metobit — Multilevel mixed-effects tobit regression

Description

metobit fits mixed-effects models for continuous responses where the outcome variable is censored. Censoring limits may be fixed for all observations or vary across observations.

Quick start

Without weights

Two-level tobit regression of y on x with random intercepts by lev2 where y is censored at a lower limit of 5

metobit y x || lev2:, ll(5)

As above, but specify that left-censoring occurs at 5 and right-censoring occurs at 25

metobit y x || lev2:, ll(5) ul(25)

As above, but where lower and upper are variables containing the censoring limits

metobit y x || lev2:, ll(lower) ul(upper)

Mixed-effects model adding random coefficients for x

metobit y x || lev2: x, ll(5)

Three-level random-intercept model of y on x with lev2 nested within lev3

metobit y x || lev3: || lev2:, ll(5)

Crossed-effects model of y on x with two-way crossed random effects by factors a and b

metobit y x || _all:R.a || b:, ll(5)

With weights

Two-level tobit regression of y on x with random intercepts by lev2 and observation-level frequency weights wvar1

metobit y x [fweight=wvar1] || lev2:, ll(5)

Two-level random-intercept model from a two-stage sampling design with PSUs identified by psu using PSU-level and observation-level sampling weights wvar2 and wvar1, respectively

metobit y x [pweight=wvar1] || psu:, pweight(wvar2) ll(5)

Same as above, but svyset data first

svyset psu, weight(wvar2) || _n, weight(wvar1)
svy: metobit y x || psu:, ll(5)
## Syntax

```
metobit depvar fe_equation [ || re_equation] [ || re_equation ...] [, options]
```

where the syntax of `fe_equation` is

```
[ indepvars] [ if] [ in] [ weight] [, fe_options]
```

and the syntax of `re_equation` is one of the following:

- for random coefficients and intercepts
  
  `levelvar: [ varlist] [, re_options]`

- for random effects among the values of a factor variable
  
  `levelvar: R.varname`

`levelvar` is a variable identifying the group structure for the random effects at that level or is `_all` representing one group comprising all observations.

### fe_options

<table>
<thead>
<tr>
<th>Description</th>
<th>fe_options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>noconstant suppress constant term from the fixed-effects equation</td>
</tr>
<tr>
<td>Offset</td>
<td>offset(varname) include varname in model with coefficient constrained to 1</td>
</tr>
</tbody>
</table>

### re_options

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
</tr>
<tr>
<td>covariancex(vartype) variance–covariance structure of the random effects</td>
</tr>
<tr>
<td>noconstant suppress constant term from the random-effects equation</td>
</tr>
<tr>
<td>fweight(varname) frequency weights at higher levels</td>
</tr>
<tr>
<td>iweight(varname) importance weights at higher levels</td>
</tr>
<tr>
<td>pweight(varname) sampling weights at higher levels</td>
</tr>
</tbody>
</table>
### options

<table>
<thead>
<tr>
<th>Model</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>`ll(varname</td>
<td>#)`</td>
</tr>
<tr>
<td>`ul(varname</td>
<td>#)`</td>
</tr>
<tr>
<td><code>constraints(constants)</code></td>
<td>apply specified linear constraints</td>
</tr>
<tr>
<td><code>colinear</code></td>
<td>keep collinear variables</td>
</tr>
</tbody>
</table>

#### SE/Robust

| `vce(vcetype)` | `vcetype` may be `oim`, `robust`, or `cluster clustvar` |

#### Reporting

| `level(#)`       | set confidence level; default is `level(95)`       |
| `nocnsreport`    | do not display constraints                          |
| `notable`        | suppress coefficient table                          |
| `noheader`       | suppress output header                               |
| `nogroup`        | suppress table summarizing groups                   |
| `display_options` | control columns and column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling |

#### Integration

| `intmethod(intmethod)` | integration method |
| `intpoints(#)`        | set the number of integration (quadrature) points for all levels; default is `intpoints(7)` |

#### Maximization

| `maximize_options` | control the maximization process; seldom used |
| `startvalues(svmethod)` | method for obtaining starting values |
| `startgrid[ gridspec ]` | perform a grid search to improve starting values |
| `noestimate`        | do not fit the model; show starting values instead |
| `dnumerical`        | use numerical derivative techniques               |
| `coeflegend`        | display legend instead of statistics               |

