

Bayesian commands — Introduction to commands for Bayesian analysis

[Description](#) [Remarks and examples](#) [Acknowledgments](#) [References](#)
[Also see](#)

Description

This entry describes commands to perform Bayesian analysis. Bayesian analysis is a statistical procedure that answers research questions by expressing uncertainty about unknown parameters using probabilities. It is based on the fundamental assumption that not only the outcome of interest but also all the unknown parameters in a statistical model are essentially random and are subject to prior beliefs.

Estimation

| | |
|-------------------------------------|--|
| Bayesian estimation | Bayesian estimation commands |
| bayes | Bayesian regression models using the <code>bayes</code> prefix |
| bayesmh | Bayesian models using MH |
| bayesmh evaluators | User-defined Bayesian models using MH |

Convergence tests and graphical summaries

| | |
|-----------------------------------|--------------------------------------|
| bayesgraph | Graphical summaries |
| bayesstats grubin | Gelman–Rubin convergence diagnostics |

Postestimation statistics

| | |
|------------------------------------|--|
| bayesstats ess | Effective sample sizes and related statistics |
| bayesstats summary | Bayesian summary statistics |
| bayesstats ic | Bayesian information criteria and Bayes factors |
| bayesirf | Bayesian IRFs and more after VAR and DSGE models |

Predictions

| | |
|-------------------------------------|-------------------------------------|
| bayespredict | Bayesian predictions |
| bayesstats ppvalues | Bayesian predictive p-values |
| bayesfcast | Bayesian forecasts after VAR models |

Hypothesis testing

| | |
|------------------------------------|--|
| bayestest model | Hypothesis testing using model posterior probabilities |
| bayestest interval | Interval hypothesis testing |

Remarks and examples

[stata.com](#)

This entry describes commands to perform Bayesian analysis. See [\[BAYES\] Intro](#) for an introduction to the topic of Bayesian analysis.

Bayesian estimation in Stata can be as easy as prefixing your estimation command with the `bayes` prefix ([\[BAYES\] bayes](#)). For example, if your estimation command is a linear regression of `y` on `x`

```
. regress y x
```

then Bayesian estimates for this model can be obtained by typing

```
. bayes: regress y x
```

See [\[BAYES\] Bayesian estimation](#) for a list of estimation commands that work with the `bayes` prefix.

In addition to the `bayes` prefix, there is a general-purpose Bayesian estimation command—the `bayesmh` command ([\[BAYES\] bayesmh](#)). `bayesmh` fits a variety of Bayesian models including multiple-equation linear and nonlinear models and, like the `bayes` prefix, estimates parameters using an adaptive MH Markov chain Monte Carlo (MCMC) method. You can choose from a variety of supported Bayesian models by specifying the `likelihood()` and `prior()` options. Or you can program your own Bayesian models by supplying a program evaluator for the posterior distributions of model parameters in the `evaluator()` option; see [\[BAYES\] bayesmh evaluators](#) for details.

After estimation, you can use `bayesgraph` to check convergence of MCMC visually. If you simulated multiple chains, you can use `bayesstats grubin` to compute Gelman–Rubin convergence diagnostics. You can also use `bayesstats ess` to compute effective sample sizes and related statistics for model parameters and functions of model parameters to assess the efficiency of the sampling algorithm and autocorrelation in the obtained MCMC sample. Once convergence is established, you can use `bayesstats summary` to obtain Bayesian summaries such as posterior means and standard deviations of model parameters and functions of model parameters and `bayesstats ic` to compute Bayesian information criteria and Bayes factors for models. You can use `bayestest model` to test hypotheses by comparing posterior probabilities of models. You can also use `bayestest interval` to test interval hypotheses about parameters and functions of parameters. You can use `bayespredict` and `bayesstats pvalues` for model diagnostics using posterior predictive checking. You can also use `bayespredict` to predict future observations.

Below we provide an overview example demonstrating the Bayesian suite of commands. In this entry, we mainly concentrate on the general command, `bayesmh`. For examples of using the simpler `bayes` prefix, see [example 11](#) and [Remarks and examples](#) in [\[BAYES\] bayes](#). Also, for more examples of `bayesmh`, see [Remarks and examples](#) in [\[BAYES\] bayesmh](#).

Overview example

Consider an example from [Kuehl \(2000, 551\)](#) about the effects of exercise on oxygen uptake. The research objective is to compare the impact of the two exercise programs—12 weeks of step aerobic training and 12 weeks of outdoor running on flat terrain—on maximal oxygen uptake. Twelve healthy men were randomly assigned to one of the two groups, the “aerobic” group or the “running” group. Their changes in maximal ventilation (liters/minute) of oxygen for the 12-week period were recorded.

`oxygen.dta` contains 12 observations of changes in maximal ventilation of oxygen, recorded in variable `change`, from two groups, recorded in variable `group`. Additionally, ages of subjects are recorded in variable `age`, and an interaction between `age` and `group` is stored in variable `interaction`.

```
. use https://www.stata-press.com/data/r18/oxygen
(Oxygen uptake data)
. describe
Contains data from https://www.stata-press.com/data/r18/oxygen.dta
Observations:      12              Oxygen uptake data
Variables:         4              20 Jan 2022 15:56
                              (_dta has notes)
```

| Variable name | Storage type | Display format | Value label | Variable label |
|---------------|--------------|----------------|-------------|---|
| change | float | %9.0g | | Change in maximal oxygen uptake (liters/minute) |
| group | byte | %8.0g | grouplab | Exercise group |
| age | byte | %8.0g | | Age (years) |
| ageXgr | byte | %9.0g | | Interaction between age and group |

Sorted by:

Kuehl (2000) uses analysis of covariance to analyze these data. We use linear regression instead,

$$\text{change} = \beta_0 + \beta_{\text{group}}\text{group} + \beta_{\text{age}}\text{age} + \epsilon$$

where ϵ is a random error with zero mean and variance σ^2 . Also see Hoff (2009) for Bayesian analysis of these data.

Examples are presented under the following headings:

Example 1: OLS

Example 2: Bayesian normal linear regression with noninformative prior

Example 3: Bayesian linear regression with informative prior

Example 4: Bayesian normal linear regression with multivariate prior

Example 5: Checking convergence

Example 6: Postestimation summaries

Example 7: Bayesian predictions

Example 8: Model comparison

Example 9: Hypothesis testing

Example 10: Erasing simulation datasets

Example 11: Bayesian linear regression using the bayes prefix

► Example 1: OLS

Let's fit OLS regression to our data first.

```
. regress change group age
```

| Source | SS | df | MS | Number of obs | = | 12 |
|----------|------------|----|------------|---------------|---|--------|
| Model | 647.874893 | 2 | 323.937446 | F(2, 9) | = | 41.42 |
| Residual | 70.388768 | 9 | 7.82097423 | Prob > F | = | 0.0000 |
| | | | | R-squared | = | 0.9020 |
| | | | | Adj R-squared | = | 0.8802 |
| Total | 718.263661 | 11 | 65.2966964 | Root MSE | = | 2.7966 |

| change | Coefficient | Std. err. | t | P> t | [95% conf. interval] |
|--------|-------------|-----------|-------|-------|----------------------|
| group | 5.442621 | 1.796453 | 3.03 | 0.014 | 1.378763 9.506479 |
| age | 1.885892 | .295335 | 6.39 | 0.000 | 1.217798 2.553986 |
| _cons | -46.4565 | 6.936531 | -6.70 | 0.000 | -62.14803 -30.76498 |

From the table, both group and age are significant predictors of the outcome in this model.

For example, we reject the hypothesis of $H_0: \beta_{\text{group}} = 0$ at a 5% level based on the p -value of 0.014. The actual interpretation of the reported p -value is that if we repeat the same experiment and use the same testing procedure many times, then given our null hypothesis of no effect of group, we will observe the result (test statistic) as extreme or more extreme than the one observed in this sample ($t = 3.03$) only 1.4% of the times. The p -value cannot be interpreted as a probability of the null hypothesis, which is a common misinterpretation. In fact, it answers the question of how likely our data are, given that the null hypothesis is true, and not how likely the null hypothesis is, given our data. The latter question can be answered using Bayesian hypothesis testing, which we demonstrate in [example 9](#).

