

In many scenarios, data are structured in groups or clusters, e.g. pupils within classes (within schools), survey respondents within countries or, for longitudinal surveys, survey answers per subject. Simply ignoring this structure will likely lead to spuriously low standard errors, i.e. a misleadingly precise estimate of our coefficients. This in turn leads to overly-narrow confidence intervals, overly-low p-values and possibly wrong conclusions.

*Clustered standard errors* are a common way to deal with this problem. Unlike Stata, R doesn't have built-in functionality to estimate clustered standard errors. There are several packages though that add this functionality and this article will introduce three of them, explaining how they can be used and what their advantages and disadvantages are. Before that, I will outline the theory behind (clustered) standard errors for linear regression. The last section is used for a performance comparison between the three presented packages. If you're already familiar with the concept of clustered standard errors, you may skip to the [hands-on part](#) right away.

## Data

We'll work with the dataset *nlswork* that's [included in Stata](#), so we can easily compare the results with Stata. The data comes from the US National Longitudinal Survey (NLS) and contains information about more than 4,000 young working women. As for this example, we're interested in the relationship between wage (here as log-scaled GNP-adjusted wage) as dependent variable (DV) `ln_wage` and survey participant's current `age`, `job tenure` in years and `union` membership as independent variables. It's a longitudinal survey, so subjects were asked repeatedly between 1968 and 1988 and each subject is identified by a unique `idcode`.

The example data is used for illustrative purposes only and we skip many things that we'd normally do, such as investigating descriptive statistics and exploratory plots. To keep the data size limited, we'll only work with a subset of the data (only subjects with IDs 1 to 100) and we also simply dismiss any observations that contain missing values.

```
library(webuse)
library(dplyr)

nlswork_orig <- webuse('nlswork')

nlswork <- filter(nlswork_orig, idcode <= 100) %>%
  select(idcode, year, ln_wage, age, tenure, union) %>%
  filter(complete.cases(.)) %>%
  mutate(union = as.integer(union),
         idcode = as.factor(idcode))
str(nlswork)
tibble [386 × 6] (S3: tbl_df/tbl/data.frame)
 $ idcode : Factor w/ 82 levels "1","2","3","4",...: 1 1 1 1 1 1 1 2 2
2 ...
 $ year   : num [1:386] 72 77 80 83 85 87 88 71 77 78 ...
 $ ln_wage: num [1:386] 1.59 1.78 2.55 2.42 2.61 ...
 $ age    : num [1:386] 20 25 28 31 33 35 37 19 25 26 ...
 $ tenure : num [1:386] 0.917 1.5 1.833 0.667 1.917 ...
 $ union  : int [1:386] 1 0 1 1 1 1 1 0 1 1 ...
```

Let's have a look at the first few observations. They contain data from subject #1, who was surveyed several times between 1972 and 1988, and a few observations from subject #2.

idcode	year	ln_wage	age	tenure	union
1	72	1.59	20	0.917	1
1	77	1.78	25	1.5	0
1	80	2.55	28	1.83	1
1	83	2.42	31	0.667	1
1	85	2.61	33	1.92	1
1	87	2.54	35	3.92	1
1	88	2.46	37	5.33	1
2	71	1.36	19	0.25	0
2	77	1.73	25	2.67	1
2	78	1.69	26	3.67	1

A summary of all but the idcode variable gives the following:

year	ln_wage	age	tenure	union
Min. :70.00	Min. :0.4733	Min. :18.0	Min. : 0.000	Min. :0.0000
1st Qu.:73.00	1st Qu.:1.6131	1st Qu.:25.0	1st Qu.: 1.167	1st Qu.:0.0000
Median :80.00	Median :1.9559	Median :31.0	Median : 2.417	Median :0.0000
Mean :79.61	Mean :1.9453	Mean :30.8	Mean : 3.636	Mean :0.2591
3rd Qu.:85.00	3rd Qu.:2.2349	3rd Qu.:36.0	3rd Qu.: 4.958	3rd Qu.:1.0000
Max. :88.00	Max. :3.5791	Max. :45.0	Max. :19.000	Max. :1.0000

