

# 26 Overview of Stata estimation commands

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## 26.1 Introduction

Stata has many estimation commands that compute summary statistics and fit statistical models, so it is easy to overlook a few. Some of these commands differ greatly from each other, others are gentle variations on a theme, and still others are equivalent to each other.

There are also estimation prefixes that modify the calculation performed by the command, such as `svy:`, `mi:`, `bayes:`, and `fm:`.

The majority of Stata's estimation commands share features that this chapter will not discuss; see [\[U\] 20 Estimation and postestimation commands](#). Especially see [\[U\] 20.22 Obtaining robust variance estimates](#), which discusses an alternative calculation for the estimated variance matrix (and hence standard errors) that many of Stata's estimation commands provide. Also see [\[U\] 20.13 Performing hypothesis tests on the coefficients](#). This overview chapter, however, will put all that aside and deal solely with matching commands to their statistical concepts.

This chapter discusses all the official estimation commands included in Stata 15. Users may have written their own estimation commands that they are willing to share. Type `search estimation`, `ssc new`, or `ssc hot` to discover more estimation commands; see [\[R\] ssc](#). And, of course, you can always write your own commands.

## 26.2 Means, proportions, and related statistics

This group of estimation commands computes summary statistics rather than fitting regression models. However, being estimation commands, they share the features discussed in [\[U\] 20 Estimation and postestimation commands](#), such as allowing the use of postestimation commands.

`mean`, `proportion`, `ratio`, and `total` provide estimates of population means, proportions, ratios, and totals, respectively. Each of these commands allows for obtaining separate estimates within subpopulations, groups defined by a separate categorical variable. In addition, `mean`, `proportion`, and `ratio` can report statistics adjusted by direct standardization.

`pwmean` provides another option for computing means of one variable for each level of one or more categorical variables. In addition, `pwmean` computes all pairwise differences in these means along with the corresponding tests and confidence intervals, which can optionally be adjusted to account for multiple comparisons.

## 26.3 Continuous outcomes

### 26.3.1 ANOVA and ANCOVA

ANOVA and ANCOVA fit general linear models and are related to the linear regression models discussed in [\[U\] 26.3.2 Linear regression](#), but we classify them separately. The related Stata commands are `anova`, `oneway`, and `loneaway`.

`anova` fits ANOVA and ANCOVA models, one-way and up—including two-way factorial, three-way factorial, etc.—and fits nested and mixed-design models as well as repeated-measures models.

`oneway` fits one-way ANOVA models. It reports Bartlett's test for equal variance and can also report multiple-comparison tests. After `anova`, use `pwcompare` to perform multiple-comparison tests.

`loneway` is an alternative to `oneway`. The results are numerically the same, but `loneway` can deal with more levels, limited only by dataset size (`oneway` is limited to 376 levels). `loneway` also reports some additional statistics, such as the intraclass correlation.

For MANOVA and MANCOVA, see [U] 26.20 Multivariate analysis.

## 26.3.2 Linear regression

Consider models of the form

$$y_j = \mathbf{x}_j\boldsymbol{\beta} + \epsilon_j$$

for a continuous  $y$  variable and where  $\sigma_\epsilon^2$  is constant across observations  $j$ . The model is called the linear regression model, and the estimator is often called the (ordinary) least-squares (OLS) estimator.

`regress` is Stata's linear regression command. `regress` produces the robust estimate of variance as well as the conventional estimate, and `regress` has a collection of commands that can be run after it to explore the nature of the fit.

The following commands will also do linear regressions, but they offer special features:

1. `areg` fits models  $y_j = \mathbf{x}_j\boldsymbol{\beta} + \mathbf{d}_j\boldsymbol{\gamma} + \epsilon_j$ , where  $\mathbf{d}_j$  is a mutually exclusive and exhaustive dummy variable set. `areg` obtains estimates of  $\boldsymbol{\beta}$  (and associated statistics) without ever forming  $\mathbf{d}_j$ , meaning that it also does not report the estimated  $\boldsymbol{\gamma}$ . If your interest is in fitting fixed-effects models, Stata has a better command—`xtreg`—discussed in [U] 26.14.1 Continuous outcomes with panel data. Most users who find `areg` appealing will probably want to use `xtreg` because it provides more useful summary and test statistics. `areg` duplicates the output that `regress` would produce if you were to generate all the dummy variables. This means, for instance, that the reported  $R^2$  includes the effect of  $\boldsymbol{\gamma}$ .
2. `cnsreg` allows you to place linear constraints on the coefficients.
3. `eivreg` adjusts estimates for errors in variables.
4. `rreg` fits robust regression models, which are not to be confused with regression with robust standard errors. Robust standard errors are discussed in [U] 20.22 Obtaining robust variance estimates. Robust regression concerns point estimates more than it does standard errors, and it implements a data-dependent method for downweighting outliers.

## 26.3.3 Regression with heteroskedastic errors

We now consider the model  $y_j = \mathbf{x}_j\boldsymbol{\beta} + \epsilon_j$ , where the variance of  $\epsilon_j$  is nonconstant.

`hetregress` fits models with multiplicative heteroskedasticity, that is, models in which the variance of  $\epsilon_j$  is an exponential function of one or more covariates. The heteroskedasticity can be modeled using either maximum likelihood or Harvey's two-step generalized least-squares method.

When not much is known about the functional form of the variance of  $\epsilon_j$ , `regress` with the `vce(robust)` option is preferred because it provides unbiased estimates. What Stata calls robust is also known as the White correction for heteroskedasticity.

`vwls` (variance-weighted least squares) produces estimates of  $y_j = \mathbf{x}_j\boldsymbol{\beta} + \epsilon_j$ , where the variance of  $\epsilon_j$  is calculated from group data or is known a priori. `vwls` is therefore of most interest to categorical-data analysts and physical scientists.

`qreg` performs quantile regression, which in the presence of heteroskedasticity is most of interest. Median regression (one of `qreg`'s capabilities) is an estimator of  $y_j = \mathbf{x}_j\beta + \epsilon_j$  when  $\epsilon_j$  is heteroskedastic. Even more useful, you can fit models of other quantiles and so model the heteroskedasticity. `bsqreg` is identical to `qreg` but reports bootstrap standard errors. Also see the `sqreg` and `iqreg` commands; `sqreg` estimates multiple quantiles simultaneously, and `iqreg` estimates differences in quantiles.

### 26.3.4 Estimation with correlated errors

By correlated errors, we mean that observations are grouped; within a group, the observations might be correlated, but across groups, they are uncorrelated. `regress` with the `vce(cluster clustvar)` option can produce “correct” estimates, that is, inefficient estimates with correct standard errors and a lot of robustness; see [U] 20.22 [Obtaining robust variance estimates](#). Alternatively, you can model the within-group correlation using `xtreg`, `xtgls`, or `mixed`; we discuss these commands in [U] 26.14.1 [Continuous outcomes with panel data](#) and [U] 26.15 [Multilevel mixed-effects models](#).

Estimation in the presence of autocorrelated errors is discussed in [U] 26.13 [Time-series models](#).

### 26.3.5 Regression with censored and truncated outcomes

1. `tobit` allows estimation of linear regression models when  $y_i$  has been subject to left-censoring, right-censoring, or both. Say that  $y_i$  is not observed if  $y_i < 1000$ , but for those observations, it is known that  $y_i < 1000$ . `tobit` fits such models.
2. `intreg` (interval regression) is a generalization of `tobit`. In addition to allowing open-ended intervals, `intreg` allows closed intervals. Rather than observing  $y_j$ , `intreg` assumes that  $y_{0j}$  and  $y_{1j}$  are observed, where  $y_{0j} \leq y_j \leq y_{1j}$ . Survey data might report that a subject's monthly income was in the range \$1,500–\$2,500. `intreg` allows such data to be used to fit a regression model. `intreg` allows  $y_{0j} = y_{1j}$  and so can reproduce results reported by `regress`. `intreg` allows  $y_{0j}$  to be  $-\infty$  and  $y_{1j}$  to be  $+\infty$  and so can reproduce results reported by `tobit`.
3. `truncreg` fits the regression model when the sample is drawn from a restricted part of the population and so is similar to `tobit`, except that here the independent variables are not observed. Under the normality assumption for the whole population, the error terms in the truncated regression model have a truncated-normal distribution.
4. `churdle` allows estimation of linear or exponential hurdle models when  $y_i$  is subject to a lower boundary  $\ell\ell$ , an upper boundary  $ul$ , or both. The dependent variable is a mixture of discrete observations at the boundary points and continuous observations over the interior. Both boundary and interior observations on  $y_i$  are actual realizations. In contrast, censored-data models such as `tobit` and `intreg` treat interior observations as actual realizations and treat boundary observations as indicating only that the actual realizations lie beyond the boundary. Hurdle models use one model to determine whether an observation is on the boundary or in the interior and another model for the values in the interior.

### 26.3.6 Multiple-equation models

When we have errors that are correlated across equations but not correlated with any of the right-hand-side variables, we can write the system of equations as

$$\begin{aligned}y_{1j} &= \mathbf{x}_{1j}\boldsymbol{\beta} + \epsilon_{1j} \\y_{2j} &= \mathbf{x}_{2j}\boldsymbol{\beta} + \epsilon_{2j} \\&\vdots \\y_{mj} &= \mathbf{x}_{mj}\boldsymbol{\beta} + \epsilon_{mj}\end{aligned}$$

where  $\epsilon_k$  and  $\epsilon_l$  are correlated with correlation  $\rho_{kl}$ , a quantity to be estimated from the data. This is called Zellner's seemingly unrelated regression, and `sureg` fits such models. When  $\mathbf{x}_{1j} = \mathbf{x}_{2j} = \dots = \mathbf{x}_{mj}$ , the model is known as multivariate regression, and the corresponding command is `mvreg`.

