Description

`regress` performs ordinary least-squares linear regression. `regress` can also perform weighted estimation, compute robust and cluster–robust standard errors, and adjust results for complex survey designs.

Quick start

Simple linear regression of \( y \) on \( x_1 \)

\[
\text{regress } y \ x_1
\]

Regression of \( y \) on \( x_1, x_2 \), and indicators for categorical variable \( a \)

\[
\text{regress } y \ x_1 \ x_2 \ i.a
\]

Add the interaction between continuous variable \( x_2 \) and \( a \)

\[
\text{regress } y \ x_1 \ c.x2##i.a
\]

Fit model for observations where \( v_1 \) is greater than zero

\[
\text{regress } y \ x_1 \ x_2 \ i.a \text{ if } v_1>0
\]

With cluster–robust standard errors for clustering by levels of \( cvar \)

\[
\text{regress } y \ x_1 \ x_2 \ i.a \text{, vce(cluster cvar)}
\]

With bootstrap standard errors

\[
\text{regress } y \ x_1 \ x_2 \ i.a \text{, vce(bootstrap)}
\]

Report standardized coefficients

\[
\text{regress } y \ x_1 \ x_2 \ i.a \text{, beta}
\]

Adjust for complex survey design using `svyset` data

\[
\text{svy: regress } y \ x_1 \ x_2 \ i.a
\]

Use sampling weight \( wvar \)

\[
\text{regress } y \ x_1 \ x_2 \ i.a \text{ [pweight=wvar]}
\]

Menu

Statistics > Linear models and related > Linear regression
regress — Linear regression

Syntax

```
regress depvar [indepvars] [if] [in] [weight] [ , options ]
```

**options**

<table>
<thead>
<tr>
<th>Model</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>noconstant</td>
<td>suppress constant term</td>
</tr>
<tr>
<td>hascons</td>
<td>has user-supplied constant</td>
</tr>
<tr>
<td>tsscons</td>
<td>compute total sum of squares with constant; seldom used</td>
</tr>
</tbody>
</table>

**SE/Robust**

```
vce(vcetype)
```

*vcetype* may be *ols*, *robust*, *cluster clustvar*, *bootstrap*, *jackknife*, *hc2*, or *hc3*

**Reporting**

```
level(#)        set confidence level; default is level(95)
beta           report standardized beta coefficients
eform(string)  report exponentiated coefficients and label as *string*
depname(varname) substitute dependent variable name; programmer’s option
display_options control columns and column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling

noheader        suppress output header
notable         suppress coefficient table
plus            make table extendable
mse1            force mean squared error to 1
coeflegend      display legend instead of statistics
```

**Options**

`indepvars` may contain factor variables; see [U] 11.4.3 Factor variables.

`depvar` and `indepvars` may contain time-series operators; see [U] 11.4.4 Time-series varlists.

`bayes`, `bootstrap`, `by`, `collect`, `fmm`, `fp`, `jackknife`, `mfp`, `mi estimate`, `nestreg`, `rolling`, `statsby`, `stepwise`, and `svy` are allowed; see [U] 11.1.10 Prefix commands. For more details, see [BAYES] bayes: regress and [FMM] fmm: regress.

`vce(bootstrap)` and `vce(jackknife)` are not allowed with the `mi estimate` prefix; see [MI] mi estimate.

Weights are not allowed with the `bootstrap` prefix; see [R] bootstrap.

`aweights` are not allowed with the `jackknife` prefix; see [R] jackknife.

`hascons`, `tsscons`, `vce()`, `beta`, `noheader`, `notable`, `plus`, `depname()`, `mse1`, and weights are not allowed with the `svy` prefix; see [SVY] svy.

`aweights`, `fweights`, `iweights`, and `pweights` are allowed; see [U] 11.1.6 weight.

`noheader`, `notable`, `plus`, `mse1`, and `coeflegend` do not appear in the dialog box.

See [U] 20 Estimation and postestimation commands for more capabilities of estimation commands.

`noconstant`; see [R] Estimation options.

`hascons` indicates that a user-defined constant or its equivalent is specified among the independent variables in `indepvars`. Some caution is recommended when specifying this option, as resulting
estimates may not be as accurate as they otherwise would be. Use of this option requires “sweeping” the constant last, so the moment matrix must be accumulated in absolute rather than deviation form. This option may be safely specified when the means of the dependent and independent variables are all reasonable and there is not much collinearity between the independent variables. The best procedure is to view hascons as a reporting option—estimate with and without hascons and verify that the coefficients and standard errors of the variables not affected by the identity of the constant are unchanged.

The hascons option forces the total sum of squares to be computed as though the model has a constant, that is, as deviations from the mean of the dependent variable. This is a rarely used option that has an effect only when specified with noconstant. It affects the total sum of squares and all results derived from the total sum of squares.

\[ SE/Robust \]

vce(vcetype) specifies the type of standard error reported, which includes types that are derived from asymptotic theory (ols), that are robust to some kinds of misspecification (robust), that allow for intragroup correlation (cluster clustvar), and that use bootstrap or jackknife methods (bootstrap, jackknife); see [R] vce_option.

vce(ols), the default, uses the standard variance estimator for ordinary least-squares regression.

regress also allows the following:

vce(hc2) and vce(hc3) specify alternative bias corrections for the robust variance calculation.

vce(hc2) and vce(hc3) may not be specified with the svy prefix. In the unclustered case, vce(robust) uses \( \hat{\sigma}_j^2 = \frac{n}{n-k} u_j^2 \) as an estimate of the variance of the \( j \)th observation, where \( u_j \) is the calculated residual and \( n/(n-k) \) is included to improve the overall estimate’s small-sample properties.

vce(hc2) instead uses \( u_j^2/(1-h_{jj}) \) as the observation’s variance estimate, where \( h_{jj} \) is the diagonal element of the hat (projection) matrix. This estimate is unbiased if the model really is homoskedastic. vce(hc2) tends to produce slightly more conservative confidence intervals.

vce(hc3) uses \( u_j^2/(1-h_{jj})^2 \) as suggested by Davidson and MacKinnon (1993), who report that this method tends to produce better results when the model really is heteroskedastic.

vce(hc3) produces confidence intervals that tend to be even more conservative.

See Davidson and MacKinnon (1993, 554–556) and Angrist and Pischke (2009, 294–308) for more discussion on these two bias corrections.

\[ Reporting \]

level(#)\); see [R] Estimation options.

beta asks that standardized beta coefficients be reported instead of confidence intervals. The beta coefficients are the regression coefficients obtained by first standardizing all variables to have a mean of 0 and a standard deviation of 1. beta may not be specified with vce(cluster clustvar) or the svy prefix.

eform(string) is used only in programs and ado-files that use regress to fit models other than linear regression. eform() specifies that the coefficient table be displayed in exponentiated form as defined in [R] Maximize and that string be used to label the exponentiated coefficients in the table.

depname(varname) is used only in programs and ado-files that use regress to fit models other than linear regression. depname() may be specified only at estimation time. varname is recorded as the identity of the dependent variable, even though the estimates are calculated using depvar. This
method affects the labeling of the output—not the results calculated—but could affect subsequent calculations made by predict, where the residual would be calculated as deviations from varname rather than depvar. depname() is most typically used when depvar is a temporary variable (see [P] macro) used as a proxy for varname.

depname() is not allowed with the svy prefix.

display_options: noci, nopvalues, noomitted, vsquish, noemptycells, baselevels, allbaselevels, noflabel, fvwrap(#), fvwrapon(style), cformat(%,fmt), pformat(%,fmt), sformat(%,fmt), and nolstretch; see [R] Estimation options.

