4    0.965     1.02     1.10    0.979       2       2       2       2
5    1.375     1.44     1.31    1.471       3       1       2       2
  ST31Q05 ST31Q06 ST31Q07 ST31Q08 ST32Q02 ST32Q04 ST32Q06 ST32Q07
1       2       2       2       3       2       3       3       3
2       1       2       1       4       2       3       3       4
3       1       1       2       3       4       2       1       1
4       2       1       2       2       3       3       2       2
5       1       3       3       3       3       2       3       3
  ST32Q09  ESCS male school.type
1       3 1.221    1           1
2       4 1.899    2           1
3       2 0.884    2           1
4       3 1.305    2           1
5       3 0.958    2           1
```

Belgium is a complex country.



In addition to the observed variables, the raw data also contain 80 replicate weights generated by ``balanced-repeated replication'' (BRR)

```
> pisa.be.2003[sample(1:8796), 21:101]

      W_FSTUWT W_FSTR1 W_FSTR2 W_FSTR3 ...  W_FSTR80
2988      1.12    1.64    0.57    1.70 ...     0.528
8666     11.90   17.84    5.95    5.95 ...     5.948
290      16.89   25.33    8.44    8.44 ...    25.333
3505     14.80    8.25    7.90   20.67 ...     8.206
4289     22.70   32.40   10.87   10.80 ...    11.755
2352     13.09   20.62    6.26   18.79 ...     6.301
....
```

Step 1: Fitting the model with lavaan

```
model.pisa <- "
    math =~ PV1MATH1 + PV1MATH2 + PV1MATH3 + PV1MATH4
    neg.efficacy =~ ST31Q01 + ST31Q02 + ST31Q03 + ST31Q04 +
                    ST31Q05 + ST31Q06 + ST31Q07 + ST31Q08
   neg.selfconcept =~ ST32Q02 + ST32Q04 + ST32Q06 + ST32Q07 + ST32Q09

    neg.selfconcept ~ neg.efficacy + ESCS + male
    neg.efficacy ~ neg.selfconcept + school.type + ESCS + male
   math ~ neg.selfconcept + neg.efficacy + school.type + ESCS + male
"

fit <- lavaan(model.pisa, data=pisa.be.2003, auto.var=TRUE, std.lv=TRUE,
           meanstructure=TRUE, int.ov.free=TRUE, estimator="MLM")
```

Step 2: Letting survey know about the replicate weight design

```
des.rep <- svrepdesign(ids=~1, weights=~W_FSTUWT,
                       data=pisa.be.2003,
                       repweights="W_FSTR[0-9]+",
                       type="Fay", rho=0.5)
```

More information on defining complex sampling objects:

Lumley (2004). Complex Surveys: A Guide to Analysis using R. New York: Wiley.

Thomas Lumley's website with **tutorials**:
`http://r-survey.r-forge.r-project.org/survey/index.html`

Complex survey SEM

```
fit.surv <-
  lavaan.survey(lavaan.fit=fit, survey.design=des.rep)
```

Point and standard error estimates using robust ML with and without correction for the sampling design using BRR replicate weights.

	Estimate		s.e.		
	Naive	PML	Naive	PML	creff
`neg.selfconcept` ~ `neg.efficacy`	-0.021	-0.050	0.032	0.046	1.415
`neg.efficacy` ~ neg.selfconcept	0.568	0.609	0.046	0.065	1.421
`neg.efficacy` ~ school.type	0.530	0.518	0.022	0.022	1.009
`math` ~ neg.selfconcept	-0.179	-0.177	0.015	0.021	1.362
`math` ~ neg.efficacy	-0.239	-0.237	0.015	0.018	1.216
`math` ~ school.type	-0.606	-0.596	0.019	0.035	1.858

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Conclusions

Conclusions

- When there are clusters, strata, and/or weights, you should usually adjust the SEM analysis for them;
- Especially important for correct **standard errors** and **model fit statistics**.
- `lavaan.survey` leverages the power of the `lavaan` and `survey` packages to let you do this.

- Future: categorical data.

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`http://daob.nl`

Oberski, D.L. (2014). lavaan.survey: An R Package for Complex Survey Analysis of Structural Equation Models. *Journal of Statistical Software*, 57 (1). `http://www.jstatsoft.org/v57/i01`

Appendix

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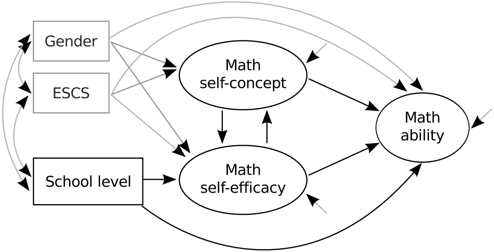
Specifying regression relations in **lavaan**



Dependent variable	``regressed on''	independent variables
`selfconcept`	`~`	`efficacy + ESCS + male`
`efficacy`	`~`	`selfconcept + school.type + ESCS + male`
`math`	`~`	`selfconcept + efficacy + school.type + ESCS + male`

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PISA data: Math self-concept (`ST32Q02,4,6,7,9`)

Math self-concept ($n = 5$, $\alpha = 88.6$)

The PISA math self-concept items assess what Eccles and Wigfield (1995) identified as the ability component of subject-specific self-concept beliefs (as opposed to the affective/motivational component).

Thinking about studying Mathematics: to what extent do you agree with the following statements?

1. I am just not good at Mathematics
2. I get good marks in Mathematics
3. I learn Mathematics quickly.
4. I have always believed that Mathematics is one of my best subjects
5. In my Mathematics class, I understand even the most difficult work.

Items are rated on a 4 point Likert scale ranging from (1) "Strongly agree" to (4) "Strongly disagree"

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Measurement model for self-concept