The equations need not be linear. If they are not linear, use `nlsur`; see [U] 26.3.8 **Nonlinear regression**.

### 26.3.7 Stochastic frontier models

`frontier` fits stochastic production or cost frontier models on cross-sectional data. The model can be expressed as

$$y_i = \mathbf{x}_i\boldsymbol{\beta} + v_i - su_i$$

where

$$s = \begin{cases} 1 & \text{for production functions} \\ -1 & \text{for cost functions} \end{cases}$$

$u_i$  is a nonnegative disturbance standing for technical inefficiency in the production function or cost inefficiency in the cost function. Although the idiosyncratic error term  $v_i$  is assumed to have a normal distribution, the inefficiency term is assumed to be one of the three distributions: half-normal, exponential, or truncated-normal. Also, when the nonnegative component of the disturbance is assumed to be either half-normal or exponential, `frontier` can fit models in which the error components are heteroskedastic conditional on a set of covariates. When the nonnegative component of the disturbance is assumed to be from a truncated-normal distribution, `frontier` can also fit a conditional mean model, where the mean of the truncated-normal distribution is modeled as a linear function of a set of covariates.

For panel-data stochastic frontier models, see [U] 26.14.1 **Continuous outcomes with panel data**.

### 26.3.8 Nonlinear regression

`nl` provides the nonlinear least-squares estimator of  $y_j = f(\mathbf{x}_j, \boldsymbol{\beta}) + \epsilon_j$ , where  $f(\mathbf{x}_j, \boldsymbol{\beta})$  is an arbitrary nonlinear regression function such as the exponential or the lognormal. `nlsur` fits a system of nonlinear equations by feasible generalized nonlinear least squares. It can be viewed as a nonlinear variant of Zellner's seemingly unrelated regression model.

A special case of a nonlinear model is the Box–Cox transform. `boxcox` obtains maximum likelihood estimates of the coefficients and the Box–Cox transform parameters in a model of the form

$$y_i^{(\theta)} = \beta_0 + \beta_1 x_{i1}^{(\lambda)} + \beta_2 x_{i2}^{(\lambda)} + \dots + \beta_k x_{ik}^{(\lambda)} + \gamma_1 z_{i1} + \gamma_2 z_{i2} + \dots + \gamma_l z_{il} + \epsilon_i$$

where  $\epsilon \sim N(0, \sigma^2)$ . Here the  $y$  is subject to a Box–Cox transform with parameter  $\theta$ . Each of the  $x_1, x_2, \dots, x_k$  is transformed by a Box–Cox transform with parameter  $\lambda$ . The  $z_1, z_2, \dots, z_l$  are independent variables that are not transformed. In addition to the general form specified above, `boxcox` can fit three other versions of this model defined by the restrictions  $\lambda = \theta$ ,  $\lambda = 1$ , and  $\theta = 1$ .

For nonlinear mixed-effects models, see [U] 26.15 **Multilevel mixed-effects models**.

### 26.3.9 Nonparametric regression

All the models discussed so far have specified a particular functional form for the relationship between the outcome and the covariates in the model. Nonparametric regression allows you to model the mean of an outcome given the covariates when you are uncertain about its functional form. Stata's command for nonparametric estimation is `npregress`. In general, for any outcome that you would be comfortable modeling using `regress`, you can use `npregress`. The difference is that you no longer have to assume a linear relationship.

`npregress` implements two nonparametric kernel-based estimators. Nonparametric kernel-based estimators rely on an optimal bandwidth parameter that trades off bias and variance. However, you must have many more observations than you need for the parametric estimators discussed previously.

The local-linear and local-constant estimators give equivalent estimators of the mean, but there are some differences that are important to consider. The local-linear estimator lets you obtain marginal effects for continuous covariates. Also, if the model is linear, the local-linear estimator will recover a linear mean whereas the local constant may not. For cases in which your outcome is nonnegative, the local-constant estimator will yield nonnegative predictions. The local-linear estimator may result in negative predictions in such cases.

See [R] [npregress intro](#) for more information about nonparametric regression.

## 26.4 Binary outcomes

### 26.4.1 Logistic, probit, and complementary log-log regression

There are many ways to write these models, one of which is

$$\Pr(y_j \neq 0) = F(\mathbf{x}_j\beta)$$

where  $F$  is some cumulative distribution. Two popular choices for  $F(\cdot)$  are the normal and logistic, and the models are called the probit and logit (or logistic regression) models. The two parent commands for the maximum likelihood estimator of probit and logit are `probit` and `logit`. `logit` has a sibling, `logistic`, that provides the same estimates but displays results in a slightly different way. There is also an exact logistic estimator; see [U] [26.10 Exact estimators](#).

A third choice for  $F(\cdot)$  is the complementary log-log function. Maximum likelihood estimates are obtained by Stata's `cloglog` command.

Do not read anything into the names `logit` and `logistic`. `Logit` and `logistic` have two interchanged definitions in two scientific camps. In the medical sciences, `logit` means the minimum  $\chi^2$  estimator, and `logistic` means maximum likelihood. In the social sciences, it is the other way around. From our experience, it appears that neither reads the other's literature, because both assert that `logit` means one thing and `logistic` the other. Our solution is to provide both `logit` and `logistic`, which do the same thing, so that each camp can latch on to the maximum likelihood command under the name each expects.

There are two slight differences between `logit` and `logistic`. `logit` reports estimates in the coefficient metric, whereas `logistic` reports exponentiated coefficients—odds ratios. This is in accordance with the expectations of each camp and makes no substantial difference. The other difference is that `logistic` has a family of post-`logistic` commands that you can run to explore the nature of the fit. Actually, that is not exactly true because all the commands for use after `logistic` can also be used after `logit`.

If you have not already selected `logit` or `logistic` as your favorite, we recommend that you try `logistic`. Logistic regression (`logit`) models are more easily interpreted in the odds-ratio metric.

`binreg` can be used to model either individual-level or grouped data in an application of the generalized linear model. The family is assumed to be binomial, and each link provides a distinct parameter interpretation. Also, `binreg` offers several options for setting the link function according to the desired biostatistical interpretation. The available links and interpretation options are the following:

Option	Implied link	Parameter
<code>or</code>	<code>logit</code>	Odds ratios = $\exp(\beta)$
<code>rr</code>	<code>log</code>	Risk ratios = $\exp(\beta)$
<code>hr</code>	<code>log complement</code>	Health ratios = $\exp(\beta)$
<code>rd</code>	<code>identity</code>	Risk differences = $\beta$

Related to `logit`, the skewed logit estimator `scobit` adds a power to the logit link function and is estimated by Stata's `scobit` command.

`hetprobit` fits heteroskedastic probit models. In these models, the variance of the error term is parameterized.

Also, Stata's `biprobit` command fits bivariate probit models, meaning models with two correlated outcomes. `biprobit` also fits partial-observability models in which only the outcomes (0, 0) and (1, 1) are observed.

## 26.4.2 Conditional logistic regression

`clogit` is Stata's conditional logistic regression estimator. In this model, observations are assumed to be partitioned into groups, and a predetermined number of events occur in each group. The model measures the risk of the event according to the observation's covariates,  $x_j$ . The model is used in matched case-control studies (`clogit` allows 1 : 1, 1 :  $k$ , and  $m$  :  $k$  matching) and is used in natural experiments whenever observations can be grouped into pools in which a fixed number of events occur. `clogit` is also used to fit logistic regression with fixed group effects.

## 26.4.3 ROC analysis

ROC stands for "receiver operating characteristics". ROC deals with specificity and sensitivity, the number of false positives and undetected true positives of a diagnostic test. The term "ROC" dates back to the early days of radar when there was a knob on the radar receiver labeled "ROC". If you turned the knob one way, the receiver became more sensitive, which meant it was more likely to show airplanes that really were there and, simultaneously, more likely to show returns where there were no airplanes (false positives). If you turned the knob the other way, you suppressed many of the false positives, but unfortunately, you also suppressed the weak returns from real airplanes (undetected positives). These days, in the statistical applications we imagine, one does not turn a knob but instead chooses a value of the diagnostic test, above which is declared to be a positive and below which, a negative.

ROC analysis is applied to binary outcomes such as those appropriate for probit or logistic regression. After fitting a model, one can obtain predicted probabilities of a positive outcome. One chooses a value, above which the predicted probability is declared a positive and below which, a negative.

ROC analysis is about modeling the tradeoff of sensitivity and specificity as the threshold value is chosen.

Stata's suite for ROC analysis consists of six commands: `roctab`, `roccomp`, `rocfit`, `rocgold`, `rocreg`, and `rocregplot`.

`roctab` provides nonparametric estimation of the ROC curve and produces Bamber and Hanley confidence intervals for the area under the curve.

`roccomp` provides tests of equality of ROC areas. It can estimate nonparametric and parametric binormal ROC curves.

`rocfit` fits maximum likelihood models for a single classifier, an indicator of the latent binormal variable for the true status.

`rocgold` performs tests of equality of ROC areas against a "gold standard" ROC curve and can adjust significance levels for multiple tests across classifiers via Šidák's method.

`rocreg` performs ROC regression; it can adjust both sensitivity and specificity for prognostic factors such as age and gender. It is by far the most general of all the ROC commands.

`rocregplot` graphs ROC curves as modeled by `rocreg`. ROC curves can be drawn across covariate values, across classifiers, and across both.

See [R] `roc`.

## 26.5 Fractional outcomes

Fractional response data occur when the outcome of interest is measured as a fraction, proportion, or rate. Two widely used methods for modeling these outcomes are beta regression and fractional regression.