Confidence intervals are popular alternatives to p -values that eliminate some of the p -value shortcomings. For example, the 95% confidence interval for the coefficient for `group` is [1.38, 9.51] and does not contain the value of 0, so we consider `group` to be a significant predictor of `change`. The interpretation of a 95% confidence interval is that if we repeat the same experiment many times and compute confidence intervals for each experiment, then 95% of those intervals will contain the true value of the parameter. Thus we cannot conclude that the true coefficient for `group` lies between 1.38 and 9.51 with a probability of 0.95—a common misinterpretation of a confidence interval. This probability is either 0 or 1, and we do not know which for any particular confidence interval. All we know is that [1.38, 9.51] is a plausible range for the true value of the coefficient for `group`. Intervals that can actually be interpreted as probabilistic ranges for a parameter of interest may be constructed within the Bayesian paradigm; see [example 9](#).

◀

► Example 2: Bayesian normal linear regression with noninformative prior

In [example 1](#), we stated that frequentist methods cannot provide probabilistic summaries for the parameters of interest. This is because in frequentist statistics, parameters are viewed as unknown but fixed quantities. The only random quantity in a frequentist model is an outcome of interest. Bayesian statistics, on the other hand, in addition to the outcome of interest, also treats all model parameters as random quantities. This is what sets Bayesian statistics apart from frequentist statistics and enables one to make probability statements about the likely values of parameters and to assign probabilities to hypotheses of interest.

Bayesian statistics focuses on the estimation of various aspects of the posterior distribution of a parameter of interest, an initial or a prior distribution that has been updated with information about a parameter contained in the observed data. A posterior distribution is thus described by the prior distribution of a parameter and the likelihood function of the data given the parameter.

Let's now fit a Bayesian linear regression to `oxygen.dta`. To fit a Bayesian parametric model, we need to specify the likelihood function or the distribution of the data and prior distributions for all model parameters. Our Bayesian linear model has four parameters: three regression coefficients and the variance of the data. We assume a normal distribution for our outcome, `change`, and start with a noninformative Jeffreys prior for the parameters. Under the Jeffreys prior, the joint prior distribution of the coefficients and the variance is proportional to the inverse of the variance.

We can write our model as follows,

$$\begin{aligned} \text{change} &\sim N(X\beta, \sigma^2) \\ (\beta, \sigma^2) &\sim \frac{1}{\sigma^2} \end{aligned}$$

where X is our design matrix, and $\beta = (\beta_0, \beta_{\text{group}}, \beta_{\text{age}})'$, which is a vector of coefficients.

We use the `bayesmh` command to fit our Bayesian model. Let's consider the specification of the model first.

```
bayesmh change group age, likelihood(normal({var}))    ///  
    prior({change:}, flat) prior({var}, jeffreys)
```

The specification of the regression function in `bayesmh` is the same as in any other Stata regression command—the name of the dependent variable follows the command, and the covariates of interest are specified next. Likelihood or outcome distribution is specified in the `likelihood()` option, and prior distributions are specified in the `prior()` options, which are repeated options.

All model parameters must be specified in curly braces, `{}`. `bayesmh` automatically creates parameters associated with the regression function—regression coefficients—but it is your responsibility to define the remaining model parameters. In our example, the only parameter we need to define is the variance parameter, which we define as `{var}`. The three regression coefficients `{change:group}`, `{change:age}`, and `{change:_cons}` are automatically created by `bayesmh`.

The last step is to specify the likelihood and the prior distributions. `bayesmh` provides several different built-in distributions for the likelihood and priors. If a certain distribution is not available or you have a particularly complicated Bayesian model, you may consider writing your own evaluator for the posterior distribution; see [\[BAYES\] bayesmh evaluators](#) for details. In our example, we specify distribution `normal({var})` in option `likelihood()` to request the likelihood function of the normal model with the variance parameter `{var}`. This specification together with the regression specification defines the likelihood model for our outcome `change`. We assign the `flat` prior, a prior with a density of 1, to all regression coefficients with `prior({change:}, flat)`, where `{change:}` is a shortcut for referring to all parameters with equation name `change`, our regression coefficients. Finally, we specify prior `jeffreys` for the variance parameter `{var}` to request the density $1/\sigma^2$.

Let's now run our command. `bayesmh` uses MCMC sampling, specifically, an adaptive random-walk MH MCMC method, to estimate marginal posterior distributions of parameters. Because `bayesmh` is using an MCMC method, which is stochastic, we must specify a random-number seed for reproducibility of our results. For consistency and simplicity, we use the same random seed of 14 in all of our examples throughout the manual.

```

. set seed 14

. bayesmh change group age, likelihood(normal({var}))
> prior({change:}, flat) prior({var}, jeffreys)
Burn-in ...
Simulation ...

Model summary
-----
Likelihood:
  change ~ normal(xb_change,{var})

Priors:
  {change:group age _cons} ~ 1 (flat)
  {var} ~ jeffreys

```

(1) Parameters are elements of the linear form `xb_change`.

```

Bayesian normal regression           MCMC iterations =    12,500
Random-walk Metropolis-Hastings sampling  Burn-in           =     2,500
                                           MCMC sample size =   10,000
                                           Number of obs    =     12
                                           Acceptance rate  =    .1371
                                           Efficiency: min  =    .02687
                                           avg              =    .03765
                                           max              =    .05724

Log marginal-likelihood = -24.703776

```

| | Mean | Std. dev. | MCSE | Median | Equal-tailed [95% cred. interval] | |
|--------|-----------|-----------|---------|----------|--------------------------------------|-----------|
| change | | | | | | |
| group | 5.429677 | 2.007889 | .083928 | 5.533821 | 1.157584 | 9.249262 |
| age | 1.8873 | .3514983 | .019534 | 1.887856 | 1.184714 | 2.567883 |
| _cons | -46.49866 | 8.32077 | .450432 | -46.8483 | -62.48236 | -30.22105 |
| var | 10.27946 | 5.541467 | .338079 | 9.023905 | 3.980325 | 25.43771 |

First, `bayesmh` provides a summary for the specified model. It is particularly useful for complicated models with many parameters and [hyperparameters](#). In fact, we recommend that you first specify the `dryrun` option, which provides only the summary of the model without estimation, to verify the specification of your model and then proceed with estimation. You can then use the `nomodelsummary` option during estimation to suppress the model summary, which may be rather long.

Next, `bayesmh` provides a header with various model summaries on the right-hand side. It reports the total number of MCMC iterations, 12,500, including the default 2,500 burn-in iterations, which are discarded from the analysis MCMC sample, and the number of iterations retained in the MCMC sample, or MCMC sample size, which is 10,000 by default. These default values should be viewed as initial estimates and further adjusted for the problem at hand to ensure convergence of the MCMC; see [example 5](#).

An acceptance rate and a summary of the parameter-specific [efficiencies](#) are also part of the output header. An acceptance rate specifies the proportion of proposed parameter values that was accepted by the algorithm. An acceptance rate of 0.14 in our example means that 14% out of 10,000 proposal parameter values were accepted by the algorithm. For the MH algorithm, this number rarely exceeds 50% and is typically below 30%. A low acceptance rate (for example, below 10%) may indicate convergence problems. In our example, the acceptance rate is a bit low, so we may need to investigate this further. In general, MH tends to have lower efficiencies compared with other MCMC methods. For example, efficiencies of 10% and higher are considered good. Efficiencies below 1% may be a source of concern. The efficiencies are somewhat low in our example, so we may consider tuning our MCMC sampler; see [Improving efficiency of the MH algorithm—blocking of parameters](#).