The following options are available with regress but are not shown in the dialog box:

noheader suppresses the display of the ANOVA table and summary statistics at the top of the output; only the coefficient table is displayed. This option is often used in programs and ado-files.

notable suppresses display of the coefficient table.

plus specifies that the output table be made extendable. This option is often used in programs and ado-files.

mse1 is used only in programs and ado-files that use regress to fit models other than linear regression and is not allowed with the svy prefix. mse1 sets the mean squared error to 1, forcing the variance–covariance matrix of the estimators to be \((X'X)^{-1}\) (see Methods and formulas below) and affecting calculated standard errors. Degrees of freedom for \(t\) statistics is calculated as \(n\) rather than \(n - k\).

coeflegend; see [R] Estimation options.

Remarks and examples

regress performs linear regression, including ordinary least squares and weighted least squares. See [U] 27 Overview of Stata estimation commands for a list of other regression commands that may be of interest. For a general discussion of linear regression, see Kutner et al. (2005).

See Stock and Watson (2019) and Wooldridge (2020) for an excellent treatment of estimation, inference, interpretation, and specification testing in linear regression models. See Wooldridge (2010, chap. 4) for a more advanced discussion along the same lines.

See Hamilton (2013, chap. 7) and Cameron and Trivedi (2010, chap. 3) for an introduction to linear regression using Stata. Dohoo, Martin, and Stryhn (2012, 2010) discuss linear regression using examples from epidemiology, and Stata datasets and do-files used in the text are available. Cameron and Trivedi (2010) discuss linear regression using econometric examples with Stata. Mitchell (2021) shows how to use graphics and postestimation commands to understand a fitted regression model.

Chatterjee and Hadi (2012) explain regression analysis by using examples containing typical problems that you might encounter when performing exploratory data analysis. We also recommend Weisberg (2014), who emphasizes the importance of the assumptions of linear regression and problems resulting from these assumptions. Becketti (2020) discusses regression analysis with an emphasis on time-series data. Angrist and Pischke (2009) approach regression as a tool for exploring relationships,
estimating treatment effects, and providing answers to public policy questions. For a mathematically
rigorous treatment, see Peracchi (2001, chap. 6). Finally, see Plackett (1972) if you are interested in
the history of regression. Least squares, which dates back to the 1790s, was discovered independently
by Legendre and Gauss.

## Ordinary least squares

### Example 1: Basic linear regression

Suppose that we have data on the mileage rating and weight of 74 automobiles. The variables in
our data are mpg, weight, and foreign. The last variable assumes the value 1 for foreign and 0 for
domestic automobiles. We wish to fit the model

\[
\text{mpg} = \beta_0 + \beta_1 \text{weight} + \beta_2 \text{foreign} + \epsilon
\]

This model can be fit with `regress` by typing

```
. use https://www.stata-press.com/data/r17/auto
(1978 automobile data)
. regress mpg weight foreign
```

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>Number of obs = 74</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>1619.2877</td>
<td>2</td>
<td>809.643849</td>
<td>F(2, 71) = 69.75</td>
</tr>
<tr>
<td>Residual</td>
<td>824.171761</td>
<td>71</td>
<td>11.608053</td>
<td>Prob &gt; F = 0.0000</td>
</tr>
<tr>
<td>Total</td>
<td>2443.45946</td>
<td>73</td>
<td>33.4720474</td>
<td>Adj R-squared = 0.6532</td>
</tr>
</tbody>
</table>

| mpg     | Coefficient | Std. err. | t    | P>|t| | [95% conf. interval] |
|---------|-------------|-----------|------|------|---------------------|
| weight  | -.0065879   | .0006371  | -10.34 | 0.000 | -.0078583 -.0053175 |
| foreign | -1.650029   | 1.075994  | -1.53 | 0.130 | -3.7955 .4954422   |
| _cons   | 41.6797     | 2.165547  | 19.25 | 0.000 | 37.36172 45.99768   |

`regress` produces a variety of summary statistics along with the table of regression coefficients.
At the upper left, `regress` reports an analysis-of-variance (ANOVA) table. The column headings SS,
df, and MS stand for “sum of squares”, “degrees of freedom”, and “mean square”, respectively. In
this example, the total sum of squares is 2,443.5: 1,619.3 accounted for by the model and 824.2 left
unexplained. Because the regression included a constant, the total sum reflects the sum after removal
of means, as does the sum of squares due to the model. The table also reveals that there are 73
total degrees of freedom (counted as 74 observations less 1 for the mean removal), of which 2 are
consumed by the model, leaving 71 for the residual.

To the right of the ANOVA table are presented other summary statistics. The \( F \) statistic associated
with the ANOVA table is 69.75. The statistic has 2 numerator and 71 denominator degrees of freedom.
The \( F \) statistic tests the hypothesis that all coefficients excluding the constant are zero. The chance of
observing an \( F \) statistic that large or larger is reported as 0.0000, which is Stata’s way of indicating
a number smaller than 0.00005. The \( R^2 \) for the regression is 0.6627, and the \( R^2 \) adjusted for degrees
of freedom (\( \hat{R}^2 \)) is 0.6532. The root mean squared error, labeled Root MSE, is 3.4071. It is the square
root of the mean squared error reported for the residual in the ANOVA table.

Finally, Stata produces a table of the estimated coefficients. The first line of the table indicates
that the left-hand-side variable is `mpg`. Thereafter follow the estimated coefficients. Our fitted model is

\[
\text{mpg}_\text{hat} = 41.68 - 0.0066 \text{weight} - 1.65 \text{foreign}
\]
Reported to the right of the coefficients in the output are the standard errors. For instance, the standard error for the coefficient on weight is 0.0006371. The corresponding $t$ statistic is $-10.34$, which has a two-sided significance level of 0.000. This number indicates that the significance is less than 0.0005. The 95% confidence interval for the coefficient is $[-0.0079, -0.0053]$.

### Example 2: Transforming the dependent variable

If we had a graph comparing mpg with weight, we would notice that the relationship is distinctly nonlinear. This is to be expected because energy usage per distance should increase linearly with weight, but mpg is measuring distance per energy used. We could obtain a better model by generating a new variable measuring the number of gallons used per 100 miles (gp100m) and then using this new variable in our model:

$$gp100m = \beta_0 + \beta_1 \text{weight} + \beta_2 \text{foreign} + \epsilon$$

We can now fit this model:

```
. generate gp100m = 100/mpg
. regress gp100m weight foreign
```

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>Number of obs = 74</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>91.1761694</td>
<td>2</td>
<td>45.5880847</td>
<td>F(2, 71) = 113.97</td>
</tr>
<tr>
<td>Residual</td>
<td>28.4000913</td>
<td>71</td>
<td>.400001287</td>
<td>Prob &gt; F = 0.0000</td>
</tr>
<tr>
<td>Total</td>
<td>119.576261</td>
<td>73</td>
<td>1.63803097</td>
<td>R-squared = 0.7625</td>
</tr>
</tbody>
</table>

| gp100m | Coefficient | Std. err. | t    | P>|t| | [95% conf. interval] |
|--------|-------------|-----------|------|------|---------------------|
| weight | .0016254    | .0001183  | 13.74| 0.000| .0013896 .0018612   |
| foreign| .6220535    | .1997381  | 3.11 | 0.003| .2237871 1.02032    |
| _cons  | -.0734839   | .4019932  | -0.18| 0.855| -.8750354 .7280677  |

Fitting the physically reasonable model increases our $R^2$ to 0.7625.