`betareg` can be used to estimate the parameters of a beta-regression model for fractional responses that are strictly greater than zero and less than one.

`fracreg` can be used to estimate the parameters of a fractional logistic model, a fractional probit model, or a fractional heteroskedastic probit model for fractional responses that are greater than or equal to zero and less than or equal to one.

Both commands use quasimaximum likelihood estimation. When the dependent variable is between zero and one, `betareg` provides more flexibility than `fracreg` in the distribution of the conditional mean of the dependent variable.

## 26.6 Ordinal outcomes

For ordered outcomes, Stata provides ordered logit, ordered probit, zero-inflated ordered probit, and rank-ordered logit, as well as alternative-specific rank-ordered logit regression.

`oprobit` and `ologit` provide maximum-likelihood ordered probit and logit. These are generalizations of probit and logit models known as the proportional odds model and are used when the outcomes have a natural ordering from low to high. The idea is that there is an unmeasured  $z_j = \mathbf{x}_j\beta$ , and the probability that the  $k$ th outcome is observed is  $\Pr(c_{k-1} < z_j < c_k)$ , where  $c_0 = -\infty$ ,  $c_k = +\infty$ , and  $c_1, \dots, c_{k-1}$  along with  $\beta$  are estimated from the data.

`zioprobit` fits zero-inflated ordered probit models. It is used to model an ordered outcome with a higher fraction of observations in the lowest category than would be expected from an ordered probit model. Representing the lowest value with a zero is common. The outcome is a result of two processes. First a probit process describes the presence of excess zeros, which is a negative outcome. Second, an ordered probit process, conditional on a positive outcome from the probit process, describes the ordered outcome.



`rologit` fits the rank-ordered logit model for rankings. This model is also known as the Plackett–Luce model, the exploded logit model, and choice-based conjoint analysis.

`asprobit` fits the probit model for rankings, a more flexible estimator than `rologit` because `asprobit` allows covariances among the rankings. The `as` in the name signifies that `asprobit` also allows alternative-specific regressors—variables that have different coefficients for each alternative.

## 26.7 Categorical outcomes

For categorical outcomes, Stata provides multinomial logistic regression, multinomial probit regression, stereotype logit regression, nested logistic regression, McFadden’s choice model (conditional fixed-effects logistic regression), alternative-specific multinomial probit regression, and alternative-specific mixed logit regression.

`mlogit` fits maximum-likelihood multinomial logistic models, also known as polytomous logistic regression. `mprobit` is similar but instead is a generalization of the probit model. Both models are intended for use when the outcomes have no natural ordering and you know only the characteristics of the outcome chosen (and, perhaps, the chooser).

`slogit` fits the stereotype logit model for data that are not truly ordered, as data are for `ologit`, but for which you are not sure that they are unordered, in which case `mlogit` would be appropriate.

`asclogit` fits McFadden’s choice model, also known as conditional logistic regression. In the context denoted by the name McFadden’s choice model, the model is used when the outcomes have no natural ordering, just as in multinomial logistic regression, but the characteristics of the outcomes chosen and not chosen are known (along with, perhaps, the characteristics of the chooser).

In the context denoted by the name conditional logistic regression—mentioned above—subjects are members of pools, and one or more are chosen, typically to be infected by some disease or to have some other unfortunate event befall them. Thus, the characteristics of the chosen and not chosen are known, and the issue of the characteristics of the chooser never arises. Either way, it is the same model.

In their choice-model interpretations, `mlogit` and `asclogit` assume that the odds ratios are independent of other alternatives, known as the independence of irrelevant alternatives (IIA) assumption. This assumption is often rejected by the data, and the nested logit model relaxes this assumption. `nlogit` is also popular for fitting the random utility choice model.

`asmprobit` is for use with outcomes that have no natural ordering and with regressors that are alternative specific. `asmixlogit` is a generalization of `mlogit` that allows for correlation of choices across outcomes. Unlike `mlogit`, `asmprobit` and `asmixlogit` do not assume the IIA. The random coefficients that are used by `asmixlogit` to relax the IIA also directly model the heterogeneity in choices given covariates.

## 26.8 Count outcomes

These models concern dependent variables that count the occurrences of an event. In this category, we include Poisson and negative binomial regression. For the Poisson model,

$$E(\text{count}) = E_j \exp(\mathbf{x}_j \boldsymbol{\beta})$$

where  $E_j$  is the exposure time. `poisson` fits this model. There is also an exact Poisson estimator; see [U] 26.10 Exact estimators.

Negative binomial regression refers to estimating with data that are a mixture of Poisson counts. One derivation of the negative binomial model is that individual units follow a Poisson regression model but that there is an omitted variable that follows a gamma distribution with parameter  $\alpha$ . Negative binomial regression estimates  $\beta$  and  $\alpha$ . `nbreg` fits such models. A variation on this, unique to Stata, allows you to model  $\alpha$ . `gnbreg` fits those models.

Sometimes, the value of the outcome variable is not observed when it falls outside a known range, and it is observed inside that range. This limitation comes in two flavors—censoring and truncation. It is called censoring when we have an observation for the outcome but know only that the value of the outcome is outside the range. It is called truncation when we do not even have an observation when the value of the outcome is outside the range. The `cpoisson` command can be used to fit models for censored count data. Commands `tpoisson` and `tnbreg` can be used to fit models for truncated count data.

Zero inflation refers to count models in which the number of zero counts is more than would be expected in the regular model. The excess zeros are explained by a preliminary probit or logit process. If the preliminary process produces a positive outcome, the usual counting process occurs, and otherwise, the count is zero. Thus, whenever the preliminary process produces a negative outcome, excess zeros are produced. The `zip` and `zinb` commands fit such models.

## 26.9 Generalized linear models

The generalized linear model is

$$g\{E(y_j)\} = \mathbf{x}_j\beta, \quad y_j \sim F$$

where  $g(\cdot)$  is called the link function and  $F$  is a member of the exponential family, both of which you specify before estimation. `glm` fits this model.

The GLM framework encompasses a surprising array of models known by other names, including linear regression, Poisson regression, exponential regression, and others. Stata provides dedicated estimation commands for many of these. For instance, Stata has `regress` for linear regression, `poisson` for Poisson regression, and `streg` for exponential regression, and that is not all the overlap.

`glm` by default uses maximum likelihood estimation and alternatively estimates via iterated reweighted least squares (IRLS) when the `irls` option is specified. For each family,  $F$ , there is a corresponding link function,  $g(\cdot)$ , called the canonical link, for which IRLS estimation produces results identical to maximum likelihood estimation. You can, however, match families and link functions as you wish, and when you match a family to a link function other than the canonical link, you obtain a different but valid estimator of the standard errors of the regression coefficients. The estimator you obtain is asymptotically equivalent to the maximum likelihood estimator, which, in small samples, produces slightly different results.

For example, the canonical link for the binomial family is logit. `glm`, `irls` with that combination produces results identical to the maximum-likelihood `logit` (and `logistic`) command. The binomial family with the probit link produces the probit model, but probit is not the canonical link here. Hence, `glm`, `irls` produces standard-error estimates that differ slightly from those produced by Stata's maximum-likelihood `probit` command.

Many researchers feel that the maximum-likelihood standard errors are preferable to IRLS estimates (when they are not identical), but they would have a difficult time justifying that feeling. Maximum likelihood probit is an estimator with (solely) asymptotic properties; `glm`, `irls` with the binomial family and probit link is an estimator with (solely) asymptotic properties, and in finite samples, the standard errors differ a little.

Still, we recommend that you use Stata's dedicated estimators whenever possible. IRLS (the theory) and `glm`, `irls` (the command) are all encompassing in their generality, meaning that they rarely use the right jargon or provide things in the way you wish they would. The narrower commands, such as `logit`, `probit`, and `poisson`, focus on the issue at hand and are invariably more convenient.

`glm` is useful when you want to match a family to a link function that is not provided elsewhere.

`glm` also offers several estimators of the variance–covariance matrix that are consistent, even when the errors are heteroskedastic or autocorrelated. Another advantage of a `glm` version of a model over a model-specific version is that many of these VCE estimators are available only for the `glm` implementation. You can also obtain the ML–based estimates of the VCE from `glm`.

## 26.10 Exact estimators

Exact estimators refer to models that, rather than being estimated by asymptotic formulas, are estimated by enumerating the conditional distribution of the sufficient statistics and then computing the maximum likelihood estimate using that distribution. Standard errors cannot be estimated, but confidence intervals can be and are obtained from the enumerations.

`exlogistic` fits logistic models of binary data in this way.

`expoisson` fits Poisson models of count data in this way.

In small samples, exact estimates have better coverage than the asymptotic estimates, and exact estimates are the only way to obtain estimates, tests, and confidence intervals of covariates that perfectly predict the observed outcome.

## 26.11 Models with endogenous covariates

A covariate is endogenous if it is correlated with the unobservable components of a model. Endogeneity encompasses cases such as measurement error, omitted variables correlated with included regressors, and simultaneity. Stata offers several commands to address endogeneity depending on your outcome of interest and how you wish to model the correlation that generates the endogeneity problem.

Solutions to endogeneity rely on the use of instrumental variables. Instrumental variables are uncorrelated with the unobservable components of a model and are related to the outcome of interest only through their relationships with the endogenous variables.

Instrumental-variable models use instrumental variables to model endogeneity. Alternatively, a control function approach can be used. In this case, instrumental variables are used to directly model the correlation between unobservable components in the model.

`ivregress` fits linear outcome models with endogenous variables using the two-stage least-squares form of instrumental variables, the limited-information form of maximum likelihood, and a version of the generalized method of moments (GMM). The three estimators differ in the efficiency and robustness to additional assumptions such as constraints on the variances of the error terms.