#### vartype

<table>
<thead>
<tr>
<th>Description</th>
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</tr>
</thead>
<tbody>
<tr>
<td>one unique variance parameter per random effect, all covariances 0; the default unless the R. notation is used</td>
<td><code>independent</code></td>
</tr>
<tr>
<td>equal variances for random effects, and one common pairwise covariance</td>
<td><code>exchangeable</code></td>
</tr>
<tr>
<td>equal variances for random effects, all covariances 0; the default if the R. notation is used</td>
<td><code>identity</code></td>
</tr>
<tr>
<td>all variances and covariances to be distinctly estimated</td>
<td><code>unstructured</code></td>
</tr>
<tr>
<td>user-selected variances and covariances constrained to specified values; the remaining variances and covariances unrestricted</td>
<td><code>fixed(matname)</code></td>
</tr>
<tr>
<td>user-selected variances and covariances constrained to be equal; the remaining variances and covariances unrestricted</td>
<td><code>pattern(matname)</code></td>
</tr>
</tbody>
</table>
### Description

<table>
<thead>
<tr>
<th>intmethod</th>
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</tr>
</thead>
<tbody>
<tr>
<td>mvaghermite</td>
<td>mean–variance adaptive Gauss–Hermite quadrature; the default unless a crossed random-effects model is fit</td>
</tr>
<tr>
<td>mcaghermite</td>
<td>mode-curvature adaptive Gauss–Hermite quadrature</td>
</tr>
<tr>
<td>ghermite</td>
<td>nonadaptive Gauss–Hermite quadrature</td>
</tr>
<tr>
<td>laplace</td>
<td>Laplacian approximation; the default for crossed random-effects models</td>
</tr>
</tbody>
</table>

**Options**

- `noconstant` suppresses the constant (intercept) term and may be specified for the fixed-effects equation and for any of or all the random-effects equations.
- `ll(varname | #)` and `ul(varname | #)` indicate the censoring points. You may specify one or both. `ll()` indicates the lower limit for left-censoring, `ul()` indicates the upper limit for right-censoring. Observations with `depvar ≤ ll()` are left-censored, observations with `depvar ≥ ul()` are right-censored, and remaining observations are not censored.
- `offset(varname)` specifies that `varname` be included in the fixed-effects portion of the model with the coefficient constrained to be 1.
- `covariance(vartype)` specifies the structure of the covariance matrix for the random effects and may be specified for each random-effects equation. `vartype` is one of the following: `independent`, `exchangeable`, `identity`, `unstructured`, `fixed(matname)`, or `pattern(matname)`.
  - `covariance(independent)` covariance structure allows for a distinct variance for each random effect within a random-effects equation and assumes that all covariances are 0. The default is `covariance(independent)` unless a crossed random-effects model is fit, in which case the default is `covariance(identity)`.
  - `covariance(exchangeable)` structure specifies one common variance for all random effects and one common pairwise covariance.
  - `covariance(identity)` is short for “multiple of the identity”; that is, all variances are equal and all covariances are 0.
  - `covariance(unstructured)` allows for all variances and covariances to be distinct. If an equation consists of `p` random-effects terms, the unstructured covariance matrix will have `p(p + 1)/2` unique parameters.
  - `covariance(fixed(matname))` and `covariance(pattern(matname))` covariance structures provide a convenient way to impose constraints on variances and covariances of random effects. Each specification requires a `matname` that defines the restrictions placed on variances and
covariances. Only elements in the lower triangle of `matname` are used, and row and column names of `matname` are ignored. A missing value in `matname` means that a given element is unrestricted. In a `fixed(matname)` covariance structure, (co)variance \((i,j)\) is constrained to equal the value specified in the \(i,j\)th entry of `matname`. In a `pattern(matname)` covariance structure, (co)variances \((i,j)\) and \((k,l)\) are constrained to be equal if `matname[i,j] = matname[k,l]`.

`fweight(varname)` specifies frequency weights at higher levels in a multilevel model, whereas frequency weights at the first level (the observation level) are specified in the usual manner, for example, `[fw=fwtvar1]`. `varname` can be any valid Stata variable name, and you can specify `fweight()` at levels two and higher of a multilevel model. For example, in the two-level model

```
  . mecmd fixed_portion [fw = wt1] || school: ... , fweight(wt2) ... 
```

the variable `wt1` would hold the first-level (the observation-level) frequency weights, and `wt2` would hold the second-level (the school-level) frequency weights.