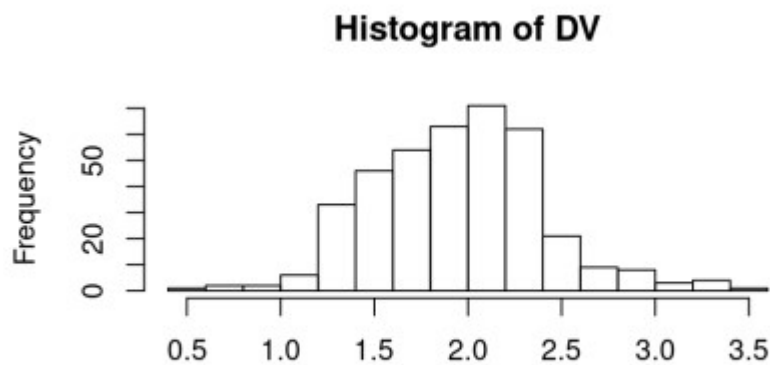
We have 82 subjects in our subset and the number of times each subject was surveyed ranges from only once to twelve times:

```
summary(as.integer(table(nlswork$idcode)))
```

Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
1.000	2.000	4.000	4.707	7.000	12.000

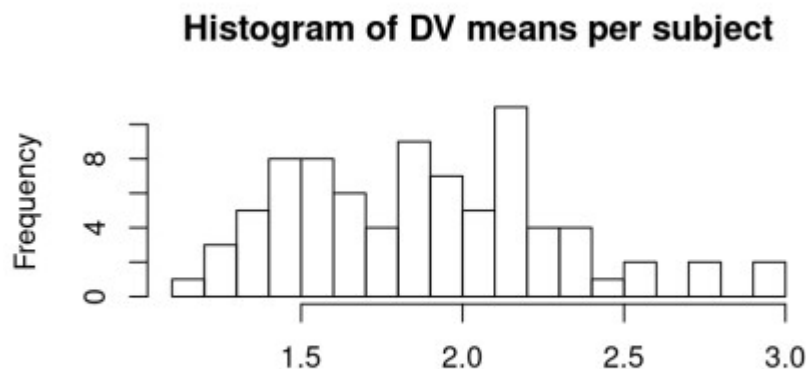
In more than one quarter of the observations, the subject answered to be currently member of a trade union.

The following shows the distribution of the DV in our data. It is roughly normally distributed with mean 1.95 and standard deviation (SD) 0.45.



We can calculate the mean and SD of the DV separately for each subject. A histogram of these subject-specific means reveals more variability:

```
y_mean_sd_cl <- sapply(levels(nlswork$idcode), function(idcode) {
  y_cl <- nlswork$ln_wage[nlswork$idcode == idcode]
  c(mean(y_cl), sd(y_cl))
})
hist(y_mean_sd_cl[1,], breaks = 20,
      main = 'Histogram of DV means per subject', xlab = NA)
```



We can compare the SD of the subject-specific means with the mean of the SDs calculated from each subjects' repeated measures.

```
c(sd(y_mean_sd_cl[1,]), mean(y_mean_sd_cl[2,], na.rm = TRUE))
[1] 0.4038449 0.2221142
```

The SD between the subject-specific means is almost twice as large as the mean of the SD from each subjects' values. This shows that there's much more variability between each subject than within each subject's repeated measures regarding the DV.

## Fixed-effects model, not adjusting for clustered observations

Our data contains repeated measures for each subject, so we have panel data in which each

subject forms a group or cluster. We can use a fixed-effects (FE) model to account for unobserved subject-specific characteristics. We do so by including the subject's `idcode` in our model formula. It's important to note that `idcode` is of type factor (we applied `idcode = as.factor(idcode)` when we prepared the data) so that for each factor level (i.e. each subject) an FE coefficient will be estimated that represents the subject-specific mean of our DV.<sup>1</sup>

Let's specify and fit such a model using `lm`. We include job tenure, union membership and an interaction between both (the latter mainly for illustrative purposes later when we estimate marginal effects). We also control for age and add `idcode` as FE variable.

```
m1 <- lm(ln_wage ~ age + tenure + union + tenure:union + idcode,
        data = nlswork)
summary(m1)
Call:
lm(formula = ln_wage ~ age + tenure + union + tenure:union +
    idcode, data = nlswork)
Residuals:
    Min       1Q   Median       3Q      Max
-0.96463 -0.09405  0.00000  0.11460  1.23525
Coefficients:
                Estimate Std. Error t value Pr(>|t|)
(Intercept)   1.882e+00  1.314e-01  14.325  < 2e-16 ***
age            5.631e-03  3.110e-03   1.811  0.071193 .
tenure         2.076e-02  6.964e-03   2.980  0.003115 **
union          1.746e-01  6.065e-02   2.879  0.004272 **
idcode2        -6.174e-01  1.285e-01  -4.803  2.47e-06 ***
idcode3        -5.625e-01  1.329e-01  -4.234  3.05e-05 ***
[...]
```