`ivprobit` fits a probit outcome model where one or more of the covariates are endogenously determined. `ivtobit` is like `ivregress` but allows for censored outcomes. `ivpoisson` fits a Poisson outcome model where one or more of the covariates are endogenously determined. It can also be used for modeling nonnegative continuous outcomes instead of counts.

The GMM estimator implemented in `ivregress` is a special case of the estimators implemented in `gmm`. For other functional forms, you can write your own moment-evaluator program or supply the moment conditions as substitutable expressions to `gmm`; see [U] 26.21 **Generalized method of moments (GMM)**.

The extended regression commands fit models with endogenous covariates that are binary, ordinal, or censored, as well as continuous. `eregress` fits a linear model with endogenous covariates, `eintreg` fits tobit and interval regression models with endogenous covariates, `eprobit` fits a probit model with endogenous covariates, and `eoprobit` fits an ordered probit model with endogenous covariates. You may also use these commands to accommodate endogenous sample selection (see [U] 26.12 Models with endogenous sample selection) and treatment effects (see [U] 26.18 Treatment-effects models) in combination with endogenous covariates.

For systems of linear equations with endogenous covariates, the three-stage least-squares (3SLS) estimator in `reg3` can produce constrained and unconstrained estimates. Structural equation models discussed in [U] 26.22 Structural equation modeling (SEM) and GMM estimators discussed in [U] 26.21 Generalized method of moments (GMM) are also widely used for such systems.

## 26.12 Models with endogenous sample selection

When unobservable factors that affect who is included in a sample are correlated with unobservable factors that affect the outcome, we say that there is endogenous sample selection. When present, endogenous sample selection should be modeled; consider using one of the commands discussed below.

What has become known as the Heckman model refers to linear regression in the presence of endogenous sample selection:  $y_j = \mathbf{x}_j\beta + \epsilon_j$  is not observed unless some event occurs that itself has probability  $p_j = F(\mathbf{z}_j\gamma + \nu_j)$ , where  $\epsilon$  and  $\nu$  might be correlated and  $\mathbf{z}_j$  and  $\mathbf{x}_j$  may contain variables in common. `heckman` fits such models by maximum likelihood or Heckman's original two-step procedure.

This model has been generalized to replace the linear regression equation with another probit equation, and that model is fit by `heckprobit`. The command `heckoprobit` fits an ordered probit model in the presence of sample selection. Finally, `heckpoisson` is used to model count data subject to endogenous sample selection.

Stata's extended regression commands allow you to model endogenous sample selection along with endogenous covariates and treatment effects. These commands are discussed in [U] 26.11 Models with endogenous covariates.

## 26.13 Time-series models

ARIMA refers to models with autoregressive integrated moving-average processes, and Stata's `arima` command fits models with ARIMA disturbances via the Kalman filter and maximum likelihood. These models may be fit with or without covariates. `arima` also fits ARMA models.

ARFIMA, or autoregressive fractionally integrated moving average, handles long-memory processes. ARFIMA generalizes the ARMA and ARIMA models. ARMA models assume short memory; after a shock, the process reverts to its trend relatively quickly. ARIMA models assume shocks are permanent and memory never fades. ARFIMA provides a middle ground in the length of the process's memory. The `arfima` command fits ARFIMA models. In addition to one-step and dynamic forecasts, `arfima` can predict fractionally integrated series.

UCM, or unobserved components model, decomposes a time series into trend, seasonal, cyclic, and idiosyncratic components after controlling for optional exogenous variables. UCM provides a flexible and formal approach to smoothing and decomposition problems. The `ucm` command fits UCM models.

The estimated parameters of ARIMA, ARFIMA, and UCM are sometimes more easily interpreted in terms of the implied spectral density. `psdensity` transforms results.

Band-pass and high-pass filters are also used to decompose a time series into trend and cyclic components, even though the `tsfilter` commands are not estimation commands. Provided are Baxter–King, Butterworth, Christiano–Fitzgerald, and Hodrick–Prescott filters.

Stata’s `prais` command performs regression with AR(1) disturbances using the Prais–Winsten or Cochrane–Orcutt transformation. Both two-step and iterative solutions are available, as well as a version of the Hildreth–Lu search procedure.

`newey` produces linear regression estimates with the Newey–West variance estimates that are robust to heteroskedasticity and autocorrelation of specified order.

Stata provides estimators for ARCH, GARCH, univariate, and multivariate models. These models are for time-varying volatility. ARCH models allow for conditional heteroskedasticity by including lagged variances. GARCH models also include lagged second moments of the innovations (errors). ARCH stands for “autoregressive conditional heteroskedasticity”. GARCH stands for “generalized ARCH”.

`arch` fits univariate ARCH and GARCH models, and the command provides many popular extensions, including multiplicative conditional heteroskedasticity. Errors may be normal or Student’s  $t$  or may follow a generalized error distribution. Robust standard errors are optionally provided.

`mgarch` fits multivariate ARCH and GARCH models, including the diagonal vech model and the constant, dynamic, and varying conditional correlation models. Errors may be multivariate normal or multivariate Student’s  $t$ . Robust standard errors are optionally provided.

Stata provides VAR, SVAR, and VEC estimators for modeling multivariate time series. VAR and SVAR deal with stationary series, and SVAR places additional constraints on the VAR model that identifies the impulse–response functions. VEC is for cointegrating VAR models. VAR stands for “vector autoregression”; SVAR, for “structural VAR”; and VEC, for “vector error-correction” model.

`var` fits VAR models, `svar` fits SVAR models, and `vec` fits VEC models. These commands share many of the same features for specification testing, forecasting, and parameter interpretation; see [TS] [var intro](#) for both `var` and `svar`, [TS] [vec intro](#) for `vec`, and [TS] [irf](#) for all three impulse–response functions and forecast-error variance decomposition. For lag-order selection, residual analysis, and Granger causality tests, see [TS] [var intro](#) (for `var` and `svar`) and [TS] [vec intro](#).

`sspace` estimates the parameters of multivariate state-space models using the Kalman filter. The state-space representation of time-series models is extremely flexible and can be used to estimate the parameters of many different models, including vector autoregressive moving-average (VARMA) models, dynamic-factor (DF) models, and structural time-series (STS) models. It can also solve some stochastic dynamic-programming problems.

`dfactor` estimates the parameters of dynamic-factor models. These flexible models for multivariate time series provide for a vector-autoregressive structure in both observed outcomes and unobserved factors. They also allow exogenous covariates for observed outcomes or unobserved factors.

Sometimes time-series data are characterized by shifts in the mean or variance. Linear autoregressive models may not adequately capture these peculiarities of the data. Stata provides Markov-switching and threshold models to fit such series.

Markov-switching models are used for series that transition over a finite set of unobserved states where the transitions occur according to a Markov process. The time of transition from one state to another and the duration between changes in state are random. By contrast, threshold models are used for series that transition over regions determined by threshold values. You can use the `mswitch` command to fit Markov-switching dynamic-regression (MSDR) and Markov-switching autoregression (MSAR) models. MSDR models can accommodate higher autoregressive lags than MSAR models because the state vector does not depend on the autoregressive lags in an MSDR model. You can use `threshold` to fit threshold regression models.

## 26.14 Panel-data models

Commands in this class begin with the letters `xt`. You must `xtset` your data before you can use an `xt` command.

### 26.14.1 Continuous outcomes with panel data

`xtreg` fits models of the form

$$y_{it} = \mathbf{x}_{it}\boldsymbol{\beta} + \nu_i + \epsilon_{it}$$

`xtreg` can produce the between-regression estimator, the within-regression (fixed-effects) estimator, or the generalized least-squares (GLS) random-effects (matrix-weighted average of between and within results) estimator. It can also produce the maximum-likelihood random-effects estimator.

`xtgee` fits population-averaged models, and it optionally provides robust estimates of variance. Moreover, `xtgee` allows other correlation structures. One of particular interest to those with a lot of data goes by the name “unstructured”. The within-panel correlations are simply estimated in an unconstrained way. [U] 26.14.4 [Generalized linear models with panel data](#) will discuss this estimator further because it is not restricted to linear regression models.

`xtfrontier` fits stochastic production or cost frontier models for panel data. You may choose from a time-invariant model or a time-varying decay model. In both models, the nonnegative inefficiency term is assumed to have a truncated-normal distribution. In the time-invariant model, the inefficiency term is constant within panels. In the time-varying decay model, the inefficiency term is modeled as a truncated-normal random variable multiplied by a specific function of time. In both models, the idiosyncratic error term is assumed to have a normal distribution. The only panel-specific effect is the random inefficiency term.

`xtivreg` contains the between-2SLS estimator, the within-2SLS estimator, the first-differenced-2SLS estimator, and two GLS random-effects-2SLS estimators to handle cases in which some of the covariates are endogenous.

`xhtaylor` uses instrumental-variables estimators to estimate the parameters of panel-data random-effects models of the form

$$y_{it} = \mathbf{X}_{1it}\boldsymbol{\beta}_1 + \mathbf{X}_{2it}\boldsymbol{\beta}_2 + \mathbf{Z}_{1i}\boldsymbol{\delta}_1 + \mathbf{Z}_{2i}\boldsymbol{\delta}_2 + u_i + \epsilon_{it}$$

The individual effects  $u_i$  are correlated with the explanatory variables  $\mathbf{X}_{2it}$  and  $\mathbf{Z}_{2i}$  but are uncorrelated with  $\mathbf{X}_{1it}$  and  $\mathbf{Z}_{1i}$ , where  $\mathbf{Z}_1$  and  $\mathbf{Z}_2$  are constant within the panel.