Finally, `bayesmh` reports a table with a summary of the results. The `Mean` column reports the estimates of posterior means, which are means of the marginal posterior distributions of the parameters. The posterior mean estimates are pretty close to the OLS estimates obtained in [example 1](#). This is expected, provided MCMC converged, because we used a noninformative prior. That is, we did not provide any additional information about parameters beyond that contained in the data.

The next column reports estimates of posterior standard deviations, which are standard deviations of the marginal posterior distribution. These values describe the variability in the posterior distribution of the parameter and are comparable to our OLS standard errors.

The precision of the posterior mean estimates is described by their Monte Carlo standard errors. These numbers should be small, relative to the scales of the parameters. Increasing the MCMC sample size should decrease these numbers.

The `Median` column provides estimates of the median of the posterior distribution and can be used to assess the symmetries of the posterior distribution. At a quick glance, the estimates of posterior means and medians are pretty close for the regression coefficients, so we suspect that their posterior distributions may be symmetric.

The last two columns provide credible intervals for the parameters. Unlike confidence intervals, as discussed in [example 1](#), these intervals have a straightforward probabilistic interpretation. For example, the probability that the coefficient for `group` is between 1.16 and 9.25 is about 0.95. The lower bound of the interval is greater than 0, so we conclude that there is an effect of the exercise program on the change in oxygen uptake. We can also use Bayesian hypothesis testing to test effects of parameters; see [example 9](#).

Before any interpretation of the results, however, it is important to verify the convergence of MCMC; see [example 5](#).

See [example 11](#) for how to fit Bayesian linear regression more easily using the `bayes` prefix. ◀

▷ Example 3: Bayesian linear regression with informative prior

In [example 2](#), we considered a noninformative prior for the model parameters. The strength (as well as the weakness) of Bayesian modeling is specifying an informative prior distribution, which may improve results. The strength is that if we have reliable prior knowledge about the distribution of a parameter, incorporating this in our model will improve results and potentially make certain analysis that would not be possible to perform in the frequentist domain feasible. The weakness is that a strong incorrect prior may lead to results that are not supported by the observed data. As with any modeling task, Bayesian or frequentist, a substantive research of the process generating the data and its parameters will be necessary for you to find appropriate models.

Let's consider an informative [conjugate prior](#) distribution for our normal regression model.

$$\begin{aligned}(\beta|\sigma^2) &\sim \text{i.i.d. } N(0, \sigma^2) \\ \sigma^2 &\sim \text{InvGamma}(2.5, 2.5)\end{aligned}$$

Here, for simplicity, all coefficients are assumed to be independently and identically distributed as normal with zero mean and variance σ^2 , and the variance parameter is distributed according to the above inverse gamma distribution. In practice, a better prior would be to allow each parameter to have a different variance, at least for parameters with different scales.

Let's fit this model using `bayesmh`. Following the model above, we specify the `normal(0, {var})` prior for the coefficients and the `igamma(2.5, 2.5)` prior for the variance.

```

. set seed 14
. bayesmh change group age, likelihood(normal({var}))
> prior({change:}, normal(0, {var}))
> prior({var}, igamma(2.5, 2.5))
Burn-in ...
Simulation ...
Model summary

```

```

Likelihood:
  change ~ normal(xb_change, {var})
Priors:
  {change:group age _cons} ~ normal(0, {var})
  {var} ~ igamma(2.5, 2.5)

```

```

(1) Parameters are elements of the linear form xb_change.
Bayesian normal regression           MCMC iterations =    12,500
Random-walk Metropolis-Hastings sampling
                                     Burn-in           =     2,500
                                     MCMC sample size =   10,000
                                     Number of obs      =     12
                                     Acceptance rate   =    .1984
                                     Efficiency: min   =    .03732
                                               avg       =    .04997
                                               max       =    .06264
Log marginal-likelihood = -49.744054

```

| | Mean | Std. dev. | MCSE | Median | Equal-tailed [95% cred. interval] | |
|--------|-----------|-----------|---------|-----------|--------------------------------------|----------|
| change | | | | | | |
| group | 6.510807 | 2.812828 | .129931 | 6.50829 | .9605561 | 12.23164 |
| age | .2710499 | .2167863 | .009413 | .2657002 | -.1556194 | .7173697 |
| _cons | -6.838302 | 4.780343 | .191005 | -6.683556 | -16.53356 | 2.495631 |
| var | 28.83438 | 10.53573 | .545382 | 26.81462 | 14.75695 | 54.1965 |

The results from this model are substantially different from the results we obtained in [example 2](#). Considering that we used this simple prior for demonstration purposes only and did not use any external information about model parameters based on prior studies, we would be reluctant to trust the results from this model.

◀

► Example 4: Bayesian normal linear regression with multivariate prior

Continuing with informative priors, we will consider Zellner's g -prior ([Zellner 1986](#)), which is one of the more commonly used priors for the regression coefficients in a normal linear regression. [Hoff \(2009\)](#) provides more details about this example, and he includes the interaction between age and group as in [example 8](#). Here we concentrate on demonstrating how to fit our model using `bayesmh`.

The mathematical formulation of the priors is the following,

$$\begin{aligned}
 (\beta | \sigma^2) &\sim \text{MVN}(0, g\sigma^2(X'X)^{-1}) \\
 \sigma^2 &\sim \text{InvGamma}(\nu_0/2, \nu_0\sigma_0^2/2)
 \end{aligned}$$

where g reflects prior sample size, ν_0 is the prior degrees of freedom for the inverse gamma distribution, and σ_0^2 is the prior variance for the inverse gamma distribution. This prior incorporates dependencies between coefficients. We use values of the parameters similar to those in [Hoff \(2009\)](#): $g = 12$, $\nu_0 = 1$, and $\sigma_0^2 = 8$.

`bayesmh` provides the `zellnersg0()` prior to accommodate the above prior. The first argument is the dimension of the distribution, which is 3 in our example, the second argument is the prior degrees of freedom, which is 12 in our example, and the last argument is the variance parameter, which is `{var}` in our example. The mean is assumed to be a zero vector of the corresponding dimension. (You can use `zellnersg()` if you want to specify a nonzero mean vector; see [BAYES] `bayesmh`.)

```
. set seed 14
. bayesmh change group age, likelihood(normal({var}))
> prior({change:}, zellnersg(3,12,{var}))
> prior({var}, igamma(0.5, 4))
Burn-in ...
Simulation ...
Model summary
```

```
Likelihood:
  change ~ normal(xb_change,{var})
Priors:
  {change:group age _cons} ~ zellnersg(3,12,0,{var})
                           {var} ~ igamma(0.5,4)                                (1)
```

(1) Parameters are elements of the linear form `xb_change`.

```
Bayesian normal regression                MCMC iterations =    12,500
Random-walk Metropolis-Hastings sampling   Burn-in           =     2,500
                                           MCMC sample size =   10,000
                                           Number of obs    =     12
                                           Acceptance rate  =    .06169
                                           Efficiency:      min =    .0165
                                                            avg =    .02018
                                                            max =    .02159
```

Log marginal-likelihood = -35.356501

| | Mean | Std. dev. | MCSE | Median | Equal-tailed [95% cred. interval] | |
|--------|-----------|-----------|---------|-----------|--------------------------------------|-----------|
| change | | | | | | |
| group | 4.988881 | 2.260571 | .153837 | 4.919351 | .7793098 | 9.775568 |
| age | 1.713159 | .3545698 | .024216 | 1.695671 | 1.053206 | 2.458556 |
| _cons | -42.31891 | 8.239571 | .565879 | -41.45385 | -59.30145 | -27.83421 |
| var | 12.29575 | 6.570879 | .511475 | 10.3609 | 5.636195 | 30.93576 |

These results are more in agreement with results from [example 2](#) than with results of [example 3](#), but our acceptance rate and efficiencies are low and require further investigation.

