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# Calibrating survey data using iterative proportional fitting (raking)

Stanislav Kolenikov  
Abt SRBI  
Columbia, MO  
kolenikovs@srbi.com

**Abstract.** In this article, I introduce the `ipfraking` package, which implements weight-calibration procedures known as iterative proportional fitting, or raking, of complex survey weights. The package can handle a large number of control variables and trim the weights in various ways. It also provides diagnostic tools for the weights it creates. I provide examples of its use and a suggested workflow for creating raked replicate weights.

**Keywords:** `st0323`, `ipfraking`, `mat2do`, `xls2row`, survey, calibration, weights, raking, iterative proportional fitting

## 1 Introduction and background

Large-scale social, behavioral, and health data are often collected via complex survey designs that may involve some of or all the following: stratification, multiple stages of selection, and unequal probabilities of selection (Korn and Graubard 1995, 1999). Ideally, varying probabilities of selection are accounted for by using the Horvitz–Thompson estimator of the totals (Horvitz and Thompson 1952; Thompson 1997); the remaining sampling fluctuations can be further worked out by poststratification (Holt and Smith 1979).

However, aside from the planned differences in probabilities of obtaining a response from a sampled unit, nonresponse is a practical problem that has been growing more acute over the recent years (Groves et al. 2002; Pew Research Center 2012). The analysis weights that are provided along with the public-use microdata by data-collecting agencies are designed to account for unequal probabilities of selection, nonresponse, and other factors affecting imbalance between the population and the sample; thus the analyses conducted on such microdata are generalizable to the target population. In this article, I will discuss the specific issue in the process of creating survey weights: calibrating survey weights to known control totals to ensure that the resulting weighted data are representative of the population of interest.

## 1.1 Population totals

For a given finite population  $\mathcal{U}$  of units indexed  $i = 1, \dots, N$ , the interests of survey statisticians often lie in estimating the population total of a variable  $Y$ :

$$T(Y) = \sum_{i \in \mathcal{U}} Y_i \quad (1)$$

(As is customary in sampling texts, the population quantities will be denoted with capital letters and the sample quantities with lowercase letters. The finite population is denoted as  $\mathcal{U}$ , and the sample drawn from it is denoted as  $\mathcal{S}$ . The indices of units in the population are  $i \in \mathcal{U}$ , and those of units in the sample are  $j \in \mathcal{S}$ .) Many other analytical problems can be cast in terms of estimating the totals of the existing or auxiliary variables and then expressing the quantities of substantive interest (means, ratios, regression coefficients) as functions of these totals (Skinner 1989). For instance, the population mean, such as mean income or the average number of hours per week spent watching television, is the ratio of the totals,

$$\bar{Y} = \frac{T(Y)}{T(1)}$$

where the denominator is a somewhat unusual total of a variable identically equal to 1, that is, the estimator of the population size (if it is unknown). The mean for a domain  $\mathcal{D}$  (mean income of females, television hours of teenagers) is also a ratio of totals,

$$\bar{Y}_{\mathcal{D}} = \frac{T(YZ)}{T(Z)}$$

where  $Z_i = 1$  when the unit is in the domain and  $Z_i = 0$  otherwise. Estimation of totals is thus the cornerstone of survey statistics.

## 1.2 Probability weights

Suppose now that a sample  $\mathcal{S}$  of  $n$  units indexed by  $j = 1, \dots, n$  is taken from  $\mathcal{U}$ . If the probability to select the  $i$ th unit is known to be  $\pi_i$ , then the probability weights, or design weights, are given by the inverse probability of selection:

$$w_{1i} = \pi_i^{-1} \quad (2)$$

With these weights, an unbiased (design-based, nonparametric) estimator of the total (1) is (Horvitz and Thompson 1952)

$$t_1(y) = \sum_{j \in \mathcal{S}} \frac{y_j}{\pi_j} \equiv \sum_{j \in \mathcal{S}} w_{1j} y_j \quad (3)$$

The subindex 1 indicates that the weights  $w_{1i}$  were used in obtaining this estimator. Probability weights protect the end user from potentially informative sampling designs, in which the probabilities of selection are correlated with outcomes, and the design-based methods generally ensure that inference can be generalized to the finite population even when the statistical models used by analysts and researchers are not specified correctly (Pfeffermann 1993; Binder and Roberts 2003).