`xtgls` produces GLS estimates for models of the form

$$y_{it} = \mathbf{x}_{it}\boldsymbol{\beta} + \epsilon_{it}$$

where you may specify the variance structure of  $\epsilon_{it}$ . If you specify that  $\epsilon_{it}$  is independent for all  $i$ 's and  $t$ 's, `xtgls` produces the same results as `regress` up to a small-sample degrees-of-freedom correction applied by `regress` but not by `xtgls`.

You may choose among three variance structures concerning  $i$  and three concerning  $t$ , producing a total of nine different models. Assumptions concerning  $i$  deal with heteroskedasticity and cross-sectional correlation. Assumptions concerning  $t$  deal with autocorrelation and, more specifically, AR(1) serial correlation.

In the jargon of GLS, the random-effects model fit by `xtreg` has exchangeable correlation within  $i$ —`xtgls` does not model this particular correlation structure. `xtgee`, however, does.

Alternative methods report the OLS coefficients and a version of the GLS variance–covariance estimator. `xtpcse` produces panel-corrected standard error (PCSE) estimates for linear cross-sectional time-series models, where the parameters are estimated by OLS or Prais–Winsten regression. When you are computing the standard errors and the variance–covariance estimates, the disturbances are, by default, assumed to be heteroskedastic and contemporaneously correlated across panels.

`xtrc` fits Swamy’s random-coefficients linear regression model. In this model, rather than only the intercept varying across groups, all the coefficients are allowed to vary.

See [U] 26.15 **Multilevel mixed-effects models** for a generalization of `xtrcg` and `xtrc` that allows for multiple levels of panels, random coefficients, and variance-component estimation in general. `xtrc` is a special case of `mixed`.

## 26.14.2 Censored outcomes with panel data

`xttobit` fits random-effects tobit models and generalizes that to observation-specific censoring.

`xtintreg` performs random-effects interval regression and generalizes that to observation-specific censoring. Interval regression, in addition to allowing open-ended intervals, allows closed intervals.

These models are generalizable to multilevel data; see [U] 26.15 **Multilevel mixed-effects models**.

## 26.14.3 Discrete outcomes with panel data

`xtprobit` fits random-effects probit regression via maximum likelihood. It also fits population-averaged models via GEE.

`xtlogit` fits random-effects logistic regression models via maximum likelihood. It also fits conditional fixed-effects models via maximum likelihood and population-averaged models via GEE.

`xtcloglog` estimates random-effects complementary log-log regression via maximum likelihood. It also fits population-averaged models via GEE.

`xtologit` and `xtoprobit` are multiple-outcome models. `xtologit` fits a random-effects ordered logistic model, and `xtoprobit` fits a random-effects ordered probit model.

`xtpoisson` fits two different random-effects Poisson regression models via maximum likelihood. The two distributions for the random effects are gamma and normal. `xtpoisson` also fits conditional fixed-effects models, and it fits population-averaged models via GEE.

`xtnbreg` fits random-effects negative binomial regression models via maximum likelihood (the distribution of the random effects is assumed to be beta). `xtnbreg` also fits conditional fixed-effects models, and it fits population-averaged models via GEE.

`xtprobit`, `xtlogit`, `xtcloglog`, `xtpoisson`, and `xtnbreg` are nothing more than `xtgee` with the appropriate family and link and an exchangeable error structure. See [U] 26.14.4 **Generalized linear models with panel data**.

These models are generalizable to multilevel data; see [U] 26.15 **Multilevel mixed-effects models**.

## 26.14.4 Generalized linear models with panel data

[U] 26.9 **Generalized linear models** discussed the model

$$g\{E(y_j)\} = \mathbf{x}_j\boldsymbol{\beta}, \quad y_j \sim F$$



where  $g(\cdot)$  is the link function and  $F$  is a member of the exponential family, both of which you specify before estimation.

There are two ways to extend the generalized linear model to panel data. They are the generalized linear mixed model (GLMM) and generalized estimation equations (GEE).

GEE uses a working correlation structure to model within-panel correlation. GEEs may be fit with the `xtgee` command.

For generalized linear models with multilevel data, including panel data, see [U] 26.15 [Multilevel mixed-effects models](#).

### 26.14.5 Survival models with panel data

`xtstreg` fits a random-effects parametric survival-time model by maximum likelihood. The conditional distribution of the response given the random effects is assumed to be exponential, Weibull, lognormal, loglogistic, or gamma. Depending on the selected distribution, `xtstreg` can fit models using a proportional hazards (PH) or accelerated failure-time (AFT) parameterization. Unlike the other panel-data commands, `xtstreg` requires that the data be `xtset` and `stset`.

These models are generalizable to multilevel data; see [U] 26.15 [Multilevel mixed-effects models](#).

### 26.14.6 Dynamic and autoregressive panel-data models

`xtregar` can produce the within estimator and a GLS random-effects estimator when the  $\epsilon_{it}$  are assumed to follow an AR(1) process.

`xtabond` is for use with dynamic panel-data models (models in which there are lagged dependent variables) and can produce the one-step, one-step robust, and two-step Arellano–Bond estimators. `xtabond` can handle predetermined covariates, and it reports both the Sargan and autocorrelation tests derived by Arellano and Bond.

`xtdpdsys` is an extension of `xtabond` and produces estimates with smaller bias when the coefficients of the AR process are large. `xtdpdsys` is also more efficient than `xtabond`. Whereas `xtabond` uses moment conditions based on the differenced errors, `xtdpdsys` uses moment conditions based on both the differenced errors and their levels.

`xtdpd` is an extension of `xtdpdsys` and can be used to estimate the parameters of a broader class of dynamic panel-data models. `xtdpd` can be used to fit models with serially correlated idiosyncratic errors, whereas `xtdpdsys` and `xtabond` assume no serial correlation. `xtdpd` can also be used with models where the structure of the predetermined variables is more complicated than that assumed by `xtdpdsys` or `xtabond`.

## 26.15 Multilevel mixed-effects models

In multilevel data, observations—subjects, for want of a better word—can be divided into groups that have something in common. Perhaps the subjects are students, and the groups attended the same high school, or they are patients who were treated at the same hospital, or they are tractors that were manufactured at the same factory. Whatever they have in common, it may be reasonable to assume that the shared attribute affects the outcome being modeled.

With regard to students and high school, perhaps you are modeling later success in life. Some high schools are better (or worse) than others, so it would not be unreasonable to assume that the identity of the high school had an effect. With regard to patients and hospital, the argument is much



the same if the outcome is subsequent health: some hospitals are better (or worse) than others, at least with respect to particular health problems. With regard to tractors and factory, it would hardly be surprising if tractors from some factories were more reliable than tractors from other factories.

Described above is two-level data. The first level is the student, patient, or tractor, and the second level is the high school, hospital, or factory. Observations are said to be nested within groups: students within a high school, patients within a hospital, or tractors within a factory.

Even though the effect on outcome is not directly observed, one can control for the effect if one is willing to assume that the effect is the same for all observations within a group and that, across groups, the effect is a random draw from a statistical distribution that is uncorrelated with the overall residual of the model and other group effects.

We have just described multilevel models.

A more complicated scenario might have three levels: students nested within teachers within a high school, patients nested within doctors within a hospital, or tractors nested within an assembly line within a factory.

An alternative to three-level hierarchical data is crossed data. We have workers and their occupation and the industry in which they work.

Stata provides a suite of multilevel estimation commands. The estimation commands are the following:

Command	Outcome variable	Equivalent to
<code>mixed</code>	continuous	linear regression
<code>metobit</code>	censored	tobit regression
<code>meintreg</code>	censored	interval regression
<code>meprobit</code>	binary	probit regression
<code>melogit</code>	binary	logistic regression
<code>meqrlogit</code>	binary	logistic regression <sup>1</sup>
<code>mecloglog</code>	binary	complementary log-log regression
<code>meoprobit</code>	ordered categorical	ordered probit regression
<code>meologit</code>	ordered categorical	ordered logistic regression
<code>mepoisson</code>	count	Poisson regression
<code>meqrpoisson</code>	count	Poisson regression <sup>1</sup>
<code>menbreg</code>	count	negative binomial regression
<code>mestreg</code>	survival-time	parametric survival-time regression
<code>meglm</code>	various	generalized linear models
<code>menl</code>	continuous	nonlinear regression

<sup>1</sup> `meqrlogit` and `meqrpoisson` use QR decomposition to produce results. They exist for historical reasons but can be useful for estimation on the boundary of the parameter space. Results are numerically equivalent to `melogit` and `mepoisson` in other cases.

The above estimators provide random intercepts and random coefficients and allow constraints to be placed on coefficients and on variance components. (The QR decomposition estimators and `menl` do not allow constraints.)

See the *Stata Multilevel Mixed-Effects Reference Manual*; in particular, see [ME] `me`.

## 26.16 Survival analysis models

Commands are provided to fit Cox proportional hazards models, competing-risks regression, and several parametric survival models, including exponential, Weibull, Gompertz, lognormal, loglogistic, and generalized gamma. The command for Cox regression is `stcox`. Parametric models may be fit to right-censored survival-time data by using the `streg` command and to interval-censored survival-time data by using the `stintreg` command.

`stcox` and `streg` support single- or multiple-failure-per-subject data. The command for competing-risks regression, `stcrreg`, and `stintreg` support only single-failure data. Conventional, robust, bootstrap, and jackknife standard errors are available with all four commands, with the exception that for `stcrreg`, robust standard errors are the conventional standard errors.

Both the Cox model and the parametric models (as fit using Stata) allow for two additional generalizations. First, the models may be modified to allow for latent random effects, or frailties. Second, the models may be stratified in that the baseline hazard function may vary completely over a set of strata. The parametric models also allow for the modeling of ancillary parameters.