### Example 3: Obtaining beta coefficients

`regress` shares the features of all estimation commands. Among other things, this means that after running a regression, we can use `test` to test hypotheses about the coefficients, `estat vce` to examine the covariance matrix of the estimators, and `predict` to obtain predicted values, residuals, and influence statistics. See [U] 20 Estimation and postestimation commands. Options that affect how estimates are displayed, such as `beta` or `level()`, can be used when replaying results.
Suppose that we meant to specify the \texttt{beta} option to obtain beta coefficients (regression coefficients normalized by the ratio of the standard deviation of the regressor to the standard deviation of the dependent variable). Even though we forgot, we can specify the option now:

```
regress, beta
```

```
Source | SS        | df | MS
------|-----------|----|-----
Model  | 91.1761694| 2  | 45.5880847 F(2, 71) = 113.97
Residual | 28.4000913 | 71 | .400001287 Prob > F = 0.0000
Total  | 119.576261 | 73 | 1.63803097

Weight | Coefficient | Std. err. | t  | P>|t| | Beta
------|-------------|-----------|----|-----|-----
weight  | .0016254    | .0001183  | 13.74 | 0.000 | .9870255
foreign | .6220535    | .1997381  | 3.11 | 0.003 | .2236673
_cons   | -.0734839   | .4019932  | -0.18 | 0.855 | .
```

### Treatment of the constant

By default, \texttt{regress} includes an intercept (constant) term in the model. The \texttt{noconstant} option suppresses it, and the \texttt{hascons} option tells \texttt{regress} that the model already has one.

#### Example 4: Suppressing the constant term

We wish to fit a regression of the \texttt{weight} of an automobile against its \texttt{length}, and we wish to impose the constraint that the weight is zero when the length is zero.

If we simply type \texttt{regress weight length}, we are fitting the model

\[
weight = \beta_0 + \beta_1 \text{length} + \epsilon
\]

Here a \texttt{length} of zero corresponds to a \texttt{weight} of \(\beta_0\). We want to force \(\beta_0\) to be zero or, equivalently, estimate an equation that does not include an intercept:

\[
weight = \beta_1 \text{length} + \epsilon
\]

We do this by specifying the \texttt{noconstant} option:

```
regress weight length, noconstant
```

```
Source | SS        | df | MS
------|-----------|----|-----
Model  | 703869302 | 1  | 703869302 F(1, 73) = 3450.13
Residual | 14892897.8 | 73 | 204012.299 Prob > F = 0.0000
Total  | 718762200 | 74 | 9713002.7 R-squared = 0.9793

Weight | Coefficient | Std. err. | t  | P>|t| | 95% conf. interval
------|-------------|-----------|----|-----|----------------------
length | 16.29829    | .2774752  | 58.74 | 0.000 | 15.74528 16.8513
```

In our data, \texttt{length} is measured in inches and \texttt{weight} in pounds. We discover that each inch of length adds 16 pounds to the weight.
Sometimes there is no need for Stata to include a constant term in the model. Most commonly, this occurs when the model contains a set of mutually exclusive indicator variables. hascons is a variation of the noconstant option—it tells Stata not to add a constant to the regression because the regression specification already has one, either directly or indirectly.

For instance, we now refit our model of weight as a function of length and include separate constants for foreign and domestic cars by specifying bn.foreign. bn.foreign is factor-variable notation for “no base for foreign” or “include all levels of variable foreign in the model”; see [U] 11.4.3 Factor variables.

```
. regress weight length bn.foreign, hascons
```

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>39647744.7</td>
<td>2</td>
<td>19823872.3</td>
</tr>
<tr>
<td>Residual</td>
<td>4446433.7</td>
<td>71</td>
<td>62625.8268</td>
</tr>
<tr>
<td>Total</td>
<td>44094178.4</td>
<td>73</td>
<td>604029.841</td>
</tr>
</tbody>
</table>

| weight | Coefficient | Std. err. | t | P>|t| | [95% conf. interval] |
|--------|-------------|-----------|---|----|---------------------|
| length | 31.44455 | 1.601234 | 19.64 | 0.000 | 28.25178 - 34.63732 |
| foreign | | | | | |
| Domestic | -2850.25 | 315.9691 | -9.02 | 0.000 | -3480.274 - 2220.225 |
| Foreign | -2983.927 | 275.1041 | -10.85 | 0.000 | -3532.469 - 2435.385 |

**Technical note**

There is a subtle distinction between the hascons and noconstant options. We can most easily reveal it by refitting the last regression, specifying noconstant rather than hascons:

```
. regress weight length bn.foreign, noconstant
```

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>714315766</td>
<td>3</td>
<td>238105255</td>
</tr>
<tr>
<td>Residual</td>
<td>4446433.7</td>
<td>71</td>
<td>62625.8268</td>
</tr>
<tr>
<td>Total</td>
<td>718762200</td>
<td>74</td>
<td>9713002.7</td>
</tr>
</tbody>
</table>

| weight | Coefficient | Std. err. | t | P>|t| | [95% conf. interval] |
|--------|-------------|-----------|---|----|---------------------|
| length | 31.44455 | 1.601234 | 19.64 | 0.000 | 28.25178 - 34.63732 |
| foreign | | | | | |
| Domestic | -2850.25 | 315.9691 | -9.02 | 0.000 | -3480.274 - 2220.225 |
| Foreign | -2983.927 | 275.1041 | -10.85 | 0.000 | -3532.469 - 2435.385 |

Comparing this output with that produced by the previous regress command, we see that they are almost, but not quite, identical. The parameter estimates and their associated statistics—the second half of the output—are identical. The overall summary statistics and the ANOVA table—the first half of the output—are different, however.

In the first case, the $R^2$ is shown as 0.8992; here it is shown as 0.9938. In the first case, the $F$ statistic is 316.54; now it is 3,802.03. The numerator degrees of freedom is different as well. In the first case, the numerator degrees of freedom is 2; now the degrees of freedom is 3. Which is correct?
Both are. Specifying the hascons option causes regress to adjust the ANOVA table and its associated statistics for the explanatory power of the constant. The regression in effect has a constant; it is just written in such a way that a separate constant is unnecessary. No such adjustment is made with the noconstant option.

## Technical note

When the hascons option is specified, regress checks to make sure that the model does in fact have a constant term. If regress cannot find a constant term, it automatically adds one. Fitting a model of weight on length and specifying the hascons option, we obtain

```
. regress weight length, hascons
note: option hascons false.

Source | SS          | df | MS
------|-------------|----|---
Model  | 39461306.8  | 1  | 39461306.8
Residual | 4632871.55 | 72 | 64345.4382
Total  | 44094178.4 | 73 | 604029.841

weight  | Coefficient | Std. err. | t  | P>|t|  | [95% conf. interval]
length  | 33.01988    | 1.333364  | 24.76 | 0.000 | 30.36187 - 35.67789
_cons   | -3186.047  | 252.3113  | -12.63 | 0.000 | -3689.02 - 2683.073
```

Even though we specified hascons, regress included a constant, anyway. It also added a note to our output: “note: option hascons false”.

## Technical note

Even if the model specification effectively includes a constant term, we need not specify the hascons option. regress is always on the lookout for collinear variables and omits them from the model. For instance,

```
. regress weight length bn.foreign
note: i.foreign omitted because of collinearity.

Source | SS          | df | MS
------|-------------|----|---
Model  | 39647744.7  | 2  | 19823872.3
Residual | 4446433.7  | 71 | 62625.8268
Total  | 44094178.4 | 73 | 604029.841

weight  | Coefficient | Std. err. | t  | P>|t|  | [95% conf. interval]
length  | 31.44455    | 1.601234  | 19.64 | 0.000 | 28.25178 - 34.63732
foreign  | Domestic    | 133.6775  | 77.47615 | 1.73 | 0.089 | -20.80555 - 288.1605
          | Foreign     | 0 (omitted) |          |     |     |            
_cons   | -2983.927  | 275.1041  | -10.85 | 0.000 | -3532.469 -2435.385
```
Robust standard errors

`regress` with the `vce(robust)` option substitutes a robust variance matrix calculation for the conventional calculation, or if `vce(cluster clustvar)` is specified, allows relaxing the assumption of independence within groups. How this method works is explained in [U] 20.22 Obtaining robust variance estimates. Below, we show how well this approach works.