We're not really interested in the subject-specific means (the FE coefficients), so let's filter them out and only show our coefficients of interest:

```
m1coeffs_std <- data.frame(summary(m1)$coefficients)
coi_indices <- which(!startsWith(row.names(m1coeffs_std), 'idcode'))
m1coeffs_std[coi_indices,]
              Estimate Std..Error   t.value    Pr...t..
(Intercept)  1.882478232 0.131411504 14.325064 8.022367e-36
age           0.005630809 0.003109803  1.810664 7.119315e-02
tenure        0.020756426 0.006964417  2.980353 3.114742e-03
union         0.174619394 0.060646038  2.879321 4.272027e-03
tenure:union  0.014974113 0.009548509  1.568215 1.178851e-01
```

Unsurprisingly, job tenure and especially union membership are positively associated with wage. The coefficient of the interaction term shows that with union membership the job tenure effect is even a bit higher, though not significantly.

In the next two sections we'll see how standard errors for our estimates are usually computed and how this fits into a framework called "sandwich estimators." Using this framework, we'll see how the standard error calculations can be adjusted for clustered data.

## Standard errors

In ordinary least squares (OLS) regression, we assume that the regression model errors are independent. This is not the case here: Each subject may be surveyed several times so within each subject's repeated measures, the errors will be correlated. Although that is not a problem for our regression estimates (they are still unbiased [Roberts 2013]), it is a problem for the precision of our estimates — the precision will typically be overestimated, i.e. the standard errors (SEs) will be lower than they should be [Cameron and Miller 2013]. The intuition behind this regarding our example is that within our clusters we usually have lower variance since the answers come from the same subject and are correlated. This lowers our estimates' SEs.

We can deal with this using *clustered standard errors* with subjects representing our clusters. But before we do this, let's first have a closer look on how "classic" OLS estimates' SEs are actually computed.

In matrix notation, a linear model has the form

$$Y = X\beta + e.$$

This model has  $p$  parameters (including the intercept parameter  $\beta_0$ ) expressed as  $p \times 1$  parameter vector  $\beta$ . The parameters will be estimated from  $n$  observations in our data. The DV is  $Y$  (an  $n \times 1$  vector), the independent variables form an  $n \times p$  matrix  $X$ . Finally, the error term  $e$  is an  $n \times 1$  vector that captures everything that influences  $Y$  but cannot be explained by  $X\beta$ . In classic OLS, we assume that  $e$  has a mean of zero and a variance of  $\sigma^2$ .

By minimizing  $e = Y - X\beta$  an estimation for our parameters,  $\hat{\beta}$ , can be found as  $\hat{\beta} = (X^T X)^{-1} Y$ . The estimated variance  $\hat{V}[\hat{\beta}]$  for these parameters is then

$$(1) \quad \hat{V}[\hat{\beta}] = \hat{\sigma}^2 (X^T X)^{-1},$$

where  $\hat{\sigma}^2$  is the estimated variance of the error or *residual variance*. This is calculated as

$$\hat{\sigma}^2 = \frac{\sum_{i=1}^n \hat{e}_i^2}{n - p},$$

with  $\hat{e}_i$  being the residuals. The numerator is also called the *residual sum of squares* and the denominator is the *degrees of freedom*.

You can see for example in Sheather 2009 for how the formulas for  $\hat{\beta}$  and  $\hat{V}[\hat{\beta}]$  are derived or watch this video for a clear step-by-step derivation.