### 1.3 Calibrated weights

Survey statisticians often have auxiliary information on the units in the frame. Some of that information can be used at the sampling stage to inform stratification and clustering. When creating areal probability samples of human populations, the survey designers have geographic information on the sampled units: from strata that can be defined as regions, states, or provinces and the primary sampling units (PSUs) that can be defined as districts, counties, or census tracts down to the address of the sampled household. When survey statisticians create establishment survey samples, the frame information that they may have at their disposal can include the industry classification codes and the size of establishment (number of employees or total revenue). When statisticians draw samples from lists of persons, such as members of a professional organization or patients in a hospital, the frame information can include the age and gender of an individual. If such additional information is available, it is usually beneficial to include it at the sampling stage to create more efficient designs. Unequal probabilities of selection are then controlled with probability weights, which are implemented as `[pw=exp]` in Stata (and can be permanently affixed to the dataset with the `svyset` command).

In many situations, however, usable information is not available beforehand and may appear only in the collected data. In the above example with areal samples, the census totals of the age and gender distribution of the population may exist, but age and gender of the sampled units is unknown until the survey measurement is taken on them. It is still possible to capitalize on this additional data by adjusting the weights in such a way that the reweighted data conforms to these known figures. The procedures to perform these reweighting steps are generally known as weight calibration (Deville and Särndal 1992; Deville, Särndal, and Sautory 1993; Kott 2006, 2009; Särndal 2007).

Suppose there are several (categorical) variables, referred to as control variables, that are available for both the population and the sample (age groups, race, gender, educational attainment, etc.). The poststratification adjustment consists of breaking down the population into poststratification cells defined by specific levels of the control variables (that is, a cell in a multivariate contingency table) and adjusting the weights within each cell so that the weights sum to the known total. Thus for the unit  $j$  in the (population-level) poststratification cells  $\mathcal{C}_k$ , the poststratified weight is

$$w_{2j} = w_{1j} \frac{\sum_{i \in \mathcal{U}} \mathbb{1}(i \in \mathcal{C}_k)}{\sum_{l \in \mathcal{S}} w_{1l} \mathbb{1}(l \in \mathcal{C}_k)} \quad (4)$$

where  $\mathbb{1}(\cdot)$  is an indicator function taking the value of 1 when its argument is true and 0 otherwise. While the probability weight  $w_{1i}$  is fixed, the poststratified weight  $w_{2j}$  is random because it depends on the random sample sizes of  $\mathcal{C}_k \cap \mathcal{S}$ . The existing Stata `svyset` options—`poststrata()` and `postweight()` (see [SVY] **poststratification**)—handle this situation and, in particular, provide appropriate standard errors. The total estimator based on  $w_{2j}$  will be naturally denoted as  $t_2(y)$ , and the expression for it coincides with (3) by replacing the probability weights  $w_{1j}$  with poststratified weights  $w_{2j}$ .