◀

□ Technical note

We can reproduce what `zellnersg0()` does above manually. First, we must compute $(X'X)^{-1}$. We can use Stata's matrix functions to do that.

```
. matrix accum xTx = group age
(obs=12)
. matrix S = invsym(xTx)
```

We now specify the desired multivariate normal prior for the coefficients, `mvnormal0(3,12*{var}*S)`. The first argument of `mvnormal0()` specifies the dimension of the distribution, and the second argument specifies the variance–covariance matrix. A mean of zero is assumed for all dimensions. One interesting feature of this specification is that the variance–covariance matrix is specified as a function of `{var}`.

```

. set seed 14
. bayesmh change group age, likelihood(normal({var}))
> prior({change:}, mvnormal(3,12*{var}*S))
> prior({var}, igamma(0.5, 4))
Burn-in ...
Simulation ...
Model summary

```

```

Likelihood:
  change ~ normal(xb_change,{var})
Priors:
  {change:group age _cons} ~ mvnormal(3,0,0,0,12*{var}*S)      (1)
  {var} ~ igamma(0.5,4)

```

(1) Parameters are elements of the linear form `xb_change`.

```

Bayesian normal regression          MCMC iterations =    12,500
Random-walk Metropolis-Hastings sampling  Burn-in           =     2,500
                                          MCMC sample size =   10,000
                                          Number of obs     =     12
                                          Acceptance rate   =    .06169
                                          Efficiency: min   =    .0165
                                          avg               =    .02018
                                          max               =    .02159
Log marginal-likelihood = -35.356501

```

| | Mean | Std. dev. | MCSE | Median | Equal-tailed [95% cred. interval] | |
|--------|-----------|-----------|---------|-----------|--------------------------------------|-----------|
| change | | | | | | |
| group | 4.988881 | 2.260571 | .153837 | 4.919351 | .7793098 | 9.775568 |
| age | 1.713159 | .3545698 | .024216 | 1.695671 | 1.053206 | 2.458556 |
| _cons | -42.31891 | 8.239571 | .565879 | -41.45385 | -59.30145 | -27.83421 |
| var | 12.29575 | 6.570879 | .511475 | 10.3609 | 5.636195 | 30.93576 |

□

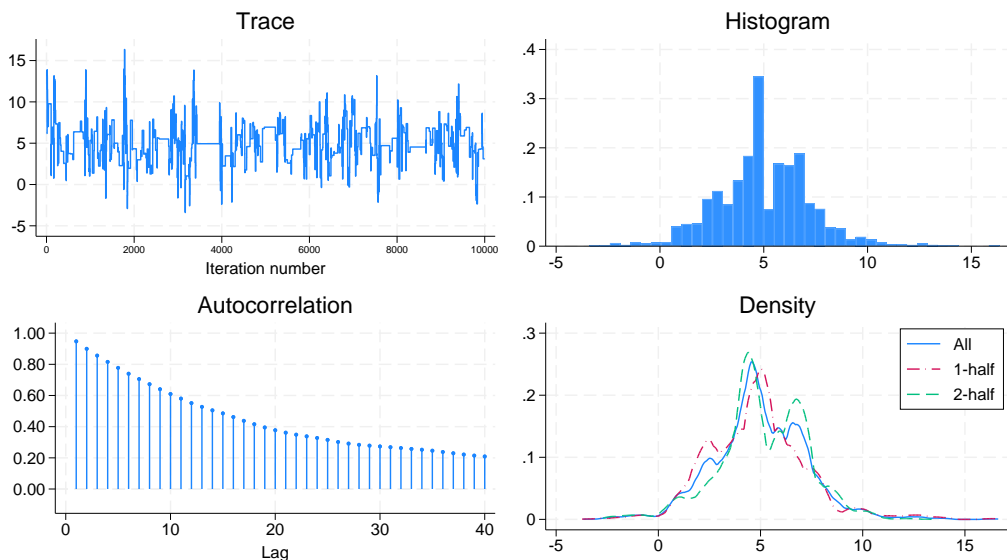
► Example 5: Checking convergence

We can use the `bayesgraph` command to visually check convergence of MCMC of parameter estimates. `bayesgraph` provides a variety of graphs. For several commonly used visual diagnostics displayed in a compact form, use `bayesgraph diagnostics`.

For example, we can look at graphical diagnostics for the coefficient for `group`.

```
. bayesgraph diagnostics {change:group}
```

change:group



The displayed diagnostics include a trace plot, an autocorrelation plot, a histogram, and a kernel density estimate overlaid with densities estimated using the first and the second halves of the MCMC sample. Both the trace plot and the autocorrelation plot demonstrate high autocorrelation. The shape of the histogram is not unimodal. We definitely have some convergence issues in this example.

Similarly, we can look at diagnostics for other model parameters. To see all graphs at once, type

```
bayesgraph diagnostics _all
```

Other useful summaries are effective sample sizes and statistics related to them. These can be obtained by using the `bayesstats ess` command.

```
. bayesstats ess
Efficiency summaries      MCMC sample size =    10,000
                          Efficiency: min =      .0165
                          avg =      .02018
                          max =      .02159
```

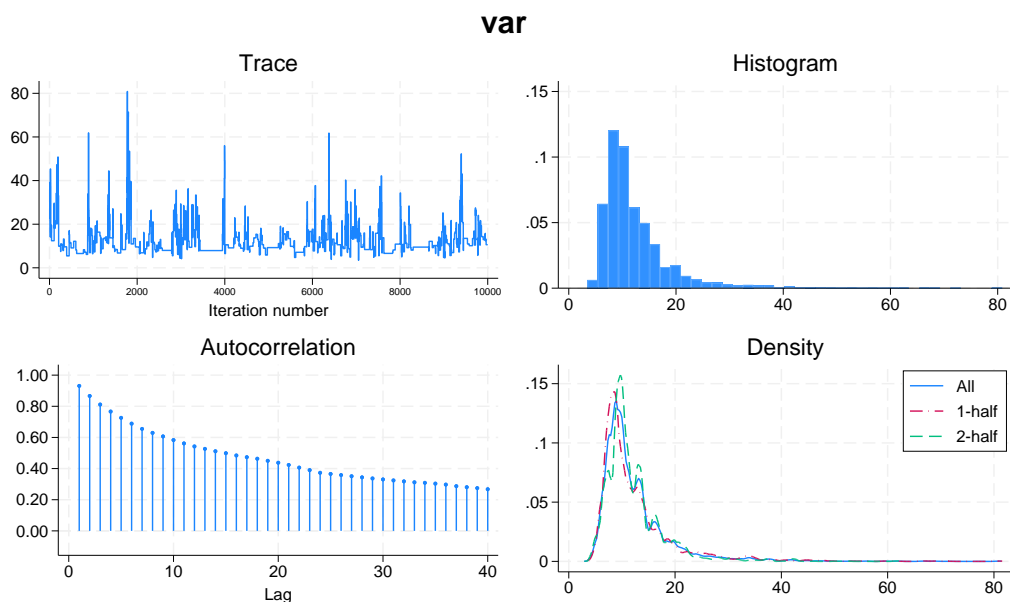
| | ESS | Corr. time | Efficiency |
|--------|--------|------------|------------|
| change | | | |
| group | 215.93 | 46.31 | 0.0216 |
| age | 214.39 | 46.64 | 0.0214 |
| _cons | 212.01 | 47.17 | 0.0212 |
| var | 165.04 | 60.59 | 0.0165 |

The closer ESS estimates are to the MCMC sample size, the less correlated the MCMC sample is, and the more precise our estimates of parameters are. Do not expect to see values close to the MCMC sample size with the MH algorithm, but values below 1% of the MCMC sample size are certainly red flags. In our example, ESS for `{var}` is somewhat low, so we may need to look into improving its sampling efficiency. For example, blocking on `{var}` should improve the efficiency for the variance; see [Improving efficiency of the MH algorithm—blocking of parameters](#). It is usually a good idea to sample regression coefficients and the variance in two separate blocks.