We now have all the pieces together to replicate the standard errors from model `m1` with our own calculations. To translate these formulae to R, we use `model.matrix` to get the design matrix  $X$ , `residuals` for the residual vector  $\hat{e}$ , `nobs` for the number of observations  $n$ , `ncol(X)` for the number of parameters, `solve` to calculate the inverse of  $X^T X$  and `diag` to extract the diagonal of a square matrix.

```
X <- model.matrix(m1)
u <- residuals(m1)
n <- nobs(m1)
p <- ncol(X)
sigma2 <- sum(u^2) / (n - p)
# solve (X^T X) A = I, where I is identity matrix -> A is (X^T X)^-1
crossXinv <- solve(t(X) %*% X, diag(p))
mlse <- sqrt(diag(sigma2 * crossXinv))
```

```
m1se
[1] 0.131411504 0.003109803 0.006964417 0.060646038 0.128532897 ...
```

Let's check if this is equal to the standard errors calculated by `lm` (using `near` because of minor deviations due to floating point number imprecision):

```
all(near(m1se, m1coeffs_std$Std..Error))
[1] TRUE
```

We extracted our parameter estimates' variance  $\hat{V}[\hat{\beta}]$  from the diagonal of the (*variance-covariance* or *vcov* matrix and R has the `vcov` function to calculate it from a fitted model. It's exactly what we computed before using eq. 1:

```
all(near(sigma2 * crossXinv, vcov(m1)))
[1] TRUE
```

## Clustered standard errors

Classic OLS SEs can be generalized so that some assumptions, namely that the regression model errors are independent, can be relaxed. The foundation for this is the *sandwich estimator*<sup>2</sup>

$$(2) \quad \hat{V}[\hat{\beta}] = (X^T X)^{-1} X^T \Omega X (X^T X)^{-1}.$$

Let's first understand how the above equation relates to eq. 1, the classic OLS parameter variance: One assumption of classic OLS is [constant variance \(or homoscedasticity\)](#) in the errors across the full spectrum of our DV. This implicates that  $\Omega$  is a diagonal matrix with identical  $\hat{\sigma}^2$  elements, i.e.  $\Omega = \hat{\sigma}^2 I$ . Plugging this into eq. 2 gives eq. 1 which shows that the classic OLS parameter variance is a specialized form of the sandwich estimator.<sup>3</sup>

When we want to obtain clustered SEs, we need to consider that  $\Omega$  in the "meat" part of eq. 2 is *not* a diagonal matrix with identical  $\hat{\sigma}^2$  elements anymore, hence this can't be simplified to eq. 1. Instead, we can assume that  $\Omega$  is block-diagonal with the clusters forming the blocks. This means we assume that the variance in the errors is constant only *within clusters* and so we first calculate  $\Omega_j$  per cluster  $j$  and then sum the  $\Omega_j$ . [Cameron and Miller 2013](#) (p. 11) show how  $\Omega$  is calculated in detail and also which finite-sample correction factor is applied. From this article we get the equation

$$(3) \quad \Omega = \frac{n-1}{n-pc-1} \frac{c}{1} \sum_{j=1}^c (X_j^T \hat{e}_j \hat{e}_j^T X_j),$$

where  $c$  is the number of clusters. It's interesting to see how the residuals are added up *per cluster* and then averaged. As [Cameron and Miller 2013](#) (p. 13) notes, this implicates an important limitation: With a low number of clusters, this averaging is imprecise.

Let's translate this formula to R. We already have  $\hat{e}$  as `u` (the residuals) and the design matrix `X`. We can generate a list of matrices  $\Omega_j$ , sum them and multiply the correction factor:

```
omegaj <- lapply(levels(nlswork$idcode), function(idcode) {
  j <- nlswork$idcode == idcode
  # drop = FALSE: don't drop dimensions when we have only one obs.
  X_j <- X[j, , drop = FALSE]
```

```
# tcrossprod is outer product x * x^T
t(X_j) %%% tcrossprod(u[j]) %%% X_j
}))

n_cl <- length(levels(nlswork$idcode)) # num. clusters
# correction factor * sum of omega_j
omega <- (n-1) / (n-p) * (n_cl / (n_cl-1)) * Reduce('+', omega_j)
# sandwich formula; extract diagonal and take square root to get SEs
mlclse <- sqrt(diag(crossXinv %%% omega %%% crossXinv))
mlclse
[1] 0.157611390 0.006339777 0.011149190 0.101970509 0.020561516 ...
```

We will later check that this matches the estimates calculated with R packages that implement clustered SE estimation. For now, let's compare the classic OLS SEs with the clustered SEs:

```
mlcoeffs_with_clse <- cbind(mlcoeffs_std, ClustSE = mlclse)
mlcoeffs_with_clse[coi_indices, c(1, 2, 5)]
```

	Estimate	Std..Error	ClustSE
(Intercept)	1.882478232	0.131411504	0.157611390
age	0.005630809	0.003109803	0.006339777
tenure	0.020756426	0.006964417	0.011149190
union	0.174619394	0.060646038	0.101970509
tenure:union	0.014974113	0.009548509	0.009646023

We can see that, as expected, the clustered SEs are all a bit higher than the classic OLS SEs.