In more complex situations, using, say, five calibration variables (such as gender, age groups, race or ethnicity, education, and urbanicity) leads to five-way contingency tables that will likely have zero-count or very small count cells. Battaglia et al. (2009) suggest collapsing the categories that contain less than 5% of either the sample cases or the population units. For a sample of size  $n = 1000$ , which is typical for social science studies or public opinion polls, this recommendation translates to cells of size  $\sum_{j \in \mathcal{S}} \mathbb{1}(i \in \mathcal{C}_k) \leq 50$ . Likewise, Lundström and Särndal (2010) recommend the minimal cell size of 30 to 50. Instead of adjusting every cell of a multiway table, weight calibration can target adjusting only the margins, or low-level interactions, via an iterative optimization aimed at satisfying the control totals for the control variables  $\mathbf{x} = (x_1, \dots, x_p)$ ,

$$\sum_{j \in \mathcal{S}} w_{3j} \mathbf{x}_j = T(\mathbf{X}_j) \quad (5)$$

where the right-hand side is assumed to be known from a census or a higher-quality survey. Deville and Särndal (1992) framed the problem of finding a suitable set of weights as that of constrained optimization with the control equations (5) serving as constraints and optimization targeted at making the discrepancy between the design weights  $w_{1j}$  and calibrated weights  $w_{3j}$  as close as possible, in a suitable sense. Again the appropriate total estimator can be denoted as  $t_3(y)$ .

## 1.4 Raking algorithm

An early algorithm to perform weight calibration is often attributed to Deming and Stephan (1940), who used it to adjust the counts in a contingency table to satisfy the known margins in log-linear analysis. In applications to the survey weights, the algorithm is described below. At a basic level, this algorithm consists of an outer cycle that checks convergence criteria and an inner cycle that iterates over the control variables. The multi-index notation of the intermediate weights,  $w_j^{k,v}$ , indicates the weight of unit  $j$  computed in the outer cycle  $k$  after poststratifying with respect to the  $v$ th variable. Thus  $k$  runs from 1 to a predefined maximum number of iterations  $K$ ;  $v$  runs from 0 (indicating the input weight to a given iteration) through 1 (indicating adjustment with respect to the first control variable) to  $p$  (indicating adjustment with respect to the last control variable).

### Algorithm 1: Basic raking

1. Initialize the iteration counter  $k \leftarrow 0$  and the weights as  $w_j^{0,p} \leftarrow w_{1j}$ . (That is, use the base weights to initialize the raked weight; the superscript  $0, p$  is used only for consistency with the notation in the next step.)
2. Increment the iteration counter  $k \leftarrow k + 1$ , and update the weights  $w_j^{k,0} \leftarrow w_j^{k-1,p}$ . (That is, use the result of the previous outer cycle iteration to initialize the weights for the current outer cycle iteration.)

3. Inner cycle: Go over the control variables  $v = 1, \dots, p$ , and update the weights

$$w_j^{k,v} = \begin{cases} w_j^{k,v-1} \frac{T(X_v)}{\sum_{l \in \mathcal{S}} w_l^{k,v-1} x_{vl}}, & x_{vj} \neq 0 \\ w_j^{k,v-1}, & x_{vj} = 0 \end{cases}$$

(That is, poststratify with respect to the  $v$ th control variable.)

4. If discrepancies between the weighted totals  $\sum_{j \in \mathcal{S}} w_j^{k,p} x_v$  and the target totals  $T(X_v)$  are within prespecified tolerances for all  $v = 1, \dots, p$ , declare convergence and go to step 7.
5. If the number of iterations  $k$  reaches a prespecified limit  $K$ , declare nonconvergence, issue corresponding warnings, and go to step 7.
6. Otherwise, return to step 2. (That is, the achieved accuracy of the control targets is insufficient, and more work is needed.)
7. Return the weights  $w_j^{k,p}$  at the final stage as the calibrated weights.

In practice, control totals are usually expressed as population counts or proportions in categories of discrete variables (such as gender, race or ethnicity, or education-level groups). The control variables are then 0 and 1 indicators representing the particular groups or their low-level interactions. Effectively, the algorithm implements poststratification adjustment (4), treating each control variable as the poststratification variable and cycling over these variables within each iteration. In terms of multivariate optimization, this algorithm proceeds by optimizing over each margin in sequence. While it is very simple and very explicit in terms of the algebra involved, it is also much slower compared with Newton–Raphson-based methods.