Example 5: Heteroskedasticity and robust standard errors

Specifying the `vce(robust)` option is equivalent to requesting White-corrected standard errors in the presence of heteroskedasticity. We use the automobile data and, in the process of looking at the energy efficiency of cars, analyze a variable with considerable heteroskedasticity.

We will examine the amount of energy—measured in gallons of gasoline—that the cars in the data need to move 1,000 pounds of their weight 100 miles. We are going to examine the relative efficiency of foreign and domestic cars.

```
. generate gpmw = ((1/mpg)/weight)*100*1000
. summarize gpmw
```

<table>
<thead>
<tr>
<th>Variable</th>
<th>Obs</th>
<th>Mean</th>
<th>Std. dev.</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>gpmw</td>
<td>74</td>
<td>1.682184</td>
<td>.2426311</td>
<td>1.09553</td>
<td>2.30521</td>
</tr>
</tbody>
</table>

In these data, the engines consume between 1.10 and 2.31 gallons of gas to move 1,000 pounds of the car’s weight 100 miles. If we ran a regression with conventional standard errors of `gpmw` on `foreign`, we would obtain

```
. regress gpmw foreign
```

```
<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>Number of obs = 74</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>.936705572</td>
<td>1</td>
<td>.936705572</td>
<td>F(1, 72) = 20.07</td>
</tr>
<tr>
<td>Residual</td>
<td>3.36079459</td>
<td>72</td>
<td>.046677703</td>
<td>Prob &gt; F = 0.0000</td>
</tr>
<tr>
<td>Total</td>
<td>4.29750017</td>
<td>73</td>
<td>.058869865</td>
<td>R-squared = 0.2180</td>
</tr>
</tbody>
</table>

| gpmw | Coefficient | Std. err. | t     | P>|t|   | [95% conf. interval] |
|------|-------------|-----------|------|-------|---------------------|
| foreign | .2461526    | .0549487  | 4.48 | 0.000 | .1366143 .3556909   |
| _cons  | 1.609004    | .0299608  | 53.70| 0.000 | 1.549278 1.655758    |
```

`regress` with the `vce(robust)` option, on the other hand, reports

```
. regress gpmw foreign, vce(robust)
```

```
<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>Number of obs = 74</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>.936705572</td>
<td>1</td>
<td>.936705572</td>
<td>F(1, 72) = 13.13</td>
</tr>
<tr>
<td>Residual</td>
<td>3.36079459</td>
<td>72</td>
<td>.046677703</td>
<td>Prob &gt; F = 0.0005</td>
</tr>
<tr>
<td>Total</td>
<td>4.29750017</td>
<td>73</td>
<td>.058869865</td>
<td>R-squared = 0.2180</td>
</tr>
</tbody>
</table>

| gpmw | Coefficient | Std. err. | t     | P>|t|   | [95% conf. interval] |
|------|-------------|-----------|------|-------|---------------------|
| foreign | .2461526    | .0679238  | 3.62 | 0.001 | .1107489 .3815563   |
| _cons  | 1.609004    | .0234535  | 68.60| 0.000 | 1.56225 1.655758    |
```

The point estimates are the same (foreign cars need one-quarter gallon more gas), but the standard errors differ by roughly 20%. Conventional regression reports the 95% confidence interval as [0.14, 0.36], whereas the robust standard errors make the interval [0.11, 0.38].
Which is right? Notice that \texttt{gpmw} is a variable with considerable heteroskedasticity:

\begin{verbatim}
. tabulate foreign, summarize(gpmw)

<table>
<thead>
<tr>
<th>Car origin</th>
<th>Summary of gpmw</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>Std. dev.</td>
<td>Freq.</td>
</tr>
<tr>
<td>Domestic</td>
<td></td>
<td>1.6090039</td>
<td>.16845182</td>
<td>52</td>
</tr>
<tr>
<td>Foreign</td>
<td></td>
<td>1.8551565</td>
<td>.30186861</td>
<td>22</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>1.6821844</td>
<td>.24263113</td>
<td>74</td>
</tr>
</tbody>
</table>
\end{verbatim}

Thus, here we favor the robust standard errors. In [U] \texttt{20.22 Obtaining robust variance estimates}, we show another example using linear regression where it makes little difference whether we specify \texttt{vce(robust)}. The linear-regression assumptions were true, and we obtained nearly linear-regression results. The advantage of the robust estimate is that in neither case did we have to check assumptions.

Technical note

\texttt{regress} purposefully suppresses displaying the ANOVA table when \texttt{vce(robust)} is specified. This is done because the sums of squares are no longer appropriate for use in the usual hypothesis tests, even though computationally the sums of squares remain the same. In the nonrobust setting, the $F$ statistic reported by \texttt{regress} is defined in terms of the sums of squares, as in ANOVA. When \texttt{vce(robust)} is specified, the ANOVA test is not valid, and the $F$ statistic corresponds to a Wald test based on the robustly estimated variance matrix.

Some references give formulas for the $F$ statistic in terms of either $R^2$ or the root MSE. It is not appropriate to use those formulas for the $F$ statistic with robust standard errors because the $R^2$ and root MSE are calculated from the sums of squares. Moreover, the root MSE can no longer be used as an estimate for $\sigma$ because there is no longer a single $\sigma$ to estimate—the variance of the residual varies observation by observation. However, \texttt{regress} continues to report the $R^2$ and the root MSE in the robust setting because those statistics are still usable in other settings. In particular, $R^2$ remains valid as a goodness-of-fit statistic.

Example 6: Alternative robust standard errors

The \texttt{vce(hc2)} and \texttt{vce(hc3)} options modify the robust variance calculation. In the context of linear regression without clustering, the idea behind the robust calculation is somehow to measure $\sigma^2_j$, the variance of the residual associated with the $j$th observation, and then to use that estimate to improve the estimated variance of $\hat{\beta}$. Because residuals have (theoretically and practically) mean 0, one estimate of $\sigma^2_j$ is the observation’s squared residual itself—$u^2_j$. A finite-sample correction could improve that by multiplying $u^2_j$ by $n/(n-k)$, and, as a matter of fact, \texttt{vce(robust)} uses \{$n/(n-k)$\}$u^2_j$ as its estimate of the residual’s variance.

\texttt{vce(hc2)} and \texttt{vce(hc3)} use alternative estimators of the observation-specific variances. For instance, if the residuals are homoskedastic, we can show that the expected value of $u^2_j$ is $\sigma^2(1-h_{jj})$, where $h_{jj}$ is the $j$th diagonal element of the projection (hat) matrix. $h_{jj}$ has average value $k/n$, so $1-h_{jj}$ has average value $1-k/n = (n-k)/n$. Thus, the default robust estimator $\hat{\sigma}_j = \{n/(n-k)\}u^2_j$ amounts to dividing $u^2_j$ by the average of the expectation.
vce(hc2) divides $u_j^2$ by $1 - h_{jj}$ itself, so it should yield better estimates if the residuals really are homoskedastic. vce(hc3) divides $u_j^2$ by $(1 - h_{jj})^2$ and has no such clean interpretation. Davidson and MacKinnon (1993) show that $u_j^2/(1 - h_{jj})^2$ approximates a more complicated estimator that they obtain by jackknifing (MacKinnon and White 1985). Angrist and Pischke (2009) also illustrate the relative merits of these adjustments.