---

The above calculations were used to show what's happening “under the hood” and also how the formulas used for these calculations are motivated. However, doing these calculations “by hand” is error-prone and slow. It's better to use well trusted packages for daily work and so next we'll have a look at some of these packages and how they can be used. Still, it's helpful to understand some background and the limitations for this approach. See [Cameron and Miller 2013](#) for a much more thorough guide (though only with examples in Stata) that also considers topics like which variable(s) to use for clustering, what to do when dealing with a low number of clusters or how to implement multi-way clustering.

## Option 1: *sandwich* and *lmtest*

The [sandwich package](#) implements several methods for robust covariance estimators, including clustered SEs. Details are explained in [Zeileis et al. 2020](#). The accompanying [lmtest package](#) provides functions for coefficient tests that take into account the calculated robust covariance estimates.

As explained initially, the parameter estimates from our model are fine despite the clustered structure of our data. But the SEs are likely biased downward and need to be corrected. This is why we can resume to work with our initially estimated model `m1` from `lm`. There's no need to refit it and `sandwich` works with `lm` model objects (and also some other types of models such as some `glm` models). We only have to adjust how we test our coefficient estimates in the following way:

1. We need to use `coeftest` from the `lmtest` package;
2. we need to pass it our model and either a function to calculate the covariance matrix or an already estimated covariance matrix to the `vcov` parameter;
3. we need to specify a cluster variable in the `cluster` parameter.

The sandwich package provides several functions for estimating robust covariance matrices. We need `vcovCL` for clustered covariance estimation and will pass this function as `vcov` parameter. Furthermore, we cluster by subject ID, so the cluster variable is `idcode`.

```
library(sandwich)
library(lmtest)

mlcoeffs_cl <- coeftest(ml, vcov = vcovCL, cluster = ~idcode)
mlcoeffs_cl[coi_indices,]
      Estimate Std. Error    t value    Pr(>|t|)
(Intercept)  1.882478232 0.157611390 11.9437956 3.667970e-27
age           0.005630809 0.006339777  0.8881715 3.751601e-01
tenure        0.020756426 0.011149190  1.8616981 6.362342e-02
union         0.174619394 0.101970509  1.7124500 8.784708e-02
tenure:union  0.014974113 0.009646023  1.5523613 1.216301e-01
```

The calculated SE values seem familiar and they are indeed equal to what we calculated before as `mlclse` “by hand”:

```
all(near(mlclse, mlcoeffs_cl[,2]))
[1] TRUE
```

The `lmtest` package provides several functions for common post-estimation tasks, for example `coefci` to calculate confidence intervals (CIs). If we use these, we need to make sure to specify the same type of covariance estimation, again by passing the appropriate `vcov` and `cluster` parameters:

```
(mlcis <- coefci(ml, parm = coi_indices, vcov = vcovCL,
                  cluster = ~idcode))
      2.5 %      97.5 %
(Intercept)  1.572314302 2.19264216
age          -0.006845258 0.01810688
tenure       -0.001184099 0.04269695
union        -0.026048678 0.37528746
tenure:union -0.004008324 0.03395655
```

This is really important, as otherwise the classic (non-clustered) covariance estimation is applied by default. This, due to lower SEs, leads to narrower CIs:

```
coefci(ml, parm = coi_indices)
      2.5 %      97.5 %
(Intercept)  1.6238731375 2.14108333
age          -0.0004889822 0.01175060
tenure        0.0070511278 0.03446172
union         0.0552738733 0.29396491
tenure:union -0.0038164264 0.03376465
```

Here, the `tenure` and `union` CIs suddenly don't include zero any more!