Competing-risks regression, as fit using Stata, is a useful alternative to Cox regression for datasets where more than one type of failure occurs, in other words, for data where failure events compete with one another. In such situations, competing-risks regression allows you to easily assess covariate effects on the incidence of the failure type of interest without having to make strong assumptions concerning the independence of failure types.

`stcox`, `stcrreg`, and `streg` require that the data be `stset` so that the proper response variables can be established. After you `stset` the data, the time/censoring response is taken as understood, and you need supply only the regressors (and other options) to `stcox`, `stcrreg`, and `streg`. With `stcrreg`, one required option deals with specifying which events compete with the failure event of interest that was previously `stset`. `stintreg` requires that you specify the interval-censored time variables with the command and thus ignores any `st` settings.

Stata also provides commands to estimate average treatment effects and average treatment effects on the treated from observational survival-time data. See [U] 26.18 [Treatment-effects models](#).

We discuss panel-data survival-time models in [U] 26.14.5 [Survival models with panel data](#). These models generalize to multilevel data; see [U] 26.15 [Multilevel mixed-effects models](#).

## 26.17 Spatial autoregressive models

Stata's Sp estimation commands fit spatial autoregressive (SAR) models, also known as simultaneous autoregressive models. The commands allow spatial lags of the dependent and independent variables and spatial autoregressive errors. In time-series analysis, lags refer to recent times. In spatial analysis, lags mean nearby areas.

An essential part of the model specification for SAR models is the formulation of spatial lags. Spatial lags are specified using spatial weighting matrices. Because of the potentially large dimensions of the weighting matrices, Stata provides commands for creating, using, and saving spatial weighting matrices.

Spatial models estimate indirect or spillover effects from one spatial unit (area) to another. The models estimate direct effects, too, just as nonspatial models would. Direct effects are the effects within a spatial unit. Viewing estimates of the direct effects, indirect effects, and total effects is done by running `estat impact` after any of the Sp estimation commands. `estat impact` makes interpreting results easy.

Datasets for SAR models contain observations on geographical areas or other units; the only requirement is some measure of distance that distinguishes which units are close to each other. Spatial data for geographic areas are typically based on shapefiles. The Sp system converts standard-format shapefiles to Stata `.dta` files so they can be merged with other Stata `.dta` datasets.

The Sp system will also work without shapefiles. Data can contain  $(x, y)$  coordinates, or data need not be geographic at all. For example, Sp can be used to analyze social networks.

Read [SP] [intro](#) and the introductory sections that follow it for an overview of SAR models and a tutorial with examples for preparing your data and creating spatial weighting matrices.

The available Sp estimation commands are as follows:

Command	Description	Equivalent to
<code>spregress, gs2sls</code>	SAR with GS2SLS estimator	<code>regress</code>
<code>spregress, ml</code>	SAR with ML estimator	<code>regress</code>
<code>spivregress</code>	SAR with endogenous regressors	<code>ivregress</code>
<code>spxtregress, fe</code>	fixed-effects SAR for panel data	<code>xtreg, fe</code>
<code>spxtregress, re</code>	random-effects SAR for panel data	<code>xtreg, re</code>
<code>spxtregress, re sarpanel</code>	random-effects SAR alternative	

`spregress`, `gs2sls` and `spivregress` will fit multiple spatial lags of the dependent variable, multiple spatial autoregressive error terms, and multiple spatial lags of covariates. The other Sp estimation commands will fit only one spatial lag of the dependent variable and only one spatial autoregressive error term, but will allow multiple spatial lags of covariates.

## 26.18 Treatment-effects models

`teffects`, `stteffects`, and `eteffects` estimate treatment effects from observational data.

A treatment effect is the change in an outcome caused by an individual getting one treatment instead of another. We can estimate average treatment effects, but not individual-level treatment effects, because we observe each individual getting only one or another treatment.

`teffects`, `stteffects`, and `eteffects` use methods that specify what the individual-level outcomes would be for each treatment level, even though only one of them can be realized. This approach is known as the potential-outcome framework. See [TE] [teffects intro](#) for a basic introduction to the key concepts associated with observational data analysis. See [TE] [teffects intro advanced](#) for a more advanced introduction that provides the intuition behind the potential-outcome framework. [TE] [stteffects intro](#) extends the concepts in the two earlier introductions to survival-time data.

Suppose we want to use observational data to learn about the effect of exercise on blood pressure. The potential-outcome framework provides the structure to estimate what would be the average effect of everyone exercising instead of everyone not exercising, an effect known as average treatment effect (ATE). Similarly, we can estimate the average effect, among those who exercise, of exercising instead of not exercising, which is known as the average treatment effect on the treated (ATET). Finally, we could estimate the average blood pressure that would be obtained if everyone exercised or if no one exercised, parameters known as potential-outcome means (POMs).

`teffects` can estimate the ATE, the ATET, and the POMs. The estimators implemented in `teffects` impose the structure of the potential-outcome framework on the data in different ways.

- Regression-adjustment estimators use models for the potential outcomes. See [TE] [teffects ra](#).
- Inverse-probability-weighted estimators use models for treatment assignment. See [TE] [teffects ipw](#).
- Augmented inverse-probability-weighted estimators and inverse-probability-weighted regression-adjustment estimators use models for the potential outcomes and for treatment assignment. These estimators have the double-robust property; they correctly estimate the treatment effect even if only one of the two models is correctly specified. See [TE] [teffects aipw](#) and [TE] [teffects ipwra](#).
- Nearest-neighbor matching (NNM) and propensity-score matching (PSM) estimators compare the outcomes of individuals who are as similar as possible except that one gets the treatment and the other does not. NNM uses a nonparametric similarity measure, while PSM uses estimated treatment probabilities to measure similarity. See [TE] [teffects nnmatch](#) and [TE] [teffects psmatch](#).

`stteffects` can estimate the ATE, the ATET, and the POMs. The estimators implemented in `stteffects` impose the structure of the potential-outcome framework on the data in different ways.

- Regression-adjustment estimators use models for the potential outcomes, and censoring is adjusted for the log-likelihood function. See [TE] [stteffects ra](#).
- Inverse-probability-weighted estimators use models for treatment assignment and for the censoring time. See [TE] [stteffects ipw](#).
- Inverse-probability-weighted regression-adjustment (IPWRA) estimators use models for the potential outcomes and for treatment assignment. IPWRA estimators can adjust for censoring in the outcome model or with a separate censoring model. These estimators have the double-robust property: they correctly estimate the treatment effect even if only the outcome model or the treatment-assignment model is correctly specified. If a censoring model is specified, both the treatment-assignment model and the censoring model must be correctly specified for the estimator to be double robust. See [TE] [stteffects ipwra](#).
- Weighted regression-adjustment estimators model the outcome and the time to censoring. See [TE] [stteffects wra](#).

`teffects` and `stteffects` can estimate treatment effects from multivalued treatments; see [TE] [teffects multivalued](#).

It is not appropriate to use `teffects` or `stteffects` when a treatment is endogenously determined (the potential outcomes are not conditionally independent). When the treatment is endogenous, an endogenous treatment-effects model can be used to estimate the ATE. These models consider the effect of an endogenously determined binary treatment variable on the outcome.

`eteffects` can estimate the ATE, the ATET, and the POMs. It fits endogenous treatment-effects models by using either a linear or a nonlinear (probit, fractional probit, or exponential) model for the outcome. `eteffects` implements control-function regression-adjustment estimators.

`etregress` and `etpoisson` also fit endogenous treatment-effects models and can be used to estimate the ATE and the ATET. See [TE] [etregress](#) and [TE] [etpoisson](#). `etregress` fits an endogenous treatment-effects model by using a linear model for the outcome. `etpoisson` fits an endogenous treatment-effects model by using a nonlinear (exponential) model for the outcome.

When the outcome is censored, `eintreg` estimates effects of endogenously or exogenously assigned treatments. `eregress`, `eprobit`, and `eoprobit` estimate effects of endogenously or exogenously assigned treatments, when the outcome is continuous, binary, or ordinal, respectively. All four commands can account for endogenous sample selection and endogenous covariates in combination with endogenous or exogenous treatment. See [U] [26.12 Models with endogenous sample selection](#) and [U] [26.11 Models with endogenous covariates](#).

## 26.19 Pharmacokinetic data

There are four estimation commands designed for analyzing pharmacokinetic data. See [R] [pk](#) for an overview of the `pk` system.

1. [pkexamine](#) calculates pharmacokinetic measures from time-and-concentration subject-level data. `pkexamine` computes and displays the maximum measured concentration, the time at the maximum measured concentration, the time of the last measurement, the elimination time, the half-life, and the area under the concentration-time curve (AUC).
2. [pksumm](#) obtains the first four moments from the empirical distribution of each pharmacokinetic measurement and tests the null hypothesis that the distribution of that measurement is normally distributed.
3. [pkcross](#) analyzes data from a crossover design experiment. When one is analyzing pharmaceutical trial data, if the treatment, carryover, and sequence variables are known, the omnibus test for separability of the treatment and carryover effects is calculated.
4. [pkequiv](#) performs bioequivalence testing for two treatments. By default, `pkequiv` calculates a standard confidence interval symmetric about the difference between the two treatment means. `pkequiv` also calculates confidence intervals symmetric about zero and intervals based on Fieller's theorem. Also, `pkequiv` can perform interval hypothesis tests for bioequivalence.

See [ME] [menl](#) for fitting pharmacokinetic models using nonlinear mixed-effects models.

## 26.20 Multivariate analysis

Stata's multivariate capabilities can be found in the *Multivariate Statistics Reference Manual*.