Correlation times may be viewed as estimates of autocorrelation lags in the MCMC samples. For example, correlation times of the coefficients range between 46 and 47, and the correlation time for the variance parameter is higher, 61. Consequently, the efficiency for the variance is lower than for the regression coefficients. More investigation of the MCMC for `{var}` is needed.

Indeed, the MCMC for the variance has very poor mixing and very high autocorrelation.

```
. bayesgraph diagnostics {var}
```



One remedy is to update the variance parameter separately from the regression coefficients by putting the variance parameter in a separate block; see [Improving efficiency of the MH algorithm—blocking of parameters](#) for details about this procedure. In `bayesmh`, this can be done by specifying the `block()` option.

```

. set seed 14
. bayesmh change group age, likelihood(normal({var}))
> prior({change:}, zellnersg(3,12,{var}))
> prior({var}, igamma(0.5, 4)) block({var})
> saving(agegroup_simdata)
Burn-in ...
Simulation ...
Model summary

```

```

Likelihood:
  change ~ normal(xb_change,{var})
Priors:
  {change:group age _cons} ~ zellnersg(3,12,0,{var})
  {var} ~ igamma(0.5,4)

```

(1) Parameters are elements of the linear form `xb_change`.

```

Bayesian normal regression          MCMC iterations = 12,500
Random-walk Metropolis-Hastings sampling  Burn-in = 2,500
                                          MCMC sample size = 10,000
                                          Number of obs = 12
                                          Acceptance rate = .3232
                                          Efficiency: min = .06694
                                          avg = .1056
                                          max = .1443
Log marginal-likelihood = -35.460606

```

| | Mean | Std. dev. | MCSE | Median | Equal-tailed [95% cred. interval] | |
|--------|-----------|-----------|---------|----------|--------------------------------------|-----------|
| change | | | | | | |
| group | 5.080653 | 2.110911 | .080507 | 5.039834 | .8564619 | 9.399672 |
| age | 1.748516 | .3347172 | .008875 | 1.753897 | 1.128348 | 2.400989 |
| _cons | -43.12425 | 7.865979 | .207051 | -43.2883 | -58.64107 | -27.79122 |
| var | 12.09916 | 5.971454 | .230798 | 10.67555 | 5.375774 | 27.32451 |

file `agegroup_simdata.dta` saved.

```
. estimates store agegroup
```

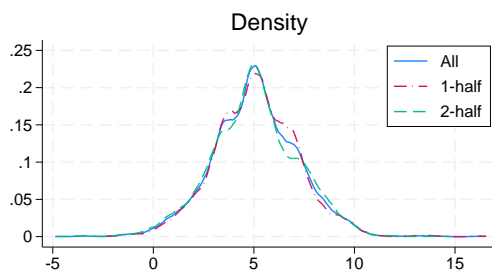
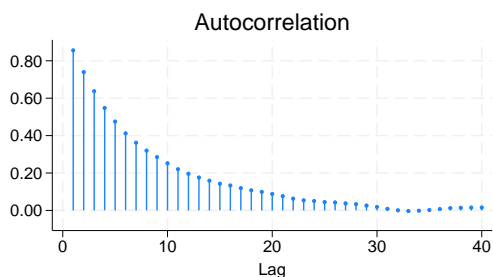
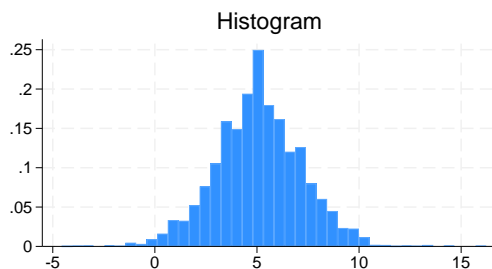
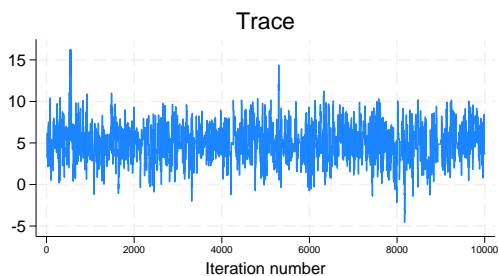
Our acceptance rate and efficiencies are now higher.

In this example, we also used `estimates store agegroup` to store current estimation results as `agegroup` for future use. To use `estimates store` after `bayesmh`, we had to specify the `saving()` option with `bayesmh` to save the `bayesmh` simulation results to a permanent Stata dataset; see [Storing estimation results after Bayesian estimation](#).

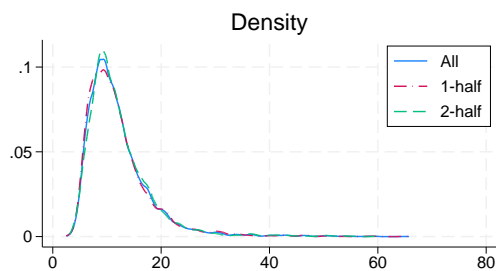
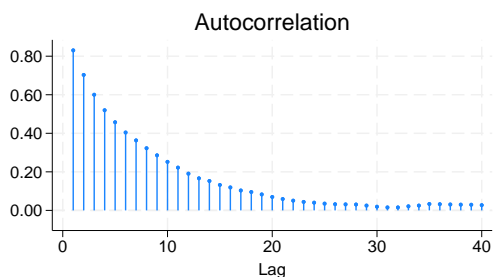
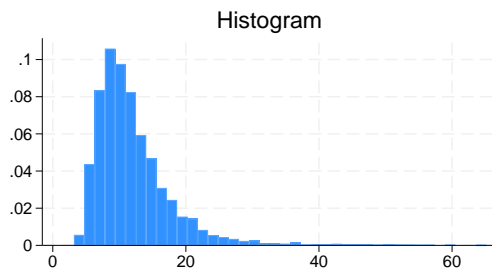
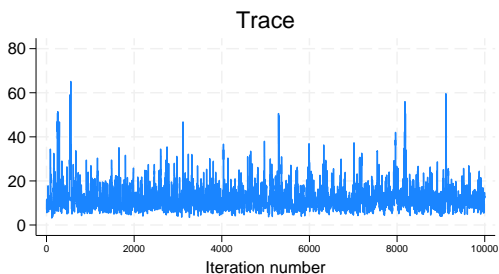
The MCMC chains are now mixing much better. We may consider increasing the default MCMC sample size to achieve even lower autocorrelation.

```
. bayesgraph diagnostics {change:group} {var}
```

change:group



var



Multiple chains are often used to diagnose the convergence of MCMC; see *Convergence diagnostics using multiple chains* in [BAYES] `bayesmh` and [BAYES] `bayesstats grubin`. Also see *Convergence of MCMC* in [BAYES] `bayesmh` for more information.

◀

▷ Example 6: Postestimation summaries

We can use the `bayesstats summary` command to compute postestimation summaries for model parameters and functions of model parameters. For example, we can compute an estimate of the standardized coefficient for `change`, which is $\hat{\beta}_{\text{group}} \times \sigma_x / \sigma_y$, where σ_x and σ_y are sample standard deviations of `group` and `change`, respectively.

We use `summarize` (see [R] `summarize`) to compute sample standard deviations and store them in respective scalars.

```
. summarize group
+-----+-----+-----+-----+-----+
| Variable | Obs | Mean | Std. dev. | Min | Max |
+-----+-----+-----+-----+-----+
| group    | 12  | .5    | .522233   | 0   | 1   |
+-----+-----+-----+-----+-----+
. scalar sd_x = r(sd)
. summarize change
+-----+-----+-----+-----+-----+
| Variable | Obs | Mean | Std. dev. | Min | Max |
+-----+-----+-----+-----+-----+
| change   | 12  | 2.469167 | 8.080637 | -10.74 | 17.05 |
+-----+-----+-----+-----+-----+
. scalar sd_y = r(sd)
```

The standardized coefficient is an expression of the model parameter `{change:group}`, so we specify it in parentheses.

```
. bayesstats summary (group_std:{change:group}*sd_x/sd_y)
Posterior summary statistics          MCMC sample size =    10,000
   group_std : {change:group}*sd_x/sd_y
+-----+-----+-----+-----+-----+-----+
|          | Mean | Std. dev. | MCSE | Median | Equal-tailed |
|          |      |           |      |         | [95% cred. interval] |
+-----+-----+-----+-----+-----+-----+
| group_std | .3283509 | .1364233 | .005203 | .3257128 | .0553512 .6074792 |
+-----+-----+-----+-----+-----+-----+
```

The posterior mean estimate of the standardized `group` coefficient is 0.33 with a 95% credible interval of [0.055, 0.61].