Instead of passing `vcovCL` as function to the `vcov` parameter, it's more convenient and computationally more efficient to calculate the covariance matrix only once using `vcovCL` and then passing this matrix to functions like `coeftest` and `coefci` instead:

```
cl_vcov_mat <- vcovCL(ml, cluster = ~idcode)
```



Now we pass this matrix for the `vcov` parameter. We don't need to specify the `cluster` parameter anymore, since this information was only needed in the previous step.

```
mlcoeffs_cl2 <- coeftest(m1, vcov = cl_vcov_mat)
all(near(mlcoeffs_cl[,2], mlcoeffs_cl2[,2]))      # same SEs?
[1] TRUE
mlcis2 <- coefci(m1, parm = coi_indices, vcov = cl_vcov_mat)
all(near(mlcis, mlcis2))      # same CIs?
[1] TRUE
```

Another example would be to calculate marginal effects, for example with the [margins](#) package. Again, to arrive at clustered SEs we will need to pass the proper covariance matrix via the `vcov` parameter. We do this for the marginal effect of `tenure` at the two levels of `union`:

```
library(margins)

margins(m1, vcov = cl_vcov_mat, variables = 'tenure',
        at = list(union = 0:1)) %>%
  summary()
factor union    AME    SE      z      p  lower upper
tenure 0.0000 0.0208 0.0111 1.8617 0.0626 -0.0011 0.0426
tenure 1.0000 0.0357 0.0083 4.3089 0.0000 0.0195 0.0520
```

Otherwise classic SEs are estimated, which are smaller:

```
margins(m1, variables = 'tenure', at = list(union = 0:1)) %>% summary()
factor union    AME    SE      z      p  lower upper
tenure 0.0000 0.0208 0.0070 2.9804 0.0029 0.0071 0.0344
tenure 1.0000 0.0357 0.0081 4.3846 0.0000 0.0198 0.0517
```

As you can see, the combination of `lm` and the packages `sandwich` and `lmtest` are all you need for estimating clustered SEs and inference. However, you really need to be careful to include the covariance matrix at all steps of your calculations.

## Option 2: `lm.cluster` from *miceadds*

There's also `lm.cluster` from the package [miceadds](#)<sup>4</sup>, which may be a bit more convenient to use. Internally, it basically does the same that we've done before by employing `sandwich`'s `vcovCL` (see source code parts [here](#) and [there](#) for example).

Instead of using `lm`, we fit the model with `lm.cluster` and specify a cluster variable (this time as string, not as formula). The model summary then contains the clustered SEs:

```
library(miceadds)

m2 <- lm.cluster(ln_wage ~ age + tenure + union + tenure:union +
  idcode,
               cluster = 'idcode',
               data = nlswork)
m2coeffs <- data.frame(summary(m2))
m2coeffs[!startsWith(row.names(m2coeffs), 'idcode'),]
      Estimate Std..Error   t.value Pr...t..
(Intercept)  1.882478232 0.157611390 11.9437956 6.995639e-33
```

```

age          0.005630809 0.006339777 0.8881715 3.744485e-01
tenure       0.020756426 0.011149190 1.8616981 6.264565e-02
union        0.174619394 0.101970509 1.7124500 8.681378e-02
tenure:union 0.014974113 0.009646023 1.5523613 1.205758e-01

```

An object `m` that is returned from `lm.cluster` is a list that contains the `lm` object as `m$lmres` and the covariance matrix as `m$vcov`. Again, these objects need to be “dragged along” if we want to do further computations. For `margins`, we also need to pass the data again via `data = nlswork`:

```

margins(m2$lm_res, vcov = m2$vcov, variables = 'tenure',
        at = list(union = 0:1), data = nlswork) %>%
  summary()

```

factor	union	AME	SE	z	p	lower	upper
tenure	0.0000	0.0208	0.0111	1.8617	0.0626	-0.0011	0.0426
tenure	1.0000	0.0357	0.0083	4.3089	0.0000	0.0195	0.0520

The result is consistent with our former computations. The advantage over the “`lm + sandwich + lmtest`” approach is that you can do clustered SE estimation and inference in one go. For further calculations you still need to be careful to supply the covariance matrix from `m$vcov`.

### Option 3: `lm_robust` from *estimatr*

Another option is to use `lm_robust` from the [estimatr](#) package which is part of the [DeclareDesign framework \[Blair et al. 2019\]](#). Like `lm.cluster`, it’s more convenient to use, but it doesn’t rely on `sandwich` and `lmtest` in the background and instead comes with an own implementation for model fitting and covariance estimation. This implementation is [supposed to be faster](#) than the other approaches and we’ll check that for our example later.