Deming and Stephan (1940) stated that the algorithm minimizes the quadratic discrepancy

$$\sum_{j \in \mathcal{S}} \frac{(w_{1j} - w_{3j})^2}{w_{1j}}$$

under the calibration constraints (5). However, the quadratic problem can be solved explicitly to produce linear calibrated weights that lead to estimates identical to the generalized regression estimates (case 1 of Deville and Särndal [1992]). The raking algorithm instead solves the optimization problem with an objective function that can be expressed as (case 2 of Deville and Särndal [1992])

$$\sum_{j \in \mathcal{S}} w_{3j} \ln(w_{3j}/w_{1j}) - w_{3j} + w_{1j}$$

## 1.5 Variance estimation

Aside from the primary challenge of finding a good set of weights (which is generally solved through iterative optimization), an additional methodological challenge with calibrated estimators is variance estimation. If variables  $x_1, \dots, x_p$  were used for weight calibration, then the asymptotic variance of the calibrated estimator of the survey variable  $y$  is

$$\mathbb{V}\{t_m(y)\} = \sum_{k,l \in \mathcal{U}} (\pi_{kl} - \pi_k \pi_l) \frac{Y_k - \mathbf{X}'_k \mathbf{B}}{\pi_k} \frac{Y_l - \mathbf{X}'_l \mathbf{B}}{\pi_l}, \quad m = 2, 3 \quad (6)$$

where  $\mathbf{B}$  is the vector of coefficients from the census regression,

$$\mathbf{B} = \left( \sum_{i \in \mathcal{U}} \mathbf{X}_i \mathbf{X}'_i \right)^{-1} \sum_{i \in \mathcal{U}} \mathbf{X}_i Y_i \quad (7)$$

This variance can be estimated with

$$v\{t_m(y)\} = \sum_{k,l \in \mathcal{S}} \frac{\pi_{kl} - \pi_k \pi_l}{\pi_{kl}} \frac{y_k - \mathbf{x}'_k \mathbf{b}}{\pi_k} \frac{y_l - \mathbf{x}'_l \mathbf{b}}{\pi_l}, \quad m = 2, 3 \quad (8)$$

where the regression coefficients now solve the sample regression problem:

$$\mathbf{b} = \left( \sum_{j \in \mathcal{S}} w_j \mathbf{x}_j \mathbf{x}'_j \right)^{-1} \sum_{j \in \mathcal{S}} w_j \mathbf{x}_j y_j \quad (9)$$

In regression (9), the calibrated weights  $w_{3j}$  should be used. As demonstrated by D'Arrigo and Skinner (2010), the use of design weights  $w_{1j}$  leads to serious biases in the resulting variance estimator. The estimator (8) is difficult to use in practice, especially with the publicly released versions of the data. First, this estimator uses the original design weights  $w_{1i} = \pi_i^{-1}$ . Hence the publicly released dataset must include both the calibrated weights and the design weights, which may create confusion. Second, the end user of the data must be given the set of the control variables, which may not be possible if confidential variables were used in calibration. Third, this estimator is not necessarily implemented in survey packages (a third-party package, `calibest` (D'Souza 2011), implements (8) in Stata). Finally, the estimator requires second-order selection probabilities, which are rarely computed in practice. The last reason is a very general issue with the Horvitz–Thompson estimator (3) as well. Its variance is

$$\mathbb{V}\{t_1(y)\} = \sum_{k,l \in \mathcal{U}} (\pi_{kl} - \pi_k \pi_l) \frac{Y_k}{\pi_k} \frac{Y_l}{\pi_l} \quad (10)$$

While the second-order selection probabilities are nominally required for this estimator, in practice, simplifications are taken, for example, to approximate the actual design as the stratified two-stage sample in which the PSUs are drawn with replacement (as is done,



for example, in Stata’s `nhanes2.dta` example dataset). Because of these complications, variance estimation with calibrated data usually proceeds along the lines of replicate variance-estimation methods (Shao 1996; Kolenikov 2010).