`iweight(varname)` specifies importance weights at higher levels in a multilevel model, whereas importance weights at the first level (the observation level) are specified in the usual manner, for example, `[iw=iwtvar1]`. `varname` can be any valid Stata variable name, and you can specify `iweight()` at levels two and higher of a multilevel model. For example, in the two-level model

```
  . mecmd fixed_portion [iw = wt1] || school: ... , iweight(wt2) ... 
```

the variable `wt1` would hold the first-level (the observation-level) importance weights, and `wt2` would hold the second-level (the school-level) importance weights.

`pweight(varname)` specifies sampling weights at higher levels in a multilevel model, whereas sampling weights at the first level (the observation level) are specified in the usual manner, for example, `[pw=pwtvar1]`. `varname` can be any valid Stata variable name, and you can specify `pweight()` at levels two and higher of a multilevel model. For example, in the two-level model

```
  . mecmd fixed_portion [pw = wt1] || school: ... , pweight(wt2) ... 
```

variable `wt1` would hold the first-level (the observation-level) sampling weights, and `wt2` would hold the second-level (the school-level) sampling weights.

`constraints(constraints)`, `collinear`; see [R] estimation options.

`SE/Robust`  
`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`oim`), that are robust to some kinds of misspecification (`robust`), and that allow for intragroup correlation (`cluster clustvar`); see [R] `vce_option`. If `vce(robust)` is specified, robust variances are clustered at the highest level in the multilevel model.

`Reporting`  
`level(#)`, `nocnsreport`; see [R] estimation options.

`noheader` suppresses the estimation table, either at estimation or upon replay.

`nogroup` suppresses the display of group summary information (number of groups, average group size, minimum, and maximum) from the output header.

`display_options`: `nci`, `nvpvalues`, `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `nofvlabel`, `fwrap(#)`, `fwrappon(style)`, `cformat(%,fmt)`, `pformat(%,fmt)`, `sformat(%,fmt)`, and `nolstretch`; see [R] estimation options.
intmethod(intmethod) specifies the integration method to be used for the random-effects model. 
mvaghermite performs mean–variance adaptive Gauss–Hermite quadrature; 
mcaghermite performs mode-curvature adaptive Gauss–Hermite quadrature; 
ghermite performs nonadaptive Gauss–Hermite quadrature; and laplace performs the Laplacian approximation, equivalent to mode-curvature adaptive Gaussian quadrature with one integration point.

The default integration method is mvaghermite unless a crossed random-effects model is fit, in which case the default integration method is laplace. The Laplacian approximation has been known to produce biased parameter estimates; however, the bias tends to be more prominent in the estimates of the variance components rather than in the estimates of the fixed effects.

For crossed random-effects models, estimation with more than one quadrature point may be prohibitively intensive even for a small number of levels. For this reason, the integration method defaults to the Laplacian approximation. You may override this behavior by specifying a different integration method.

intpoints(#) sets the number of integration points for quadrature. The default is intpoints(7), which means that seven quadrature points are used for each level of random effects. This option is not allowed with intmethod(laplace).

The more integration points, the more accurate the approximation to the log likelihood. However, computation time increases as a function of the number of quadrature points raised to a power equaling the dimension of the random-effects specification. In crossed random-effects models and in models with many levels or many random coefficients, this increase can be substantial.

maximize_options: difficult, technique(algorithm_spec), iterate(#), [no]log, trace, gradient, showstep, hessian, showtolerance, tolerance(#), ltolerance(#), nrtolerance(#), nonrtolerance, and from(init_specs); see [R] maximize. Those that require special mention for metobit are listed below.

from() accepts a properly labeled vector of initial values or a list of coefficient names with values. A list of values is not allowed.

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

startvalues(svmethod), startgrid[(gridspec)], noestimate, and dnumerical; see [ME] meglm.

coefflegend; see [R] estimation options.

Remarks and examples

Mixed-effects tobit regression is tobit regression containing both fixed effects and random effects. In longitudinal data and panel data, random effects are useful for modeling intracluster correlation; that is, observations in the same cluster are correlated because they share common cluster-level random effects.

In a mixed-effects tobit regression, the values of the outcome variable may be observed, unobserved but known to fall below a given limit (left-censored data), or unobserved but known to fall above a given limit (right-censored data). That is, the observed data, \( y_{ij}^* \), represent possibly censored versions of \( y_{ij} \) for the \( i \)th observation within the \( j \)th cluster.
The observed outcome is therefore defined as
\[ y_{ij}^* = \begin{cases} 
  y_{ij} & \text{if } a < y_{ij} < b \\
  a & \text{if } y_{ij} \leq a \\
  b & \text{if } y_{ij} \geq b 
\end{cases} \]

where \( a \) is the lower-censoring limit and \( b \) is the upper-censoring limit. If the data are uncensored, \( y_{ij}^* = y_{ij} \), and the value is determined by the value of the outcome variable. If they are left-censored, all that is known is that \( y_{ij} \leq a \) and \( y_{ij}^* \) is determined by \( ll() \). If they are right-censored, all that is known is that \( y_{ij} \geq b \) and \( y_{ij}^* \) is determined by \( ul() \). The censoring limits specified in \( ll() \) and \( ul() \) can be the same for all observations or can vary from observation to observation.