```
neg.selfconcept  =~          ST32Q02 + ST32Q04 +
                             ST32Q06 + ST32Q07 +
                             ST32Q09
```

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Measurement model for self-concept

Latent variable

```
neg.selfconcept  =~         ST32Q02 + ST32Q04 +
                            ST32Q06 + ST32Q07 +
                            ST32Q09
```


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Measurement model for self-concept

Latent variable ``measured by''

```
neg.selfconcept  =~        ST32Q02 + ST32Q04 +
                           ST32Q06 + ST32Q07 +
                           ST32Q09
```

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Measurement model for self-concept

Latent variable	``measured by''	obs. variables
`neg.selfconcept`	`=~`	`ST32Q02 + ST32Q04 + ST32Q06 + ST32Q07 + ST32Q09`

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PISA data: math self-efficicacy (ST31Q01--08)

Math self-efficacy ($n = 8$, $\alpha = 81.6$)

The PISA math self-efficacy scale was developed according to Bandura's (1997) guidelines regarding the specificity of self-efficacy beliefs assessment and their correspondence with criterial tasks.

How confident do you feel about having to do the following Mathematics tasks?

1. Using a train timetable to work out how long it would take to get from one place to another
2. Calculating how much cheaper a TV would be after a 30% discount.
3. Calculating how many square metres of tiles you need to cover a floor.
4. Understanding graphs presented in newspapers
5. Solving an equation like $3x + 5 = 17$
6. Finding the actual distance between two places on a map with a 1:10,000 scale.
7. Solving an equation like $2(x + 3) = (x + 3)(x - 3)$
8. Calculating the petrol consumption rate of a car.

Items are rated on a 4 point Likert scale ranging from (1) "Very confident" to (4) "Not at all confident"

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Measurement model for self-efficacy