◀

▷ Example 7: Bayesian predictions

Bayesian predictions are useful for checking model fit and for predicting future observations.

We can use the `bayespredict` command to generate replication samples for the outcome variable `change` and save them in a new dataset, `change_pred.dta`. Samples are drawn from the *posterior predictive distribution* of `change`. We specify `{_ysim}` with `bayespredict` to simulate the outcome values and use a random-number seed for reproducibility.

```
. bayespredict {_ysim}, saving(change_pred) rseed(16)
Computing predictions ...
file change_pred.dta saved.
file change_pred.ster saved.
```


`change_pred.dta` contains an MCMC sample of predicted values for each of the 12 observations. We can use `bayesstats summary` to calculate posterior summaries for the predicted observations by specifying using with the prediction dataset.

```
. bayesstats summary {_ysim} using change_pred
```

```
Posterior summary statistics                                MCMC sample size =    10,000
```

| | Mean | Std. dev. | MCSE | Median | Equal-tailed [95% cred. interval] | |
|-----------|-----------|-----------|---------|-----------|--------------------------------------|-----------|
| _ysim1_1 | -2.954378 | 3.763301 | .060963 | -2.930854 | -10.39297 | 4.528522 |
| _ysim1_2 | -4.610688 | 3.771203 | .059014 | -4.660554 | -11.9289 | 2.948378 |
| _ysim1_3 | -4.620784 | 3.758543 | .057517 | -4.645584 | -12.03851 | 2.917013 |
| _ysim1_4 | .6417156 | 3.756645 | .063162 | .6019013 | -6.83463 | 8.330498 |
| _ysim1_5 | 4.069868 | 3.972042 | .072874 | 4.065139 | -3.780329 | 12.06363 |
| _ysim1_6 | -8.120147 | 3.832453 | .061674 | -8.096888 | -15.54334 | -.3579446 |
| _ysim1_7 | 16.18539 | 4.076738 | .072385 | 16.2033 | 8.105208 | 24.23569 |
| _ysim1_8 | 2.156433 | 3.921 | .072344 | 2.135557 | -5.528265 | 10.00732 |
| _ysim1_9 | 9.14268 | 3.780417 | .071241 | 9.154486 | 1.571643 | 16.59816 |
| _ysim1_10 | 10.91948 | 3.776916 | .068083 | 10.92263 | 3.445305 | 18.59981 |
| _ysim1_11 | .3919052 | 3.969695 | .079798 | .344616 | -7.389234 | 8.386358 |
| _ysim1_12 | 3.902787 | 3.809399 | .077872 | 3.884087 | -3.530938 | 11.49579 |

The first column contains posterior means, MCMC estimates of the expected outcome observations with respect to the posterior predictive distribution. Both posterior means and medians can be used as Bayesian predictors.

One way to assess goodness of fit of the model is by comparing replicated outcome samples with the observed outcome sample. The discrepancy between these two can be measured using the so-called posterior predictive p -values. We can use the `bayesstats ppvalues` command to compute these p -values. The posterior predictive p -values are typically computed for functions of the data or test statistics. Here, as a quick demonstration, we will compute them for each individual observation.

```
. bayesstats ppvalues {_ysim} using change_pred
Posterior predictive summary   MCMC sample size =   10,000
```

| T | Mean | Std. dev. | E(T_obs) | P(T>=T_obs) |
|-----------|-----------|-----------|----------|-------------|
| _ysim1_1 | -2.954378 | 3.763301 | -.87 | .2786 |
| _ysim1_2 | -4.610688 | 3.771203 | -10.74 | .9512 |
| _ysim1_3 | -4.620784 | 3.758543 | -3.27 | .3479 |
| _ysim1_4 | .6417156 | 3.756645 | -1.97 | .773 |
| _ysim1_5 | 4.069868 | 3.972042 | 7.5 | .1819 |
| _ysim1_6 | -8.120147 | 3.832453 | -7.25 | .4034 |
| _ysim1_7 | 16.18539 | 4.076738 | 17.05 | .4124 |
| _ysim1_8 | 2.156433 | 3.921 | 4.96 | .2198 |
| _ysim1_9 | 9.14268 | 3.780417 | 10.4 | .3644 |
| _ysim1_10 | 10.91948 | 3.776916 | 11.05 | .4858 |
| _ysim1_11 | .3919052 | 3.969695 | .26 | .5106 |
| _ysim1_12 | 3.902787 | 3.809399 | 2.51 | .6498 |

Note: P(T>=T_obs) close to 0 or 1 indicates lack of fit.

All estimated posterior predictive p -values are between 0.05 and 0.95 (except for `_ysim1_2`) and thus indicate adequate fit for the individual observations. However, more stringent [model checking](#) typically requires that various [test quantities](#) be computed using the entire replicated sample to inspect the distribution of replicated outcome values to assess the overall fit of the model. See [\[BAYES\] bayesstats ppvalues](#) for examples.

We can also use [bayespredict](#) to generate out-of-sample predictions. For illustration, let's add two new observations to the dataset: one for age 26 and group Aerobic (`group=1`) and another for age 26 and group Running (`group=0`).

```
. set obs 14
Number of observations (_N) was 12, now 14.
. replace group = 1 in 13
(1 real change made)
. replace group = 0 in 14
(1 real change made)
. replace age = 26 in 13/14
(2 real changes made)
```

We want to predict the outcome `change` for the new observations. Possible Bayesian predictors are the posterior means of the simulated outcome observations. These can be calculated using the `mean` option and saved in a new variable, say, `pname`.

```
. bayespredict pmean, mean rseed(16)
Computing predictions ...
. list change age group pmean
```

| | change | age | group | pmean |
|-----|--------|-----|---------|-----------|
| 1. | -.87 | 23 | Running | -2.914124 |
| 2. | -10.74 | 22 | Running | -4.613421 |
| 3. | -3.27 | 22 | Running | -4.701283 |
| 4. | -1.97 | 25 | Running | .545417 |
| 5. | 7.5 | 27 | Running | 4.060798 |
| 6. | -7.25 | 20 | Running | -8.111091 |
| 7. | 17.05 | 31 | Aerobic | 16.15393 |
| 8. | 4.96 | 23 | Aerobic | 2.183771 |
| 9. | 10.4 | 27 | Aerobic | 9.155602 |
| 10. | 11.05 | 28 | Aerobic | 10.87576 |
| 11. | .26 | 22 | Aerobic | .4234267 |
| 12. | 2.51 | 24 | Aerobic | 3.937901 |
| 13. | . | 26 | Aerobic | 7.380203 |
| 14. | . | 26 | Running | 2.405744 |

The predicted estimates for the out-of-sample observations 13 and 14 are 7.4 and 2.4 for the change in maximal oxygen uptake (liters/minute) for a 26-year old in the aerobic and running groups, respectively.

See [BAYES] [bayespredict](#) for more examples.

Finally, we drop the two new observations we added and erase the prediction dataset and the auxiliary estimation file created by `bayespredict`.

```
. drop in 13/14
(2 observations deleted)
. erase change_pred.dta
. erase change_pred.ster
```

◀

► Example 8: Model comparison

As we can with frequentist analysis, we can use various information criteria to compare different models. There is great flexibility in which model can be compared: you can compare models with different distributions for the outcome, you can compare models with different priors, you can compare models with different forms for the regression function, and more. The only requirement is that the same data are used to fit the models. Comparisons using Bayes factors additionally require that parameters be sampled from the complete posterior distribution, which includes the normalizing constant.