Regardless of the type of censoring, the expected value of the underlying dependent variable—say, \( y \)—is modeled using the following linear prediction:
\[
E(y|X, u) = X\beta + Zu
\]  

\( X \) is an \( n \times p \) design/covariate matrix, analogous to the covariates you would find in a standard linear regression model, with regression coefficients (fixed effects) \( \beta \). \( Z \) is the \( n \times q \) design/covariate matrix for the random effects \( u \). This linear prediction also contains the offset when offset() is specified.

The columns of matrix \( Z \) are the covariates corresponding to the random effects and can be used to represent both random intercepts and random coefficients. For example, in a random-intercepts model, \( Z \) is simply the scalar 1. The random effects \( u \) are realizations from a multivariate normal distribution with mean 0 and \( q \times q \) variance matrix \( \Sigma \). The random effects are not directly estimated as model parameters but are instead summarized according to the unique elements of \( \Sigma \), known as variance components. One special case of (1) places \( Z = X \) so that all covariate effects are essentially random and distributed as multivariate normal with mean \( \beta \) and variance \( \Sigma \).

Below we present a short example of mixed-effects tobit regression; refer to [ME] me and [ME] meglm for additional examples of random-effects models. A two-level tobit model can also be fit using xttobit; see [XT] xttobit. In the absence of random effects, mixed-effects tobit regression reduces to standard tobit regression; see [R] tobit.

Example 1: Random-intercept model

We have wage data on young women who were between ages 14 and 26 in 1968 and who were surveyed over the period 1968–1988; see [XT] xt for a more detailed discussion of the data. We are interested in the effect of completed years of schooling, current age, union membership, and residence in the South on wages.

```
. use http://www.stata-press.com/data/r15/nlswork
(National Longitudinal Survey. Young Women 14–26 years of age in 1968)
```

We fit a mixed-effects tobit model of the log of inflation-adjusted wages (ln_wage). For illustration purposes, we use the ul() option to impose an artificial upper limit at 1.96, the 75th percentile of the recorded log wages.
The estimation table reports the fixed effects, which are interpreted just as you would the output from `tobit`, and the estimated variance components. Because the dependent variable is log transformed, the fixed-effects coefficients can be interpreted in terms of a percent change. For example, we see that on average, union members make 14.2% more than nonunion members and that each additional year of age is associated with a 1.1% increase in wages.
The random-effects equation is labeled idcode. The estimated variance of the subject-specific random intercept is 0.098 with standard error 0.003. A likelihood-ratio test comparing the model with a tobit model without random effects is provided under the table and indicates that the two-level tobit model is preferred.

**Stored results**

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

Scalars

- `e(N)` number of observations
- `e(N_unc)` number of uncensored observations
- `e(N_lc)` number of left-censored observations
- `e(N_rc)` number of right-censored observations
- `e(k)` number of parameters
- `e(k_dv)` number of dependent variables
- `e(k_eq)` number of equations in `e(b)`
- `e(k_eq_model)` number of equations in overall model test
- `e(k_f)` number of fixed-effects parameters
- `e(k_r)` number of random-effects parameters
- `e(k_rs)` number of variances
- `e(df_m)` model degrees of freedom
- `e(ll)` log likelihood
- `e(N_clust)` number of clusters
- `e(chi2)` \( \chi^2 \)
- `e(p)` \( p \)-value for model test
- `e(ll_c)` log likelihood, comparison model
- `e(chi2_c)` \( \chi^2 \), comparison test
- `e(df_c)` degrees of freedom, comparison test
- `e(p_c)` \( p \)-value for comparison test
- `e(rank)` rank of `e(V)`
- `e(ic)` number of iterations
- `e(rc)` return code
- `e(converged)` 1 if converged, 0 otherwise