1. [mvreg](#) fits multivariate regressions.
2. [manova](#) provides MANOVA and MANCOVA (multivariate ANOVA and ANCOVA). The command fits MANOVA and MANCOVA models, one-way and up—including two-way factorial, three-way factorial, etc.—and it fits nested and mixed-design models.
3. [canon](#) estimates canonical correlations and their corresponding loadings. Canonical correlation attempts to describe the relationship between two sets of variables.
4. [pca](#) extracts principal components and reports eigenvalues and loadings. Some people consider principal components a descriptive tool—in which case standard errors as well as coefficients are relevant—and others look at it as a dimension-reduction technique.
5. [factor](#) fits factor models and provides principal factors, principal-component factors, iterated principal-component factors, and maximum likelihood solutions. Factor analysis is concerned with finding few common factors  $\hat{\mathbf{Z}}_k$ ,  $k = 1, \dots, q$ , that linearly reconstruct the original variables  $\mathbf{y}_i$ ,  $i = 1, \dots, L$ .
6. [tetrachoric](#), in conjunction with `pca` or `factor`, allows you to perform PCA or factor analysis on binary data.
7. [rotate](#) provides a wide variety of orthogonal and oblique rotations after `factor` and `pca`. Rotations are often used to produce more interpretable results.
8. [procrustes](#) performs Procrustes analysis, one of the standard methods of multidimensional scaling. It can perform orthogonal or oblique rotations as well as translation and dilation.
9. [mds](#) performs metric and nonmetric multidimensional scaling for dissimilarity between observations with respect to a set of variables. A wide variety of dissimilarity measures are available and, in fact, are the same as those for `cluster`.

10. `ca` performs correspondence analysis, an exploratory multivariate technique for analyzing cross-tabulations and the relationship between rows and columns.
11. `mca` performs multiple correspondence analysis (MCA) and joint correspondence analysis (JCA).
12. `mvtest` performs tests of multivariate normality along with tests of means, covariances, and correlations.
13. `cluster` provides cluster analysis; both hierarchical and partition clustering methods are available. Strictly speaking, cluster analysis does not fall into the category of statistical estimation. Rather, it is a set of techniques for exploratory data analysis. Stata's cluster environment has many different similarity and dissimilarity measures for continuous and binary data.
14. `discrim` and `candisc` perform discriminant analysis. `candisc` performs linear discriminant analysis (LDA). `discrim` also performs LDA, and it performs quadratic discriminant analysis (QDA),  $k$ th nearest neighbor (KNN), and logistic discriminant analysis. The two commands differ in default output. `discrim` shows the classification summary, `candisc` shows the canonical linear discriminant functions, and both will produce either.

## 26.21 Generalized method of moments (GMM)

`gmm` fits models using generalized method of moments (GMM). With the interactive version of the command, you enter your moment equations directly into the dialog box or command line using substitutable expressions just like with `nl` or `nlstur`. The moment-evaluator program version gives you greater flexibility in exchange for increased complexity; with this version, you write a program that calculates the moments based on a vector of parameters passed to it.

`gmm` can fit both single- and multiple-equation models, and you can combine moment conditions of the form  $E\{\mathbf{z}_i u_i(\boldsymbol{\beta})\} = \mathbf{0}$ , where  $\mathbf{z}_i$  is a vector of instruments and  $u_i(\boldsymbol{\beta})$  is often an additive regression error term, as well as more general moment conditions of the form  $E\{\mathbf{h}_i(\mathbf{z}_i; \boldsymbol{\beta})\} = \mathbf{0}$ . In the former case, you specify the expression for  $u_i(\boldsymbol{\beta})$  and use the `instruments()` and `xtinstruments()` options to specify  $\mathbf{z}_i$ . In the latter case, you specify the expression for  $\mathbf{h}_i(\mathbf{z}_i; \boldsymbol{\beta})$ ; because that expression incorporates your instruments, you do not use the `instruments()` or `xtinstruments()` option.

`gmm` supports cross-sectional, time-series, and panel data. You can request weight matrices and VCEs that are suitable for independent and identically distributed errors, that are suitable for heteroskedastic errors, that are appropriate for clustered observations, or that are heteroskedasticity- and autocorrelation-consistent (HAC). For HAC weight matrices and VCEs, `gmm` lets you specify the bandwidth or request an automatic bandwidth selection algorithm.

## 26.22 Structural equation modeling (SEM)

SEM stands for “structural equation modeling”. The `sem` and `gsem` commands fit SEM.

`sem` fits standard linear SEMs. `gsem` fits what we call generalized SEMs, generalized to allow for generalized linear responses and multilevel modeling.

Generalized linear means, among other types of responses, binary responses such as probit and logit, count responses such as Poisson and negative binomial, categorical responses such as multinomial logit, ordered responses such as ordered probit and ordered logit, censored responses such as tobit, and survival responses such as exponential and Weibull. Generalized linear includes linear responses.

Multilevel modeling allows for nested effects, such as patient within doctor and patients within doctor within hospital, and crossed effects, such as occupation and industry.

Let's start with `sem`. `sem` can fit models ranging from linear regression to measurement models to simultaneous equations, including confirmatory factor analysis (CFA) models, correlated uniqueness models, latent growth models, and multiple indicators and multiple causes (MIMIC) models. You can obtain standardized or unstandardized results, direct and indirect effects, goodness-of-fit statistics, modification indices, score tests, Wald tests, linear and nonlinear tests of estimated parameters, and linear and nonlinear combinations of estimated parameters with confidence intervals. You can perform estimation across groups with easy model specification and easy-to-use tests for group invariance. This can all be done using raw or summary statistics data. In addition, `sem` optionally can use full information maximum-likelihood (FIML) estimation to handle observations containing missing values.

`gsem` extends the types of models that can be fit. Responses may be continuous, ordinal, count, categorical, or survival time, and `gsem` allows for multilevel modeling. Latent variables can be included at any level. This allows for fitting models with random intercepts and random slopes. These random effects may be nested or crossed.

There is considerable overlap in the capabilities of `sem` and `gsem`. Whenever there is overlap, `sem` is faster and sometimes easier to use.

The generalized response variables allowed by `gsem` permit fitting measurement models with different types of responses, latent growth models with different types of responses, and so on.

`gsem` can also fit item response theory (IRT) models, multilevel CFA models, models for latent class analysis (LCA), finite mixture models (FMMs), multilevel mixed-effects models, and multilevel structural equation models. See [U] 26.25 [Item response theory \(IRT\)](#), [U] 26.23 [Latent class models](#), and [U] 26.24 [Finite mixture models \(FMMs\)](#).

Where appropriate, results can be reported in exponentiated form to provide odds ratios, incidence-rate ratios, and relative-risk ratios. You can also obtain predictions, likelihood-ratio tests, Wald tests, predictive margins, contrasts, and pairwise comparisons.

Whether fitting a model with `sem` or `gsem`, you can specify your model by typing the command or by using the SEM Builder to draw path diagrams.

For those of you unfamiliar with SEM, it is worth your time to learn about it if you ever fit linear regressions, logistic regressions, ordered logit regressions, ordered probit regressions, Poisson regressions, seemingly unrelated regressions, multivariate regressions, simultaneous systems, measurement error models, selection models, endogenous treatment-effects models, tobit models, survival models, fractional response models, or multilevel mixed-effects models.

You may also want to learn about SEM if you are interested in GMM. `sem` and `gsem` fit many of the same models by maximum likelihood and quasimaximum likelihood that you can fit by GMM.

`sem` and `gsem` can be used to fit many models that can be fit by other Stata commands. The advantage of using `sem` and `gsem` is in the extensions they can provide. They allow for introduction of latent variables to account for measurement error, simultaneous equations with different types of responses, multilevel versions of popular models such as selection models, and more.

See the *Stata Structural Equation Modeling Reference Manual*; in particular, see [SEM] [intro 5](#).

## 26.23 Latent class models

Latent class models (LCMs) are used to identify and understand unobserved groups in a population. Individuals in the population are assumed to be divided among these unobserved subpopulations called classes. The classes are represented by one or more categorical latent variables. LCMs often include a group of observed variables that are thought of as being measurements or indicators of class membership. The parameters in the models for these observed variables are allowed to vary across



classes. In addition to modeling the observed variables, we also model the probability of being in each class.

After fitting an LCM, we can estimate the proportion of individuals in the population who belong to each class. We can also predict each individual's probability of belonging to each class.

We use LCM to refer to any model that includes categorical latent variables. In some literature, LCMs are more narrowly defined to include only categorical latent variables and the binary or categorical observed measurement variables, but we do not make such a restriction. Other labels closely associated with LCMs are latent class analysis, latent cluster models, latent cluster analysis, latent profile models, latent profile analysis, and finite mixture models. Each of these models can be fit as an LCM in Stata. See [SEM] [intro 5](#).

You fit latent class models in Stata by specifying the `lclass()` option with `gsem`. See the *Stata Structural Equation Modeling Reference Manual*; in particular, see [SEM] [intro 1](#), [SEM] [intro 2](#), [SEM] [intro 5](#), [SEM] [example 50g](#), and [SEM] [example 52g](#).

## 26.24 Finite mixture models (FMMs)

Finite mixture models (FMMs) are used to classify observations, to adjust for clustering, and to model unobserved heterogeneity. In finite mixture modeling, the observed data are assumed to belong to unobserved subpopulations called classes, and mixtures of probability densities or regression models are used to model the outcome of interest.

You can use FMMs to estimate the means and variances of the underlying densities for each unobserved subpopulation. Along with densities, they allow mixtures of regression models for continuous, binary, ordinal, categorical, count, fractional, and survival outcomes, where parameters are allowed to vary across subpopulations. You also can use FMMs to estimate each subpopulation's proportion in the overall population. In addition, FMMs allow the inclusion of covariates that model the probability of being in each subpopulation.