Here are the results of refitting our efficiency model using vce(hc2) and vce(hc3):

```
. regress gpmw foreign, vce(hc2)
Linear regression
Number of obs = 74
F(1, 72) = 12.93
Prob > F = 0.0006
R-squared = 0.2180
Root MSE = .21605

                      Robust HC2
                      Coefficient std. err.    t    P>|t|      [95% conf. interval]
foreign             .2461526   .0684669    3.60  0.001     .1096662    .3826389
_cons              1.609004   .0233601   68.88  0.000     1.562437    1.655571
```

```
. regress gpmw foreign, vce(hc3)
Linear regression
Number of obs = 74
F(1, 72) = 12.38
Prob > F = 0.0008
R-squared = 0.2180
Root MSE = .21605

                      Robust HC3
                      Coefficient std. err.    t    P>|t|      [95% conf. interval]
foreign             .2461526   .069969    3.52  0.001     .1066719    .3856332
_cons              1.609004   .023588    68.21  0.000     1.561982    1.656026
```

Example 7: Standard errors for clustered data

The vce(cluster clustvar) option relaxes the assumption of independence. Below, we have 28,534 observations on 4,711 women aged 14–46 years. Data were collected on these women between 1968 and 1988. We are going to fit a classic earnings model, and we begin by ignoring that the majority of the women in the dataset have multiple observations.
use https://www.stata-press.com/data/r17/regsmpl, clear 
(NLS women 14-26 in 1968)
.regress ln_wage age c.age#c.age tenure

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>Number of obs</th>
<th>28,101</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>1054.52501</td>
<td>3</td>
<td>351.508335</td>
<td>F(3, 28097)</td>
<td>1842.45</td>
</tr>
<tr>
<td>Residual</td>
<td>5360.43962</td>
<td>28,097</td>
<td>.190783344</td>
<td>Prob &gt; F</td>
<td>0.0000</td>
</tr>
<tr>
<td>Total</td>
<td>6414.96462</td>
<td>28,100</td>
<td>.228290556</td>
<td>R-squared</td>
<td>0.1644</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Adj R-squared</td>
<td>0.1643</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Root MSE</td>
<td>.43679</td>
</tr>
</tbody>
</table>

ln_wage | Coefficient | Std. err. | t | P>|t| | [95% conf. interval] |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>age</td>
<td>.0752172</td>
<td>.0034736</td>
<td>21.65</td>
<td>0.000</td>
<td>.0684088 - .0820257</td>
</tr>
<tr>
<td>c.age#c.age</td>
<td>-.0010851</td>
<td>.0000575</td>
<td>-18.86</td>
<td>0.000</td>
<td>-.0011979 - -.0009724</td>
</tr>
<tr>
<td>tenure</td>
<td>.0390877</td>
<td>.0007743</td>
<td>50.48</td>
<td>0.000</td>
<td>.0375699 - .0406054</td>
</tr>
<tr>
<td>_cons</td>
<td>.3339821</td>
<td>.0504413</td>
<td>6.62</td>
<td>0.000</td>
<td>.2351148 - .4328495</td>
</tr>
</tbody>
</table>

The number of observations in our model is 28,101 because Stata drops observations that have a missing value for one or more of the variables in the model. We can be reasonably certain that the standard errors reported above are meaningless. Without a doubt, a woman with higher-than-average wages in one year typically has higher-than-average wages in other years, and so the residuals are not independent. One way to deal with this is to use cluster–robust standard errors. We do this by specifying vce(cluster id), which treats only observations with different person ids as truly independent:

.regress ln_wage age c.age#c.age tenure, vce(cluster id)
Linear regression
Number of obs = 28,101
F(3, 4698) = 748.82
Prob > F = 0.0000
R-squared = 0.1644
Root MSE = .43679
(Std. err. adjusted for 4,699 clusters in idcode)

| ln_wage | Coefficient | Std. err. | t | P>|t| | [95% conf. interval] |
|---------|-------------|-----------|---|-------|---------------------|
| age     | .0752172    | .0045711  | 16.45 | 0.000 | .0662557 - .0841788 |
| c.age#c.age | -.0010851 | .0000778   | -13.94 | 0.000 | -.0012377 - -.0009325 |
| tenure  | .0390877    | .00504413 | 6.62 | 0.000 | .0362596 - .0419157 |
| _cons   | .3339821    | .0641918  | 5.20 | 0.000 | .208136 - .4598282 |

For comparison, we focus on the tenure coefficient, which in economics jargon can be interpreted as the rate of return for keeping your job. The 95% confidence interval we previously estimated—an interval we do not believe—is [0.038, 0.041]. The robust interval is twice as wide, being [0.036, 0.042].
Another possible way to account for the lack of independence is to fit a random-effects model. Here is the random-effects result:

```
.xtreg ln_wage age c.age#c.age tenure, re
```

Random-effects GLS regression  Number of obs = 28,101
Group variable: idcode  Number of groups = 4,699
R-squared:  Obs per group:
  Within = 0.1370  min = 1
  Between = 0.2154  avg = 6.0
  Overall = 0.1608  max = 15

Wald chi2(3) = 4717.05
corr(u_i, X) = 0 (assumed)  Prob > chi2 = 0.0000

| lnl_wage | Coefficient | Std. err. | z  | P>|z| | [95% conf. interval] |
|----------|-------------|-----------|----|------|---------------------|
| age      | .0568296    | .0026958  | 21.08 | .000 | .0515459 - .0621132 |
| c.age#c.age | -.0007566   | .0000447  | -16.93 | .000 | -.0008441 - .000669 |
| tenure   | .0260135    | .0007477  | 34.79 | .000 | .0245481 - .0274789 |
| _cons    | .6136792    | .0394611  | 15.55 | .000 | .5363368 - .6910216 |

| sigma_u  | .33542449   |
| sigma_e  | .29674679   |
| rho      | .56095413   | (fraction of variance due to u_i) |

Robust regression estimated the 95% interval [0.036, 0.042], and `xtreg` (see `[XT] xtreg`) estimates [0.025, 0.027]. Which is better? The random-effects regression estimator assumes a lot. We can check some of these assumptions by performing a Hausman test. Using `estimates` (see `[R] estimates store`), we store the random-effects estimation results, and then we run the required fixed-effects regression to perform the test.

```
.estimates store random
.xtreg ln_wage age c.age#c.age tenure, fe
```

Fixed-effects (within) regression  Number of obs = 28,101
Group variable: idcode  Number of groups = 4,699
R-squared:  Obs per group:
  Within = 0.1375  min = 1
  Between = 0.2066  avg = 6.0
  Overall = 0.1568  max = 15

F(3,23399) = 1243.00
corr(u_i, Xb) = 0.1380  Prob > F = 0.0000

| lnln_wage | Coefficient | Std. err. | t    | P>|t| | [95% conf. interval] |
|-----------|-------------|-----------|------|------|---------------------|
| age       | .0522751    | .002783   | 18.78 | .000 | .0468202 - .05773   |
| c.age#c.age | -.0006717   | .0000461  | -14.56 | .000 | -.0007621 - -.0005813 |
| tenure    | .021738     | .000799   | 27.21 | .000 | .020172 - .023304   |
| _cons     | .687178     | .0405944  | 16.93 | .000 | .6076103 - .7667456 |

| sigma_u  | .38743138   |
| sigma_e  | .29674679   |
| rho      | .6302569    | (fraction of variance due to u_i) |

F test that all u_i=0: F(4698, 23399) = 7.98  Prob > F = 0.0000
The Hausman test casts grave suspicions on the random-effects model we just fit, so we should be careful in interpreting those results.