Macros

- `e(cmd)` meglm
- `e(cmd2)` metobit
- `e(cmdline)` command as typed
- `e(depvar)` names of dependent variables
- `e(llopt)` minimum of `depvar` or contents of `ll()`
- `e(ulopt)` maximum of `depvar` or contents of `ul()`
- `e(wtype)` weight type
- `e(wexp)` weight expression (first-level weights)
- `e(fweightk)` \( fweight \) variable for \( k \)th highest level, if specified
- `e(iweightk)` \( iweight \) variable for \( k \)th highest level, if specified
- `e(pweightk)` \( pweight \) variable for \( k \)th highest level, if specified
- `e(covariates)` list of covariates
- `e(kvars)` grouping variables
- `e(model)` tobit
- `e(title)` title in estimation output
- `e(link)` identity
- `e(family)` gaussian
- `e(clustvar)` name of cluster variable
- `e(offset)` offset
- `e(intmethod)` integration method
- `e(n_quad)` number of integration points
- `e(chi2type)` Wald; type of model \( \chi^2 \)
Methods and formulas

Without a loss of generality, consider a two-level regression model

$$E(y_j|X_j, u_j) = X_j\beta + Z_j u_j \quad y \sim \text{normal}$$

for $j = 1, \ldots, M$ clusters, with the $j$th cluster consisting of $n_j$ observations, where, for the $j$th cluster, $y_j$ is the $n_j \times 1$ censored response vector, $X_j$ is the $n_j \times p$ matrix of fixed predictors, $Z_j$ is the $n_j \times q$ matrix of random predictors, $u_j$ is the $q \times 1$ vector of random effects, and $\beta$ is the $p \times 1$ vector of regression coefficients on the fixed predictors. The random effects, $u_j$, are assumed to be multivariate normal with mean $0$ and variance $\Sigma$.

Let $\eta_j$ be the linear predictor, $\eta_j = X_j\beta + Z_j u_j$, that also includes the offset variable when offset() is specified. $y_{ij}$ and $\eta_{ij}$ are the $i$th individual elements of $y_j$ and $\eta_j$, $i = 1, \ldots, n_j$. $a_{ij}$ refers to the lower limit for observation $ij$, and $b_{ij}$ refers to the upper limit for observation $ij$. The conditional density function for the response at observation $ij$ is then
\[ f(y_{ij}^* | \eta_{ij}) = \begin{cases} 
(\sqrt{2\pi}\sigma_e)^{-1} \exp\left(-\frac{(y_{ij} - \eta_{ij})^2}{2\sigma_e^2}\right) & \text{if } y_{ij} = y_{ij}^* \\
\Phi\left(\frac{a_{ij} - \eta_{ij}}{\sigma_e}\right) & \text{if } y_{ij} \leq y_{ij}^* \\
1 - \Phi\left(\frac{b_{ij} - \eta_{ij}}{\sigma_e}\right) & \text{if } y_{ij} \geq y_{ij}^* 
\end{cases} \]

where \( \Phi(\cdot) \) is the cumulative normal distribution.

Because the observations are assumed to be conditionally independent, the conditional log density function for cluster \( j \) is

\[
\log f(y_j^* | \eta_j) = \sum_{j=1}^{n_j} \log f(y_{ij}^* | \eta_{ij})
\]

and the likelihood function for cluster \( j \) is given by

\[
L_j(\beta, \Sigma) = (2\pi)^{-q/2} |\Sigma|^{-1/2} \int_{\mathbb{R}^q} f(y_j^* | \eta_j) \exp\left(-\frac{1}{2} u_j^t \Sigma^{-1} u_j\right) \, du_j \\
= (2\pi)^{-q/2} |\Sigma|^{-1/2} \int_{\mathbb{R}^q} \exp\left\{ \log f(y_j^* | \eta_j) - \frac{1}{2} u_j^t \Sigma^{-1} u_j \right\} \, du_j
\]

where \( \mathbb{R} \) denotes the set of values on the real line and \( \mathbb{R}^q \) is the analog in \( q \)-dimensional space.

The integration in (2) has no closed form and thus must be approximated; see Methods and formulas in [ME] meglm for details.

metobit supports multilevel weights and survey data; see Methods and formulas in [ME] meglm for details.

Also see

[ME] metobit postestimation — Postestimation tools for metobit
[ME] meintreg — Multilevel mixed-effects interval regression
[ME] me — Introduction to multilevel mixed-effects models
[BAYES] bayes: metobit — Bayesian multilevel tobit regression
[R] tobit — Tobit regression
[SEM] intro 5 — Tour of models (Multilevel mixed-effects models)
[SVY] svy estimation — Estimation commands for survey data
[XT] xttobit — Random-effects tobit models
[U] 20 Estimation and postestimation commands