You fit FMMs in Stata by specifying the `fmm` prefix with the number of subpopulations; see [FMM] [fmm estimation](#) for models that can be specified as FMMs.

The *Stata Finite Mixture Models Reference Manual* provides complete documentation of Stata's finite mixture modeling features. See [FMM] [fmm intro](#) for an overview of FMMs and an introductory example.

## 26.25 Item response theory (IRT)

Item response theory (IRT) is used in the design, analysis, scoring, and comparison of tests and similar instruments whose purpose is to measure a latent trait. Latent traits cannot be measured directly because they are unobservable, but they can be quantified with an instrument. An instrument is simply a collection of items designed to measure a person's level of the latent trait. For example, a researcher interested in measuring mathematical ability (latent trait) may design a test (instrument) consisting of 100 questions (items).

When designing the instrument or analyzing data from the instrument, the researcher is interested in how each individual item relates to the trait and how the group of items as a whole relates to the trait. IRT models allow us to study these relationships.

Stata provides a suite of IRT estimation commands to fit a variety of models for binary responses and categorical responses. Models can also be combined. The available commands are the following:



Command	Description	Response
<code>irt 1pl</code>	One-parameter logistic model	binary
<code>irt 2pl</code>	Two-parameter logistic model	binary
<code>irt 3pl</code>	Three-parameter logistic model	binary
<code>irt grm</code>	Graded response model	categorical
<code>irt nrm</code>	Nominal response model	categorical
<code>irt pcm</code>	Partial credit model	categorical
<code>irt rsm</code>	Rating scale model	categorical
<code>irt hybrid</code>	Hybrid IRT model	combination

A major concept in IRT is the item characteristic curve (ICC). The ICC maps the relationship between the latent trait and the probability that a person “succeeds” on a given item (individual test question). `irtgraph icc` can be used to plot the ICCs for items after any of the models above.

`irtgraph tcc` is used to plot the test characteristic curve (TCC), which shows the relationship between the expected score on the whole test and the latent trait. Plots of the item information and test information can be obtained with `irtgraph iif` and `irtgraph tif`.

See [IRT] `irt` for more information.

## 26.26 Linearized dynamic stochastic general equilibrium (DSGE) models

Linearized DSGE models are time-series models used in economics for policy analysis and forecasting. The models are derived from macroeconomic theory and include multiple equations. A key feature of these models is that expectations of future variables affect variables today; this distinguishes DSGE models from other multivariate time-series models. Another key feature is that, being derived from theory, the parameters can usually be interpreted in terms of that theory.

The `dsgc` command fits linear DSGE models, which means that the system of equations specified to `dsgc` is linear in the variables but may be nonlinear in the parameters. See the *Stata Linearized Dynamic Stochastic General Equilibrium Reference Manual*; in particular, [DSGE] [intro 1](#).

## 26.27 Survey data

Stata’s `svy` command fits statistical models for complex survey data. `svy` is a prefix command, so to obtain linear regression, you type

```
. svy: regress ...
```

or to obtain probit regression, you type

```
. svy: probit ...
```

but you must first type a `svyset` command to define the survey design characteristics. Prefix `svy` works with many estimation commands, and everything is documented together in the *Stata Survey Data Reference Manual*.

`svy` supports the following variance-estimation methods:

- Taylor-series linearization
- Bootstrap

- Balanced repeated replication (BRR)
- Jackknife
- Successive difference replication (SDR)

See [SVY] [variance estimation](#) for details.

svy supports the following survey design characteristics:

- With- and without-replacement sampling
- Observation-level sampling weights
- Stage-level sampling weights
- Stratification
- Poststratification
- Clustering
- Multiple stages of clustering without replacement
- BRR and jackknife replication weights

See [SVY] [svyset](#) for details. For an application of the svy prefix with stage-level sampling weights, see [example 6](#) in [ME] [meglm](#).

Subpopulation estimation is available for all estimation commands.

Tabulations and summary statistics are also available, including means, proportions, ratios, and totals over multiple subpopulations and direct standardization of means, proportions, and ratios.

See [SVY] [survey](#).

## 26.28 Multiple imputation

Multiple imputation (MI) is a statistical technique for estimation in the presence of missing data. If you estimate the parameters of  $y$  on  $x_1$ ,  $x_2$ , and  $x_3$  using any of the other Stata estimation commands, parameters are estimated on the data for which  $y$ ,  $x_1$ ,  $x_2$ , and  $x_3$  contain no missing values. This process is known as listwise or casewise deletion because observations for which any of  $y$ ,  $x_1$ ,  $x_2$ , or  $x_3$  contain missing values are ignored or, said differently, deleted from consideration. MI is a technique to recover the information in those ignored observations when the missing values are missing at random (MAR) or missing completely at random (MCAR). Data are MAR if the probability that a value is missing may depend on observed data but not on unobserved data. Data are MCAR if the probability of missingness is not even a function of the observed data.

MI is named for the imputations it produces to replace the missing values in the data. MI does not just form replacement values for the missing data; it produces multiple replacements. The purpose is not to create replacement values as close as possible to the true ones but to handle missing data in a way resulting in valid statistical inference.

There are three steps in an MI analysis. First, one forms  $M$  imputations for each missing value in the data. Second, one fits the model of interest separately on each of the  $M$  resulting datasets. Finally, one combines those  $M$  estimation results into the desired single result.

The `mi` command does this for you. It can be used with most of Stata's estimation commands, including with survey, survival, and panel and multilevel models. See [MI] [intro](#).

## 26.29 Power and sample-size analysis

Power and sample-size (PSS) analysis is performed during the planning stage of a study. The main goal of PSS analysis is to provide an estimate of the sample size needed to successfully achieve the research objective of a study.

For example, suppose that we want to design a study to evaluate a new drug for lowering blood pressure. We want to test whether the mean blood pressure of the experimental group, which will receive the new drug, is the same as the mean blood pressure of the control group, which will receive the old drug. The post hoc analysis will use a two-sample  $t$  test to test the difference between the two means. How many subjects do we need to enroll in our study to detect a difference between means that is of clinical importance? PSS analysis can answer this question.

PSS analysis can also answer other questions that may arise during the planning stage of a study. For example, what is the power of a test given an available sample size, and how likely is it to detect an effect of interest given limited study resources? The answers to these questions may help reduce the cost of a study by preventing an overpowered study or may help avoid wasting resources on an underpowered study.

See [PSS] [intro](#) for more information about PSS analysis.

The `power` command performs PSS analysis. It provides PSS analysis for comparison of means, variances, proportions, correlations, and contingency tables. It also provides PSS analysis for simple and multiple linear regression and for survival analysis. One-sample, two-sample, and paired analyses of means, variances, proportions, and correlations are supported. Contingency table analyses may be performed for matched samples,  $2 \times 2 \times K$  tables, or  $2 \times J$  tables. For survival-time data, one-sample analysis is supported for Cox proportional hazards models; two-sample analysis is supported for parametric or nonparametric comparison of survivor functions.

The `power` command can also account for a cluster randomized design (CRD) for some analyses, such as one- and two-sample analyses of means and proportions. In a CRD, groups of subjects or clusters are randomized instead of individual subjects. As a result, observations within a cluster are usually correlated, and this must be taken into account when performing PSS analysis.

You can also add your own PSS methods to the `power` command; see [PSS] [power usermethod](#).

`power` provides both tabular output and graphical output, or power curves; see [PSS] [power, table](#) and [PSS] [power, graph](#) for details.

See [PSS] [power](#) for a full list of supported methods and the description of the command.

You can work with `power` commands either interactively or via a convenient point-and-click interface; see [PSS] [GUI](#) for details.

## 26.30 Bayesian analysis

Bayesian analysis is a statistical analysis that answers research questions about unknown parameters of statistical models by using probability statements. Bayesian analysis rests on the assumption that all model parameters are random quantities and are subject to prior knowledge. This assumption is in sharp contrast with more traditional, frequentist analysis where all parameters are considered unknown but fixed quantities.

Bayesian analysis is based on modeling and summarizing the posterior distribution of parameters conditional on the observed data. The posterior distribution is composed of a likelihood distribution of the data and the prior distribution of the model parameters. Many posterior distributions do not have a closed form and must be approximated using, for example, Markov chain Monte Carlo

(MCMC) methods such as Metropolis–Hastings (MH) methods, the Gibbs method, or sometimes their combination. The convergence of MCMC must be verified before any inference can be made.

In Bayesian analysis, marginal posterior distributions of parameters are used for inference. They are summarized using point estimators, such as posterior mean and median, and using interval estimators, such as equal-tailed credible intervals and highest-posterior density intervals.

Stata provides a suite of commands for conducting Bayesian analysis. Bayesian estimation ([BAYES] **bayesian estimation**) consists of the **bayes** prefix for fitting a variety of Bayesian regression models and the **bayesmh** command for fitting general Bayesian models. Both commands offer three MCMC sampling methods: an adaptive MH sampling, a Gibbs sampling, or a combination of the two. You can choose from a variety of supported Bayesian models, including multilevel models, or you can program your own Bayesian models; see [BAYES] **bayes**, [BAYES] **bayesmh**, and [BAYES] **bayesmh evaluators**.

Convergence of MCMC can be accessed visually using **bayesgraph**. Marginal summaries can be obtained using **bayesstats summary**, and hypothesis testing can be performed using **bayestest**; see [BAYES] **bayesian postestimation**.

See [BAYES] **bayesian commands** for more information about commands and for a quick *Overview example*.

## 26.31 References

- Gould, W. W. 2000. *sg124: Interpreting logistic regression in all its forms*. *Stata Technical Bulletin* 53: 19–29. Reprinted in *Stata Technical Bulletin Reprints*, vol. 9, pp. 257–270. College Station, TX: Stata Press.
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