Meanwhile, our robust regression results still stand, as long as we are careful about the interpretation. The correct interpretation is that, if the data collection were repeated (on women sampled the same way as in the original sample), and if we were to refit the model, 95% of the time we would expect the estimated coefficient on tenure to be in the range \[0.036, 0.042\].

Even with robust regression, we must be careful about going beyond that statement. Here the Hausman test is probably picking up something that differs within and between person, which would cast doubt on our robust regression model in terms of interpreting \[0.036, 0.042\] to contain the rate of return for keeping a job, economywide, for all women, without exception.

---

Weighted regression

regress can perform weighted and unweighted regression. We indicate the weight by specifying the [weight] qualifier.

Example 8: Using means as regression variables

We have census data recording the deathrate (drate) and median age (medage) for each state. The data also record the region of the country in which each state is located and the overall population of the state:

```
. use https://www.stata-press.com/data/r17/census9
(1980 Census data by state)
. describe
Contains data from https://www.stata-press.com/data/r17/census9.dta
Observations: 50 1980 Census data by state
Variables: 6 2 Dec 2020 15:22

<table>
<thead>
<tr>
<th>Variable label</th>
<th>Storage type</th>
<th>Display format</th>
<th>Value label</th>
<th>Variable label</th>
</tr>
</thead>
<tbody>
<tr>
<td>state</td>
<td>str13</td>
<td>%-13s</td>
<td>State</td>
<td></td>
</tr>
<tr>
<td>state2</td>
<td>str2</td>
<td>%-2s</td>
<td>Two-letter state abbreviation</td>
<td></td>
</tr>
<tr>
<td>drate</td>
<td>int</td>
<td>%9.0g</td>
<td>Deathrate</td>
<td></td>
</tr>
<tr>
<td>pop</td>
<td>long</td>
<td>%12.0gc</td>
<td>Population</td>
<td></td>
</tr>
<tr>
<td>medage</td>
<td>float</td>
<td>%9.2f</td>
<td>Median age</td>
<td></td>
</tr>
<tr>
<td>region</td>
<td>byte</td>
<td>%-8.0g</td>
<td>cenreg</td>
<td>Census region</td>
</tr>
</tbody>
</table>
```

Sorted by:
We can use factor variables to include dummy variables for region. Because the variables in the regression reflect means rather than individual observations, the appropriate method of estimation is analytically weighted least squares (Davidson and MacKinnon 2004, 261–262), where the weight is total population:

```
.regress drate medage i.region [aweight=pop]
(aweight=pop)
```

```
Source | SS        | df    | MS          | Number of obs = 50  
Model   | 4096.6093 | 4     | 1024.15232  | F(4, 45) = 37.21  
Residual| 1238.40987 | 45   | 27.5202192  | Prob > F = 0.0000  
Total   | 5335.01916 | 49   | 108.877942  | R-squared = 0.7679  
          |            |      | Adj R-squared = 0.7472 | Root MSE = 5.2472
```

| drate | Coefficient | Std. err. | t  | P>|t| | [95% conf. interval] |
|-------|-------------|-----------|----|-----|----------------------|
| medage | 4.283183    | .5393329  | 7.94 | 0.000 | 3.196911 - 5.369455 |
| region |             |           |     |      |                      |
| N Cntrl | .3138738    | 2.456431  | 0.13 | 0.899 | -4.633632 - 5.26138 |
| South   | -1.438452   | 2.320244  | -0.62 | 0.538 | -6.111663 3.234758 |
| West    | -10.90629   | 2.681349  | -4.07 | 0.000 | -16.30681 -5.505777 |
| _cons  | -39.14727   | 17.23613  | -2.27 | 0.028 | -73.86262 -4.431915 |

To weight the regression by population, we added the qualifier [aweight=pop] to the end of the `regress` command. Stata informed us that the sum of the weight is $2.2591 \times 10^8$; there were approximately 226 million people residing in the United States according to our 1980 data.

In the weighted regression, we see that the coefficient on `West` is statistically significant but that the coefficients on `N Cntrl` and `South` are not. We use `testparm` to test the joint significance of the `region` variable. Because we fit a weighted regression, `testparm` uses the appropriately weighted variance–covariance matrix.

```
.testparm i.region
( 1) 2.region = 0
( 2) 3.region = 0
( 3) 4.region = 0
F( 3, 45) = 9.84
Prob > F = 0.0000
```

The results indicate that the region variables are jointly significant. Note that we could have performed this same test by typing `contrast region`. You may prefer to use the `contrast` command because, in addition to the joint test, you can perform other tests such as comparisons of each region’s mean to the grand mean; see [R] `contrast` for more information.

`regress` also accepts frequency weights (`fweights`). Frequency weights are appropriate when the data do not reflect cell means but instead represent replicated observations. Specifying `aweight`s or `fweight`s will not change the parameter estimates, but it will change the corresponding significance levels.

For instance, if we specified `[fweight=pop]` in the weighted regression example above—which would be statistically incorrect—Stata would treat the data as if the data represented 226 million independent observations on death rates and median age. The data most certainly do not represent that—they represent 50 observations on state averages.
With `aweight`s, Stata treats the number of observations on the process as the number of observations in the data. When we specify `fweight`s, Stata treats the number of observations as if it were equal to the sum of the weights; see Methods and formulas below.

## Technical note

A frequent inquiry sent to StataCorp Technical Services is to describe the effect of specifying `[aweight=exp]` with `regress` in terms of transformation of the dependent and independent variables. The mechanical answer is that typing

```
    . regress y x1 x2 [aweight=n]
```

is equivalent to fitting the model

\[ y_j \sqrt{n_j} = \beta_0 \sqrt{n_j} + \beta_1 x_{1j} \sqrt{n_j} + \beta_2 x_{2j} \sqrt{n_j} + u_j \sqrt{n_j} \]

This regression will reproduce the coefficients and covariance matrix produced by the `aweight`ed regression. The mean squared errors (estimates of the variance of the residuals) will, however, be different. The transformed regression reports \( s^2_t \), an estimate of \( \text{Var}(u_j \sqrt{n_j}) \). The `aweight`ed regression reports \( s^2_a \), an estimate of \( \text{Var}(u_j \sqrt{n_j} / \sum_k n_k) \), where \( N \) is the number of observations. Thus,

\[ s^2_a = \frac{N}{\sum_k n_k} s^2_t = \frac{s^2_t}{\bar{n}} \]  \hspace{1cm} (1)

The logic for this adjustment is as follows: Consider the model

\[ y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + u \]

Assume that, were this model fit on individuals, \( \text{Var}(u) = \sigma^2_u \), a constant. Assume that individual data are not available; what is available are averages \( (\bar{y}_j, \bar{x}_{1j}, \bar{x}_{2j}) \) for \( j = 1, \ldots, N \), and each average is calculated over \( n_j \) observations. Then it is still true that

\[ \bar{y}_j = \beta_0 + \beta_1 \bar{x}_{1j} + \beta_2 \bar{x}_{2j} + \bar{u}_j \]

where \( \bar{u}_j \) is the average of \( n_j \) mean 0, variance \( \sigma^2_u \) deviates and has variance \( \sigma^2_{\bar{u}} = \sigma^2_u / n_j \). Thus, multiplying through by \( \sqrt{n_j} \) produces

\[ \bar{y}_j \sqrt{n_j} = \beta_0 \sqrt{n_j} + \beta_1 \bar{x}_{1j} \sqrt{n_j} + \beta_2 \bar{x}_{2j} \sqrt{n_j} + \bar{u}_j \sqrt{n_j} \]

and \( \text{Var}(\bar{y}_j \sqrt{n_j}) = \sigma^2_{\bar{u}} \). The mean squared error, \( s^2_t \), reported by fitting this transformed regression is an estimate of \( \sigma^2_{\bar{u}} \). The coefficients and covariance matrix could also be obtained by `aweight`ed `regress`. The only difference would be in the reported mean squared error, which from (1) is \( \sigma^2_{\bar{u}} / \bar{n} \). On average, each observation in the data reflects the averages calculated over \( n_j \) for \( j = 1, \ldots, N \) individuals, and thus this reported mean squared error is the average variance of an observation in the dataset. We can retrieve the estimate of \( \sigma^2_u \) by multiplying the reported mean squared error by \( \bar{n} \).