But first, let’s fit a model with clustered SEs using `lm_robust`. We use the same formula as with `lm` or `lm.cluster`, but also specify the `clusters` parameter: <sup>5</sup>

```

library(estimatr)

m3 <- lm_robust(ln_wage ~ age + tenure + union + tenure:union + idcode,
               clusters = idcode,
               data = nlswork)

summary(m3)

```

Call:

```

lm_robust(formula = ln_wage ~ age + tenure + union + tenure:union +
          idcode, data = nlswork, clusters = idcode)

```

Standard error type: CR2

Coefficients:

	Estimate	Std. Error	t value	Pr(> t )	CI Lower	CI
Upper						
(Intercept)	1.882e+00	0.141424	13.310872	8.596e-14	1.5930761	
2.171880						28.642
age	5.631e-03	0.005726	0.983442	3.342e-01	-0.0061215	
0.017383						26.790
tenure	2.076e-02	0.010089	2.057345	5.771e-02	-0.0007714	
0.042284						14.812
union	1.746e-01	0.093790	1.861817	7.735e-02	-0.0209918	

```
0.370231 20.049
  idcode2      -6.174e-01    0.019094 -32.334722 2.810e-07 -0.6656871
-0.569086  5.283
  idcode3      -5.625e-01    0.078607  -7.156034 9.687e-07 -0.7273116
-0.397718 18.550
```

Unlike `lm`, `lm_robust` allows to specify fixed effects in a separate `fixed_effects` formula parameter which, according to the [documentation](#), should speed up computation for many types of SEs. Furthermore, this cleans up the summary output since there are no more FE coefficients:

```
m3fe <- lm_robust(ln_wage ~ age + tenure + union + tenure:union,
                  clusters = idcode,
                  fixed_effects = ~idcode,
                  data = nlswork)

summary(m3fe)
Call:
lm_robust(formula = ln_wage ~ age + tenure + union + tenure:union,
          data = nlswork, clusters = idcode, fixed_effects = ~idcode)
Standard error type: CR2
Coefficients:
              Estimate Std. Error t value Pr(>|t|)    CI Lower CI Upper
DF
age              0.005631   0.005726   0.9834  0.33419 -0.0061215  0.01738
26.790
tenure           0.020756   0.010089   2.0573  0.05771 -0.0007714  0.04228
14.812
union            0.174619   0.093790   1.8618  0.07735 -0.0209918  0.37023
20.049
tenure:union     0.014974   0.009043   1.6558  0.14062 -0.0062982  0.03625
7.187
Multiple R-squared:  0.7554 ,    Adjusted R-squared:  0.6861
[...]
```

When we compare the results from `lm_robust` with `lm`, we can see that the point estimates are the same. The `lm_robust` SEs are, as expected, higher than the “classic” SEs from `lm`. However, the `lm_robust` SEs are also a bit smaller than those calculated from `sandwich::vcovCL`:

```
m3fe_df <- tidy(m3fe) %>% rename(est.lm_robust = estimate,
                                se.lm_robust = std.error)
m3fe_df$se.sandwich <- mlcoeffs_cl[coi_indices,2][2:5]
m3fe_df$est.classic <- mlcoeffs_std[coi_indices,1][2:5]
m3fe_df$se.classic <- mlcoeffs_std[coi_indices,2][2:5]
m3fe_df[c('term', 'est.classic', 'est.lm_robust', 'se.classic',
          'se.lm_robust', 'se.sandwich')]
      term est.classic est.lm_robust se.classic se.lm_robust
se.sandwich
      age 0.005630809   0.005630809 0.003109803  0.005725617
0.006339777
      tenure 0.020756426   0.020756426 0.006964417  0.010088940
0.011149190
```

```

      union 0.174619394    0.174619394 0.060646038    0.093789776
0.101970509
    tenure:union 0.014974113    0.014974113 0.009548509    0.009043429
0.009646023

```

This is because `lm_robust` by default uses a different cluster-robust variance estimator “*to correct hypotheses tests for small samples and work with commonly specified fixed effects and weights*” as explained in the [Getting started vignette](#). Details can be found in the [Mathematical notes for estimatr](#).