Let's compare our reduced model with the full model including an interaction term. We again use a multivariate Zellner's g -prior for the coefficients and an inverse gamma prior for the variance. We use the same values as in [example 4](#) for prior parameters. (We use the interaction variable in this example for notational simplicity. We could have used the factor-variable notation `c.age#i.group` to include this interaction directly in our model; see [U] [11.4.3 Factor variables](#).)

```

. set seed 14
. bayesmh change group age ageXgr, likelihood(normal({var}))
> prior({change:}, zellnersg(4,12,{var}))
> prior({var}, igamma(0.5, 4)) block({var})
> saving(full_simdata)
Burn-in ...
Simulation ...
Model summary

```

```

Likelihood:
  change ~ normal(xb_change,{var})
Priors:
  {change:group age ageXgr _cons} ~ zellnersg(4,12,0,{var})           (1)
  {var} ~ igamma(0.5,4)

```

(1) Parameters are elements of the linear form `xb_change`.

```

Bayesian normal regression          MCMC iterations =    12,500
Random-walk Metropolis-Hastings sampling  Burn-in           =     2,500
                                          MCMC sample size =   10,000
                                          Number of obs    =     12
                                          Acceptance rate  =    .3113
                                          Efficiency: min =    .0562
                                          avg              =    .06425
                                          max              =    .08478
Log marginal-likelihood = -36.738363

```

| | Mean | Std. dev. | MCSE | Median | Equal-tailed [95% cred. interval] | |
|--------|-----------|-----------|---------|-----------|--------------------------------------|-----------|
| change | | | | | | |
| group | 11.94079 | 16.74992 | .706542 | 12.13983 | -22.31056 | 45.11963 |
| age | 1.939266 | .5802772 | .023359 | 1.938756 | .7998007 | 3.091072 |
| ageXgr | -.2838718 | .6985226 | .028732 | -.285647 | -1.671354 | 1.159183 |
| _cons | -47.57742 | 13.4779 | .55275 | -47.44761 | -74.64672 | -20.78989 |
| var | 11.72886 | 5.08428 | .174612 | 10.68098 | 5.302265 | 24.89543 |

```

file full_simdata.dta saved.
. estimates store full

```

We can use the `bayesstats ic` command to compare the models. We list the names of the corresponding estimation results following the command name.

```

. bayesstats ic full agegroup
Bayesian information criteria

```

| | DIC | log(ML) | log(BF) |
|----------|----------|-----------|----------|
| full | 65.03326 | -36.73836 | . |
| agegroup | 63.5884 | -35.46061 | 1.277756 |

Note: Marginal likelihood (ML) is computed using Laplace-Metropolis approximation.

The smaller that DIC is and the larger that $\log(\text{ML})$ is, the better. The model without interaction, `agegroup`, is preferred according to these statistics. The log Bayes-factor for the `agegroup` model relative to the `full` model is 1.28. [Kass and Raftery \(1995\)](#) provide a table of values for Bayes factors; see, for example, *Bayes factors* in `[BAYES] bayesstats ic`. According to their scale, because $2 \times 1.28 = 2.56$ is greater than 2 (slightly), there is some mild evidence that model `agegroup` is better than model `full`.

▷ Example 9: Hypothesis testing

Continuing with [example 8](#), we can compute the actual probability associated with each of the models. We can use the `bayestest model` command to do this.

Similar to `bayesstats ic`, this command requires the names of estimation results corresponding to the models of interest.

```
. bayestest model full agegroup
Bayesian model tests
```

| | log(ML) | P(M) | P(M y) |
|----------|----------|--------|--------|
| full | -36.7384 | 0.5000 | 0.2179 |
| agegroup | -35.4606 | 0.5000 | 0.7821 |

Note: Marginal likelihood (ML) is computed using Laplace–Metropolis approximation.

Under the assumption that both models are equally probable a priori, the model without interaction, `agegroup`, has the probability of 0.78, whereas the `full` model has the probability of only 0.22. Despite the drastic disparity in the probabilities, according to the results from [example 8](#), model `agegroup` is only slightly preferable to model `full`. To have stronger evidence against `full`, we would expect to see higher probabilities (above 0.9) for `agegroup`.

We may be interested in testing an interval hypothesis about the parameter of interest. For example, for a model without interaction, let's compute the probability that the coefficient for `group` is between 4 and 8. We use `estimates restore` (see [\[R\] estimates store](#)) to load the results of the `agegroup` model back into memory.

```
. estimates restore agegroup
(results agegroup are active now)
. bayestest interval {change:group}, lower(4) upper(8)
Interval tests      MCMC sample size =      10,000
      prob1 : 4 < {change:group} < 8
```

| | Mean | Std. dev. | MCSE |
|-------|-------|-----------|----------|
| prob1 | .6159 | 0.48641 | .0155788 |

The estimated probability or, technically, its posterior mean estimate is 0.62 with a standard deviation of 0.49 and Monte Carlo standard errors of 0.016.

◀

▷ Example 10: Erasing simulation datasets

After you are done with your analysis, remember to erase any simulation datasets that you created using `bayesmh` and no longer need. If you want to save your estimation results to disk for future reference, use `estimates save`; see [\[R\] estimates save](#).

We are done with our analysis, and we do not need the datasets for future reference, so we remove both simulation files we created using `bayesmh`.

```
. erase agegroup_simdata.dta
. erase full_simdata.dta
```

◀

▷ Example 11: Bayesian linear regression using the bayes prefix

Recall our OLS regression from [example 1](#). There is a more convenient way to obtain Bayesian estimates for this regression than using the `bayesmh` command as in previous examples. Because `regress` is one of the estimation commands that supports the `bayes` prefix (`[BAYES] Bayesian estimation`), we can simply type

```
. set seed 14
. bayes: regress change group age
Burn-in ...
Simulation ...
Model summary
```

```
Likelihood:
  change ~ regress(xb_change,{sigma2})
Priors:
  {change:group age _cons} ~ normal(0,10000)
  {sigma2} ~ igamma(.01,.01) (1)
```

(1) Parameters are elements of the linear form `xb_change`.

```
Bayesian linear regression          MCMC iterations =    12,500
Random-walk Metropolis-Hastings sampling  Burn-in =        2,500
                                          MCMC sample size =   10,000
                                          Number of obs =        12
                                          Acceptance rate =     .283
                                          Efficiency: min =    .02715
                                          avg =     .05779
                                          max =     .0692
Log marginal-likelihood = -45.562124
```

| | Mean | Std. dev. | MCSE | Median | Equal-tailed [95% cred. interval] | |
|--------|-----------|-----------|---------|-----------|--------------------------------------|----------|
| change | | | | | | |
| group | 5.425311 | 2.111038 | .080252 | 5.368975 | 1.104434 | 9.425197 |
| age | 1.885651 | .3255098 | .012472 | 1.887263 | 1.244666 | 2.517292 |
| _cons | -46.47537 | 7.632058 | .295505 | -46.73244 | -60.39245 | -30.5054 |
| sigma2 | 10.28431 | 7.614468 | .462105 | 8.412747 | 3.595971 | 31.47161 |

Note: Default priors are used for model parameters.

With the `bayes` prefix command, the likelihood is determined automatically by the specified estimation command—`regress` in our example. The `bayes` prefix also provides the default prior specifications for model parameters, displaying this information as a note at the bottom of the output table; see [Default priors](#) in `[BAYES] bayes`. Model summary provides details about the used default priors. For linear regression, the regression coefficients are assigned independent normal priors with zero mean and variance of 10,000, and the variance is assigned an inverse-gamma prior with the same shape and scale parameters of 0.01.

The default priors are provided for convenience and are chosen to be fairly uninformative for models with moderately scaled parameters. However, they are not guaranteed to be uninformative for all models and datasets; see [Linear regression: A case of informative default priors](#) in `[BAYES] bayes`. You should choose priors carefully based on your research and model of interest.