More generally, `aweight`s are used to solve general heteroskedasticity problems. In these cases, we have the model

\[ y_j = \beta_0 + \beta_1 x_{1j} + \beta_2 x_{2j} + u_j \]

and the variance of \( u_j \) is thought to be proportional to \( a_j \). If the variance is proportional to \( a_j \), it is also proportional to \( \alpha a_j \), where \( \alpha \) is any positive constant. Not quite arbitrarily, but with no loss of generality, we could choose \( \alpha = \sum_k (1/a_k) / N \), the average value of the inverse of \( a_j \). We can then write \( \text{Var}(u_j) = k \alpha a_j \sigma^2 \), where \( k \) is the constant of proportionality that is no longer a function of the scale of the weights.
Dividing this regression through by the $\sqrt{a_j}$, 

$$y_j / \sqrt{a_j} = \beta_0 / \sqrt{a_j} + \beta_1 x_{1j} / \sqrt{a_j} + \beta_2 x_{2j} / \sqrt{a_j} + u_j / \sqrt{a_j}$$

produces a model with $\text{Var}(u_j / \sqrt{a_j}) = k\alpha\sigma^2$, which is the constant part of $\text{Var}(u_j)$. This variance is a function of $\alpha$, the average of the reciprocal weights; if the weights are scaled arbitrarily, then so is this variance.

We can also fit this model by typing

```
. regress y x1 x2 [aweight=1/a]
```

This input will produce the same estimates of the coefficients and covariance matrix; the reported mean squared error is, from (1), $\left\{ N / \sum_k 1/a_k \right\} k\alpha\sigma^2 = k\sigma^2$. This variance is independent of the scale of $a_j$.

Video example

Simple linear regression in Stata

Stored results

`regress` stores the following in `e()`:

Scalars
- `e(N)` number of observations
- `e(mss)` model sum of squares
- `e(df_m)` model degrees of freedom
- `e(rss)` residual sum of squares
- `e(df_r)` residual degrees of freedom
- `e(r2)` $R^2$
- `e(r2_a)` adjusted $R^2$
- `e(F)` $F$ statistic
- `e(rmse)` root mean squared error
- `e(ll)` log likelihood under additional assumption of i.i.d. normal errors
- `e(ll0)` log likelihood, constant-only model
- `e(N_clust)` number of clusters
- `e(rank)` rank of $e(V)$

Macros
- `e(cmd)` `regress`
- `e(cmdline)` command as typed
- `e(depvar)` name of dependent variable
- `e(wtype)` weight type
- `e(wexp)` weight expression
- `e(model)` ols
- `e(title)` title in estimation output when `vce()` is not ols
- `e(clustvar)` name of cluster variable
- `e(vce)` `vcetype` specified in `vce()`
- `e(vcetype)` title used to label Std. err.
- `e(properties)` b V
- `e(estat_cmd)` program used to implement `estat`
- `e(predict)` program used to implement `predict`
- `e(marginsok)` predictions allowed by margins
- `e(asbalanced)` factor variables `fvset` as asbalanced
- `e(asobserved)` factor variables `fvset` as asobserved
Matrices
- `e(b)` coefficient vector
- `e(V)` variance–covariance matrix of the estimators
- `e(V_modelbased)` model-based variance

Functions
- `e(sample)` marks estimation sample

In addition to the above, the following is stored in `r()`:

Matrices
- `r(table)` matrix containing the coefficients with their standard errors, test statistics, \( p \)-values, and confidence intervals

Note that results stored in `r()` are updated when the command is replayed and will be replaced when any r-class command is run after the estimation command.

**Methods and formulas**

Methods and formulas are presented under the following headings:

- Coefficient estimation and ANOVA table
- Weighted regression
- A general notation for the robust variance calculation
- Robust calculation for `regress`

**Coefficient estimation and ANOVA table**

Variables printed in lowercase and not boldfaced (for example, \( x \)) are scalars. Variables printed in lowercase and boldfaced (for example, \( \mathbf{x} \)) are column vectors. Variables printed in uppercase and boldfaced (for example, \( \mathbf{X} \)) are matrices.

Let \( \mathbf{X} \) denote the matrix of observations on the right-hand-side variables, \( \mathbf{y} \) the vector of observations on the left-hand-side variables. Define \( \mathbf{A} = \mathbf{X}'\mathbf{X} \) and \( \mathbf{a} = \mathbf{X}'\mathbf{y} \). The coefficient vector \( \mathbf{b} \) is defined as \( \mathbf{A}^{-1}\mathbf{a} \). Although not shown in the notation, unless `hascons` is specified, \( \mathbf{A} \) and \( \mathbf{a} \) are accumulated in deviation form and the constant is calculated separately. This comment applies to all statistics listed below.

The total sum of squares, TSS, equals \( \mathbf{y}'\mathbf{y} \) if there is no intercept and \( \mathbf{y}'\mathbf{y} - \left\{ \mathbf{1}'\mathbf{y}^2/n \right\} \) otherwise. The degrees of freedom is \( n - c \), where \( n \) is the number of observations and \( c = 1 \) if there is a constant in the regression and 0 otherwise.

The residual sum of squares, RSS, is defined as \( (\mathbf{y} - \mathbf{X}\mathbf{b})'(\mathbf{y} - \mathbf{X}\mathbf{b}) \). The degrees of freedom is \( n - k \), where \( n \) is the number of observations and \( k \) is the number of right-hand-side variables (including the constant).

The model sum of squares, MSS, equals TSS − RSS. The degrees of freedom is \( k - c \).

The mean squared error, \( s^2 \), is defined as RSS/(\( n - k \)). The root mean squared error is \( s \), its square root.

The \( F \) statistic with \( k - c \) and \( n - k \) degrees of freedom is defined as

\[
F = \frac{\text{MSS}}{(k-c)s^2}
\]

The \( R^2 \) is defined as \( R^2 = 1 - \text{RSS}/\text{TSS} \).

The adjusted \( R^2 \) is defined as \( R_a^2 = 1 - (1 - R^2)(n - c)/(n - k) \).

The conventional estimate of variance is \( s^2 \mathbf{A}^{-1} \). The calculation of variance estimates when robust variance estimates are specified is described below.
Weighted regression

Let $v$ be a column vector of weights specified by the user. Let $w$ be a column vector of normalized weights, $w = \{v/(1'v)\}(1'1)$. For $f$weights, $w = v$. For historical reasons, $i$weights are treated like $f$weights when robust standard errors are not specified. Instead, when $vce(robust)$, $vce(cluster clustvar)$, $vce(hc2)$, or $vce(hc3)$ is specified, $i$weights are treated like $a$weights.