As with the `lm` and `lm.cluster` results, we can also estimate marginal effects with a `lm_robust` result object. However, this doesn't seem to work when you specify FEs via `fixed_effects` parameter as done for `m3fe`:

```

margins(m3fe, variables = 'tenure', at = list(union = 0:1)) %>%
  summary()
Error in predict.lm_robust(model, newdata = data, type = type, se.fit =
TRUE, :
  Can't set `se.fit` == TRUE with `fixed_effects`

```

With `m3` (where FEs were directly specified in the model formula), marginal effects estimation works and we don't even need to pass a separate `vcov` matrix, since this information already comes with the `lm_robust` result object `m3`.<sup>6</sup>

```

margins(m3, variables = 'tenure', at = list(union = 0:1)) %>% summary()
factor union    AME    SE      z      p lower upper
tenure 0.0000 0.0208 0.0101 2.0573 0.0397 0.0010 0.0405
tenure 1.0000 0.0357 0.0077 4.6174 0.0000 0.0206 0.0509

```

As already said, `lm_robust` uses a different variance estimator than `sandwich`'s `vcovCL` and Stata. However, by setting `se_type` to `'stata'` we can replicate these “Stata Clustered SEs”:

```

m3stata <- lm_robust(ln_wage ~ age + tenure + union + tenure:union +
idcode,
                    clusters = idcode,
                    se_type = 'stata',
                    data = nlswork)
m3stata_se <- tidy(m3stata) %>% pull(std.error)
all(near(m3stata_se, mlclse)) # same SEs?
[1] TRUE

```

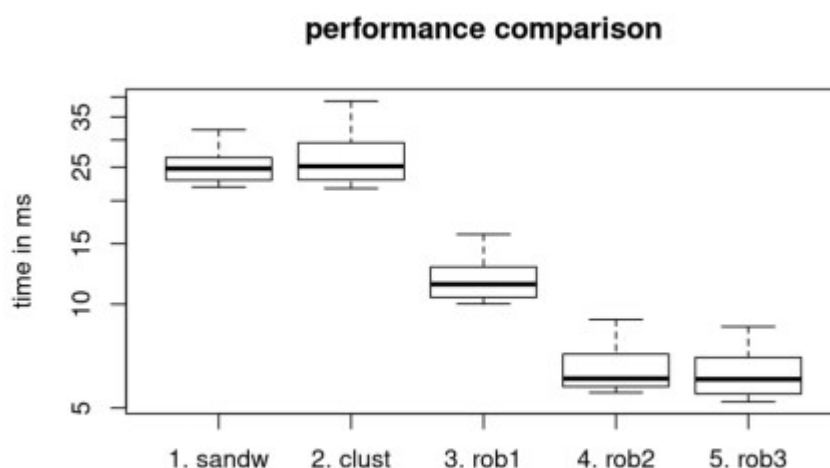
In summary, `lm_robust` is as convenient to use as `lm` or `lm.cluster`, but offers similar flexibility as `sandwich` for estimating clustered SEs. A big advantage is that you don't need to care about supplying the right covariance matrix to further post-estimation functions like `margins`. The proper covariance matrix is directly attached to the fitted `lm_robust` object (and can be accessed via `model$vcov` or `vcov(model)` if you need to). Is parameter estimation also faster with `lm_robust`?

## Performance comparison

We'll make a rather superficial performance comparison only using the `nlswork` dataset and [microbenchmark](#). We will compare the following implementations for estimating model coefficients and clustered SEs:

1. `lm` and `vcovCL` from `sandwich`
2. `lm.cluster`
3. `lm_robust` with default SEs (`se_type = 'CR2'`)
4. `lm_robust` with Stata SEs (`se_type = 'stata'`)
5. `lm_robust` with `fixed_effects` parameter and Stata SEs (`fixed_effects = idcode, se_type = 'stata'`)

For a fair comparison, we don't calculate CIs (which `lm_robust` by default does). These are the results for 100 test runs:



As expected, `lm/sandwich` and `lm.cluster` have similar run times. `lm_robust` is faster for all three configurations (3. to 5.) and is especially fast when estimating Stata SEs (4. and 5.). With our example data, specifying `fixed_effects` (5.) doesn't seem to speed up the calculations.

## Conclusion

We've seen that it's important to account for clusters in data when estimating model parameters, since ignoring this fact will likely result in overestimated precision which in turn can lead to wrong inference. R provides many ways to estimate clustered SEs. The packages `sandwich` and `lmtest` come with a rich set of tools for this task (and also for other types of robust SEs) and work with `lm` and other kinds of models. `lm.cluster` from the `miceadds` package provides a more convenient wrapper around `sandwich` and `lmtest`. However, users should be careful to not forget passing along the separate cluster robust covariance matrix for post-estimation tasks. This is something users don't need to care for when using `lm_robust` from the `estimatr` package, since the covariance matrix is not separate from the fitted model object. Another advantage is that `lm_robust` seems to be faster than the other options.