HMMA 307 : Advanced Linear Modeling

Linear mixed models with LM and REML

Delage Cindy

Université de Montpellier

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Introduction to the linear mixed models

Remark

Fixed effect : can be generalised
Random effect : sample-specific

Model

$$Y = X\beta + Zu + \epsilon$$

$$\begin{pmatrix} u \\ \epsilon \end{pmatrix} \sim (\mathcal{N}(\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} G & 0 \\ 0 & R \end{pmatrix}))$$

X and Z are design matrix, β is the fix effect vector and u is the random effect vector.

Meaning of this project

Definition

- ML : maximum likelihood regression
- REML : restrained maximum likelihood regression

Goals

- Compare ML and REML
- Application with Python
- explain the differences

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Manual estimation

Beta

For linear mixed model:

$$\hat{\beta} = (X^\top V^{-1} X)^{-1} X^\top V^{-1} Y$$

V is the variance of Y, $V = ZGZ^\top + R$

Manual estimation : Using these formulas in Python, we obtain the following parameters :

$$\beta = \begin{pmatrix} 70.18571429 \\ 5.71428571 \\ 0.91428571 \end{pmatrix}$$

ML estimation

```
                 Mixed Linear Model Regression Results
=============================================================================
Model:                    MixedLM     Dependent Variable:         pres
No. Observations:         21          Method:                     ML
No. Groups:               7           Scale:                      2.3045
Min. group size:          3           Log-Likelihood:             -52.8621
Max. group size:          3           Converged:                  No
Mean group size:          3.0
-----------------------------------------------------------------------------
                                  Coef.  Std.Err.   z    P>|z| [0.025 0.975]
-----------------------------------------------------------------------------
Intercept                         70.186   1.036 67.718 0.000 68.154 72.217
metal[T.i]                         5.714   1.865  3.064 0.002  2.059  9.369
metal[T.n]                         0.914   1.379  0.663 0.507 -1.789  3.618
Group Var                          5.215
Group x df.metal[T.i] Cov          2.267   2.974
df.metal[T.i] Var                 19.736
Group x df.metal[T.n] Cov          0.363   2.380
df.metal[T.i] x df.metal[T.n] Cov 12.379   1.622
df.metal[T.n] Var                  8.712
=============================================================================
```

REML estimation

```
                  Mixed Linear Model Regression Results
=============================================================================
Model:                    MixedLM        Dependent Variable:         pres
No. Observations:         21             Method:                     REML
No. Groups:               7              Scale:                      0.9865
Min. group size:          3              Log-Likelihood:             -49.3760
Max. group size:          3              Converged:                  No
Mean group size:          3.0
-----------------------------------------------------------------------------
                                  Coef.  Std.Err.   z    P>|z| [0.025 0.975]
-----------------------------------------------------------------------------
Intercept                         70.186    1.124 62.434 0.000 67.982 72.389
metal[T.i]                         5.714    2.053  2.784 0.005  1.691  9.738
metal[T.n]                         0.914    1.592  0.574 0.566 -2.206  4.035
Group Var                          7.860
Group x df.metal[T.i] Cov         -2.288    5.234
df.metal[T.i] Var                 27.526
Group x df.metal[T.n] Cov         -3.292    3.036
df.metal[T.i] x df.metal[T.n] Cov 18.563
df.metal[T.n] Var                 15.769
=============================================================================
```

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Variances estimated by ML

Likelihood

$$f_Y(y_1, ..., y_n) = \frac{e^{\frac{-1}{2}(Y-X\beta)^T V^{-1}(Y-X\beta)}}{\sqrt{2\pi^n |V|}}$$

Optimizing the log likelihood with python gives :

$$\begin{pmatrix} \sigma_Y^2 \\ \sigma_{residuals}^2 \end{pmatrix} = \begin{pmatrix} 9.812383 \\ 8.889932 \end{pmatrix}$$

Variances estimated by REML

Log likelihood

$$-2\log(\beta, Y) = log(|V|) + \log\left(\left|X^T V - 1X\right|\right) + (Y - X\beta)^T V^{-1}(Y - X\beta) + Cste$$

Optimisation

Optimizing the log likelihood with python gives :

$$\begin{pmatrix} \sigma_Y^2 \\ \sigma_{residuals}^2 \end{pmatrix} = \begin{pmatrix} 11.44780323 \\ 10.3715852 \end{pmatrix}$$

Reason of the differences

Main differences

- Variance of the parameters
- Confidence intervals regression

ML has a bias

$$\mathbb{E}[\hat{\sigma}^2] = \sigma^2 - \frac{\sigma^2}{N}$$

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Conclusion

Conclusion

REML corrects the bias of ML by adding a term in the log likelihood.
The confidence intervals is larger, so are the variances calculated.