If the user specifies weights, the number of observations, $n$, in the above formulas is defined as $1'w$. For $i$weights, this is truncated to an integer. The sum of the weights is $1w$. $X'X$, $X'y$, and $y'y$ are replaced in the above formulas by $X'DX$, $X'Dy$, and $y'Dy$, respectively, where $D$ is a diagonal matrix whose diagonal elements are the elements of $w$.

### A general notation for the robust variance calculation

Put aside all context of linear regression and the notation that goes with it—we will return to it. First, we are going to establish a notation for describing robust variance calculations.

The calculation formula for the robust variance calculation is

$$\hat{V} = q_c \hat{V} \left( \sum_{k=1}^{M} u_k^{(G)}' u_k^{(G)} \right) \hat{V}$$

where

$$u_k^{(G)} = \sum_{j \in G_k} w_j u_j$$

$G_1, G_2, \ldots, G_M$ are the clusters specified by $vce(cluster clustvar)$, and $w_j$ are the user-specified weights, normalized if $a$weights or $p$weights are specified and equal to 1 if no weights are specified.

For $f$weights without clusters, the variance formula is

$$\hat{V} = q_c \hat{V} \left( \sum_{j=1}^{N} w_j u_j' u_j \right) \hat{V}$$

which is the same as expanding the dataset and making the calculation on the unweighted data.

If $vce(cluster clustvar)$ is not specified, $M = N$, and each cluster contains 1 observation. The inputs into this calculation are

- $\hat{V}$, which is typically a conventionally calculated variance matrix;
- $u_j$, $j = 1, \ldots, N$, a row vector of scores; and
- $q_c$, a constant finite-sample adjustment.

Thus, we can now describe how estimators apply the robust calculation formula by defining $\hat{V}$, $u_j$, and $q_c$.

Two definitions are popular enough for $q_c$ to deserve a name. The regression-like formula for $q_c$ (Fuller et al. 1986) is

$$q_c = \frac{N - 1}{N - k} \frac{M}{M - 1}$$

where $M$ is the number of clusters and $N$ is the number of observations. For weights, $N$ refers to the sum of the weights if weights are frequency weights and the number of observations in the dataset (ignoring weights) in all other cases. Also note that, weighted or not, $M = N$ when $vce(cluster clustvar)$ is not specified, and then $q_c = N/(N - k)$. 
The asymptotic-like formula for $q_c$ is

$$q_c = \frac{M}{M - 1}$$

where $M = N$ if `vce(cluster clustvar)` is not specified.

See [U] 20.22 Obtaining robust variance estimates and [P] _robust for a discussion of the robust variance estimator and a development of these formulas.

## Robust calculation for regress

For `regress`, $\hat{V} = A^{-1}$. The other terms are

- `vce(robust)`, but not `vce(hc2)` or `vce(hc3)`,

$$u_j = (y_j - x_j b)x_j$$

and $q_c$ is given by its regression-like definition.

- `vce(hc2)`,

$$u_j = \frac{1}{\sqrt{1 - h_{jj}}}(y_j - x_j b)x_j$$

where $q_c = 1$ and $h_{jj} = x_j (X'X)^{-1}x_j$.

- `vce(hc3)`,

$$u_j = \frac{1}{1 - h_{jj}}(y_j - x_j b)x_j$$

where $q_c = 1$ and $h_{jj} = x_j (X'X)^{-1}x_j$.

## Acknowledgments

The robust estimate of variance was first implemented in Stata by Mead Over of the Center for Global Development, Dean Jolliffe of the World Bank, and Andrew Foster of the Department of Economics at Brown University (Over, Jolliffe, and Foster 1996).
The history of regression is long and complicated: the books by Stigler (1986) and Hald (1998) are devoted largely to the story. Legendre published first on least squares in 1805. Gauss published later in 1809, but he had the idea earlier. Gauss, and especially Laplace, tied least squares to a normal errors assumption. The idea of the normal distribution can itself be traced back to De Moivre in 1733. Laplace discussed a variety of other estimation methods and error assumptions over his long career, while linear models long predate either innovation. Most of this work was linked to problems in astronomy and geodesy.

A second wave of ideas started when Galton used graphical and descriptive methods on data bearing on heredity to develop what he called regression. His term reflects the common phenomenon that characteristics of offspring are positively correlated with those of parents but with regression slope such that offspring “regress toward the mean”. Galton’s work was rather intuitive: contributions from Pearson, Edgeworth, Yule, and others introduced more formal machinery, developed related ideas on correlation, and extended application into the biological and social sciences. So most of the elements of regression as we know it were in place by 1900.

Pierre-Simon Laplace (1749–1827) was born in Normandy and was early recognized as a remarkable mathematician. He weathered a changing political climate well enough to rise to Minister of the Interior under Napoleon in 1799 (although only for 6 weeks) and to be made a Marquis by Louis XVIII in 1817. He made many contributions to mathematics and physics, his two main interests being theoretical astronomy and probability theory (including statistics). Laplace transforms are named for him.

Adrien-Marie Legendre (1752–1833) was born in Paris (or possibly in Toulouse) and educated in mathematics and physics. He worked in number theory, geometry, differential equations, calculus, function theory, applied mathematics, and geodesy. The Legendre polynomials are named for him. His main contribution to statistics is as one of the discoverers of least squares. He died in poverty, having refused to bow to political pressures.

Johann Carl Friedrich Gauss (1777–1855) was born in Braunschweig (Brunswick), now in Germany. He studied there and at Göttingen. His doctoral dissertation at the University of Helmstedt was a discussion of the fundamental theorem of algebra. He made many fundamental contributions to geometry, number theory, algebra, real analysis, differential equations, numerical analysis, statistics, astronomy, optics, geodesy, mechanics, and magnetism. An outstanding genius, Gauss worked mostly in isolation in Göttingen.

Francis Galton (1822–1911) was born in Birmingham, England, into a well-to-do family with many connections: he and Charles Darwin were first cousins. After an unsuccessful foray into medicine, he became independently wealthy at the death of his father. Galton traveled widely in Europe, the Middle East, and Africa, and became celebrated as an explorer and geographer. His pioneering work on weather maps helped in the identification of anticyclones, which he named. From about 1865, most of his work was centered on quantitative problems in biology, anthropology, and psychology. In a sense, Galton (re)invented regression, and he certainly named it. Galton also promoted the normal distribution, correlation approaches, and the use of median and selected quantiles as descriptive statistics. He was knighted in 1909.
References


Cameron, A. C., and P. K. Trivedi. 2010. Microeconometrics Using Stata. Rev. ed. College Station, TX: Stata Press.


Mitchell, M. N. 2021. Interpreting and Visualizing Regression Models Using Stata. 2nd ed. College Station, TX: Stata Press.


**Also see**

[R] regress postestimation — Postestimation tools for regress

[R] regress postestimation diagnostic plots — Postestimation plots for regress

[R] regress postestimation time series — Postestimation tools for regress with time series

[R] anova — Analysis of variance and covariance

[R] contrast — Contrasts and linear hypothesis tests after estimation

[R] hetregress — Heteroskedastic linear regression

[BAYES] bayes: regress — Bayesian linear regression

[FMM] fmm: regress — Finite mixtures of linear regression models

[LASSO] Lasso intro — Introduction to lasso

[META] meta regress — Meta-analysis regression

[MII] Estimation — Estimation commands for use with mi estimate

[SEM] Example 6 — Linear regression

[SEM] Intro 5 — Tour of models

[SP] spregress — Spatial autoregressive models

[SVY] svy estimation — Estimation commands for survey data

[TS] forecast — Econometric model forecasting

[TS] mswitch — Markov-switching regression models

[U] 20 Estimation and postestimation commands