```
neg.efficacy =~ ST31Q01 + ST31Q02 + ST31Q03 +
                    ST31Q04 + ST31Q05 + ST31Q06 +
                    ST31Q07 + ST31Q08
```


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[1/3] PISA sampling design: clustering

- Target population in each country: 15-year-old students attending educational institutions in grades 7+;
- Minimum of 150 schools selected/country;
- Within each participating school, (usually 35) students randomly selected with equal probability;
- Total sample size at least 4,500+ students.
- Other complications (with sampling):
    - Getting a population frame
    - School nonresponse
    - Student nonresponse
    - Small schools (< 35 students): representation vs. costs
    - Countries with few schools

[2/3] PISA sampling design: stratification

- Before sampling, schools **stratified** in the sampling frame;
- Schools classified into ``like'' groups, for purpose:
    - improve efficiency of the sample design;
    - disproportionate sample allocations to specific groups of schools, e.g. states, provinces, or other regions;
    - ensure all parts of population included in the sample;
    - representation of specific groups in sample.

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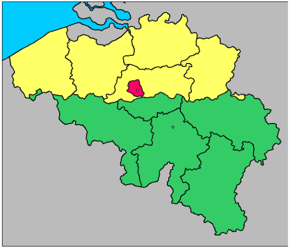
PISA sampling: stratification in Belgium



- **Region** $\times$ **Public/private education** $\rightarrow$ 23 strata
- Then sampling within stratum with **probability proportional to**:
  - (Flanders) ISCED; Retention Rate; Vocational/Special Education; Percentage of Girls;
  - (French Community) National/International School; Retention Rate; Vocational-Special Education/Other;
  - (German Community) Public/Private.

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[3/3] Weighting

$$w_{ij} = w_{1i} w_{2ij} f_{1i} f_{2ij} t_{1i}$$

w_{1i}: Base weight for school i;

w_{2ij}: Base weight for student j in school i;

f_{2ij}, f_{1i}: Nonresponse factor for student and school nonparticipation;

t_{1i}: Weight trimming factor.

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Weighting

$$w_{ij} = w_i^{\mathrm{brr}} w_{1i} w_{2ij} f_{1i} f_{2ij} t_{1i}$$

w_{1i}: Base weight for school i;

w_{2ij}: Base weight for student j in school i;

f_{2ij}, f_{1i}: Nonresponse factor for student and school nonparticipation;

t_{1i}: Weight trimming factor.

w_{ij}^{brr} : ``Balanced-repeated replication'' weight (80 replications per case) created by the WesVar software

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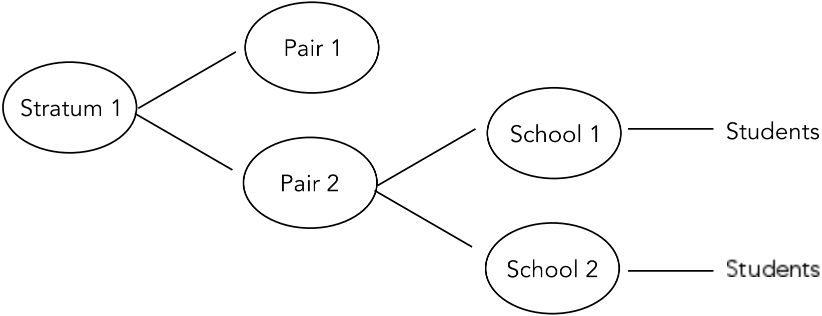
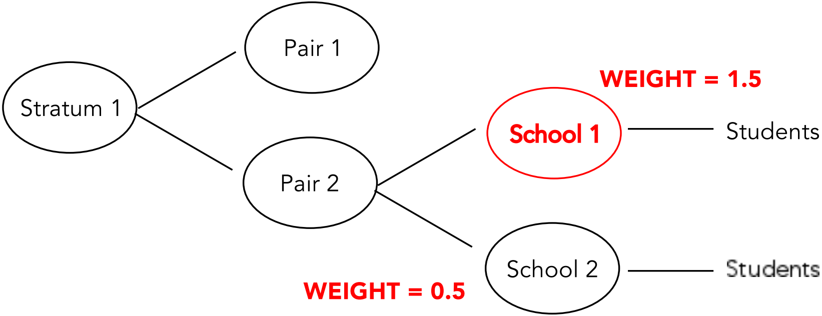
Balanced-repeated replication (BRR), Fay's $\rho = 0.5$



Balanced-repeated replication (BRR), Fay's $\rho = 0.5$



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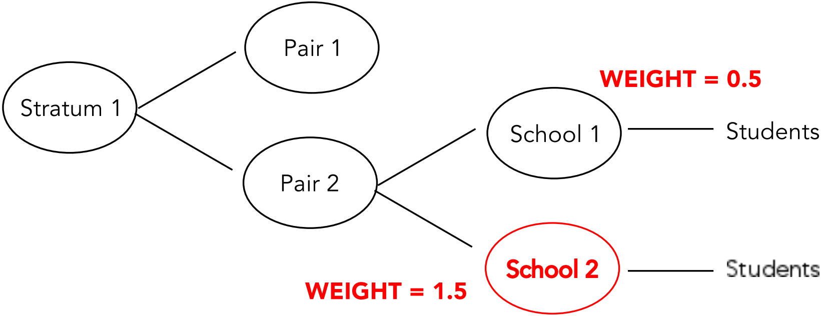
Balanced-repeated replication (BRR), Fay's $\rho = 0.5$



Structural parameter estimates and standard errors taking nonnormality into account

```
                     Estimate  Std.err  Z-value  P(>|z|)
Regressions:
  neg.selfconcept ~
    neg.efficacy       -0.021    0.032   -0.657    0.511
    ESCS               -0.062    0.018   -3.381    0.001
    male               -0.389    0.027  -14.607    0.000
  neg.efficacy ~
    neg.selfcncpt       0.568    0.046   12.354    0.000
    school.type         0.530    0.022   24.331    0.000
    ESCS               -0.252    0.016  -16.199    0.000
    male               -0.360    0.031  -11.668    0.000
  math ~
    neg.selfcncpt      -0.179    0.015  -11.644    0.000
    neg.efficacy       -0.239    0.015  -16.413    0.000
    school.type        -0.606    0.019  -32.154    0.000
    ESCS                0.312    0.014   22.511    0.000
    male                0.009    0.024    0.375    0.708
```

Model fit taking nonnormality into account

```
                                                  Used       Total
  Number of observations                          7785        8796

  Estimator                                         ML      Robust
  Minimum Function Test Statistic             8088.256    7275.544
  Degrees of freedom                               158         158
  P-value (Chi-square)                           0.000       0.000
  Scaling correction factor                                  1.112
    for the Satorra-Bentler correction

  Comparative Fit Index (CFI)                    0.921       0.921
  Tucker-Lewis Index (TLI)                       0.907       0.907

  RMSEA                                          0.080       0.076
  P-value RMSEA <= 0.05                          0.000       0.000

  SRMR                                           0.056       0.056
```

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Complex survey SEM: fit measures

```
Number of observations                          7785

Estimator                                         ML      Robust
Minimum Function Test Statistic             8187.514    5642.873
Degrees of freedom                               158         158
P-value (Chi-square)                           0.000       0.000
Scaling correction factor                                  1.451
  for the Satorra-Bentler correction


Comparative Fit Index (CFI)                    0.921       0.894
Tucker-Lewis Index (TLI)                       0.906       0.875

RMSEA                                          0.081       0.067
P-value RMSEA <= 0.05                          0.000       0.000

SRMR                                           0.058       0.058
```


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