As with `bayesmh`, the default MCMC method is an adaptive MH, but we can specify the `gibbs` option to request Gibbs sampling.

```
. set seed 14
. bayes, gibbs: regress change group age
Burn-in ...
Simulation ...
Model summary
```

```
Likelihood:
  change ~ normal(xb_change,{sigma2})
Priors:
  {change:group age _cons} ~ normal(0,10000)          (1)
  {sigma2} ~ igamma(.01,.01)
```

(1) Parameters are elements of the linear form `xb_change`.

```
Bayesian linear regression      MCMC iterations =    12,500
Gibbs sampling                  Burn-in           =     2,500
                                MCMC sample size =    10,000
                                Number of obs     =      12
                                Acceptance rate   =      1
                                Efficiency: min =    .556
                                avg =            .889
                                max =            1
Log marginal-likelihood = -45.83666
```

| | Mean | Std. dev. | MCSE | Median | Equal-tailed [95% cred. interval] | |
|---------------|-----------|-----------|---------|-----------|--------------------------------------|-----------|
| change | | | | | | |
| group | 5.452439 | 2.062795 | .020628 | 5.460372 | 1.360104 | 9.512987 |
| age | 1.875606 | .330127 | .003301 | 1.877129 | 1.228647 | 2.543129 |
| _cons | -46.21334 | 7.746862 | .077469 | -46.18291 | -61.82541 | -31.09702 |
| sigma2 | 9.929756 | 5.899176 | .079113 | 8.426173 | 3.731261 | 24.76194 |

Note: Default priors are used for model parameters.

As expected, we obtain higher efficiency when using the Gibbs sampling. However, the `gibbs` option is available only with `bayes: regress` and `bayes: mvreg` and only for certain prior distributions.

We can easily change the default priors by specifying the `prior()` option, as with `bayesmh`. For example, we can reproduce `bayesmh`'s results from [example 4](#) but with the `bayes` prefix.

```
. set seed 14
. bayes, prior({change:}, zellnersg(3,12,{sigma2}))
> prior({sigma2}, igamma(0.5, 4)): regress change group age
Burn-in ...
Simulation ...
Model summary
```

```
Likelihood:
  change ~ regress(xb_change,{sigma2})
Priors:
  {change:group age _cons} ~ zellnersg(3,12,0,{sigma2})           (1)
  {sigma2} ~ igamma(0.5,4)
```

(1) Parameters are elements of the linear form `xb_change`.

```
Bayesian linear regression                MCMC iterations =    12,500
Random-walk Metropolis-Hastings sampling  Burn-in           =     2,500
                                           MCMC sample size =   10,000
                                           Number of obs    =     12
                                           Acceptance rate  =    .2838
                                           Efficiency: min =    .06423
                                           avg              =    .07951
                                           max              =    .09277
Log marginal-likelihood = -35.448029
```

| | Mean | Std. dev. | MCSE | Median | Equal-tailed [95% cred. interval] | |
|--------|-----------|-----------|---------|-----------|--------------------------------------|-----------|
| change | | | | | | |
| group | 4.944955 | 2.184113 | .086181 | 5.052278 | .7065487 | 9.35098 |
| age | 1.747984 | .3390581 | .011132 | 1.747477 | 1.045677 | 2.416091 |
| _cons | -43.09605 | 7.904334 | .263186 | -43.01961 | -58.57942 | -27.11278 |
| sigma2 | 12.17932 | 5.87997 | .220888 | 10.72651 | 5.511202 | 28.1211 |

The results are similar to those from [example 4](#) using `bayesmh` but not identical. By default, `bayes: regress` automatically splits the regression coefficients and the variance into two separate blocks, whereas `bayesmh` treats all parameters as one block; see [Improving efficiency of the MH algorithm—blocking of parameters](#) in [\[BAYES\] bayesmh](#) for details about blocking.

To match the results exactly, you can either specify the `block({var})` option with `bayesmh` in example 4 or specify the `noblocking` option to request no default blocking with the `bayes` prefix.

```
. set seed 14
. bayes, prior({change:}, zellnersg(3,12,{sigma2}))
> prior({sigma2}, igamma(0.5, 4)) noblocking: regress change group age
Burn-in ...
Simulation ...
Model summary
```

```
Likelihood:
  change ~ regress(xb_change,{sigma2})
Priors:
  {change:group age _cons} ~ zellnersg(3,12,0,{sigma2})          (1)
  {sigma2} ~ igamma(0.5,4)
```

```
(1) Parameters are elements of the linear form xb_change.
Bayesian linear regression                MCMC iterations =      12,500
Random-walk Metropolis-Hastings sampling  Burn-in           =       2,500
                                           MCMC sample size =     10,000
                                           Number of obs    =       12
                                           Acceptance rate  =     .06169
                                           Efficiency: min =     .0165
                                           avg             =     .02018
                                           max             =     .02159
```

```
Log marginal-likelihood = -35.356501
```

| | Mean | Std. dev. | MCSE | Median | Equal-tailed [95% cred. interval] | |
|--------|-----------|-----------|---------|-----------|--------------------------------------|-----------|
| change | | | | | | |
| group | 4.988881 | 2.260571 | .153837 | 4.919351 | .7793098 | 9.775568 |
| age | 1.713159 | .3545698 | .024216 | 1.695671 | 1.053206 | 2.458556 |
| _cons | -42.31891 | 8.239571 | .565879 | -41.45385 | -59.30145 | -27.83421 |
| sigma2 | 12.29575 | 6.570879 | .511475 | 10.3609 | 5.636195 | 30.93576 |

See [\[BAYES\] bayes](#) for more details.



Acknowledgments

We thank John Thompson (retired) of the Department of Health Sciences at the University of Leicester, UK, and author of *Bayesian Analysis with Stata*, and Matthew J. Baker of Hunter College and the Graduate Center, CUNY for their software and contributions to Bayesian analysis in Stata.

References

- Baker, M. J. 2014. Adaptive Markov chain Monte Carlo sampling and estimation in Mata. *Stata Journal* 14: 623–661.
- Balov, N. 2020. Bayesian inference using multiple Markov chains. *The Stata Blog: Not Elsewhere Classified*. <https://blog.stata.com/2020/02/24/bayesian-inference-using-multiple-markov-chains/>.
- Hoff, P. D. 2009. *A First Course in Bayesian Statistical Methods*. New York: Springer.
- Kass, R. E., and A. E. Raftery. 1995. Bayes factors. *Journal of the American Statistical Association* 90: 773–795. <https://doi.org/10.1080/01621459.1995.10476572>.
- Kuehl, R. O. 2000. *Design of Experiments: Statistical Principles of Research Design and Analysis*. 2nd ed. Belmont, CA: Duxbury.

Zellner, A. 1986. On assessing prior distributions and Bayesian regression analysis with g -prior distributions. In Vol. 6 of *Bayesian Inference and Decision Techniques: Essays in Honor of Bruno De Finetti (Studies in Bayesian Econometrics and Statistics)*, ed. P. K. Goel and A. Zellner, 233–343. Amsterdam: North-Holland.

Also see

[BAYES] [Intro](#) — Introduction to Bayesian analysis

[BAYES] [bayesmh](#) — Bayesian models using Metropolis–Hastings algorithm

[BAYES] [bayes](#) — Bayesian regression models using the bayes prefix

[BAYES] [Bayesian estimation](#) — Bayesian estimation commands

[BAYES] [Bayesian postestimation](#) — Postestimation tools for bayesmh and the bayes prefix

[BAYES] [Glossary](#)

Stata, Stata Press, and Mata are registered trademarks of StataCorp LLC. Stata and Stata Press are registered trademarks with the World Intellectual Property Organization of the United Nations. Other brand and product names are registered trademarks or trademarks of their respective companies. Copyright © 1985–2023 StataCorp LLC, College Station, TX, USA. All rights reserved.