When the control totals are obtained from another survey, the sampling variability of these methods should be taken into account (Dever and Valliant 2010). For instance, to calibrate population surveys conducted in the United States, researchers often use the American Community Survey (U.S. Census Bureau 2009) for demographic variables and the National Health Interview Survey (Botman et al. 2000) for phone usage. These large-scale surveys have sample sizes in the hundreds of thousands. For typical surveys with sample sizes in the hundreds to low thousands, the impact on the standard errors is in the second or third decimal point and is usually ignored.

## 1.6 Pros and cons of weight calibration

By comparing expressions (6) and (10), we can identify the source of efficiency gains associated with weight calibration. If the survey variable  $y$  is associated with calibration variables  $x_1, \dots, x_p$ —in the sense of having a nontrivial  $R^2$  in the census regression (7)—then the calibrated estimator is (asymptotically) more efficient than the direct Horvitz–Thompson estimator by a factor of  $1 - R^2$ .

Weight calibration can also reduce nonresponse and coverage errors (Chang and Kott 2008; Kott 2006; Lundström and Särndal 1999), which feature prominently as some of the most important issues that the survey community currently faces (Groves 2006). However, for weight calibration to be successful in reducing the nonresponse bias, the control variables need to be correlated with the response propensity or the outcome variables or both (Bethlehem 2002; Judkins et al. 2007).

Weight calibration comes with some costs, too. From an analytic perspective, manipulating the weights almost inevitably leads to an increase in their variation, which in turn leads to increases in the design effects (DEFFs). For the unequal probability sample without stratification or clustering, Korn and Graubard (1999) show that the DEFF is

$$\text{DEFF}_w = \frac{\sum_{j \in \mathcal{S}} w_j^2}{\left(\sum_{j \in \mathcal{S}} w_j\right)^2} = 1 + \text{CV}_w^2 \quad (11)$$

where  $\text{CV}_w$  is the coefficient of variation (CV) of the weights (a simple standard deviation divided by the simple mean). In practice, I have encountered increases of this CV between 20% and 100% on the relative scale, or between 0.2 and 1.5 on the absolute scale, for DEFFs varying between 1 and 2 in the typical public opinion surveys. From a practical perspective, weight calibration requires additional time by statisticians preparing the data, which increases the cost of the survey and the time between the end of the data-collection period and delivery of the final dataset. Additionally, as noted in section 1.5, variance estimation with calibrated data tends to get complicated.

## 1.7 Weight trimming

As expression (11) shows, it is undesirable for a survey to have a large spread of weights (Théberge 2000): many survey estimates are unduly affected by the observations with large weights, while those with small weights make but minimal contributions. The impact of the observations with large weights will be exacerbated in the analysis of domains, where these observations will stand apart even more given the smaller sizes of domains. For these reasons, weights are often trimmed. The largest weights are reduced (say, all the weights greater than the largest allowable number are reduced to that number), and the smallest weights are increased so that for all  $j$ ,  $L \leq w_{3j} \leq U$  for some absolute limits  $L$  and  $U$ . Alternatively, the relative change in weights can be constrained: for all  $j$ ,  $l \leq w_{3j}/w_{1j} \leq u$  for some ratio limits  $l$  and  $u$ . Weight trimming may introduce bias, so the amount of trimming needs to be seen as a tradeoff between an apparent improvement in efficiency and latent bias (Elliott 2008).

With trimming, the modified algorithm implemented in `ipfraking` proceeds as follows. (See section 2.1 for the syntax diagram and section 2.2 for specification of the trimming options. If not specified otherwise, the default values are  $U = u = +\infty$ ,  $L = l = 0$ .)

### Algorithm 2: Raking with simultaneous trimming

1. Initialize the outer cycle iteration counter  $k \leftarrow 0$ . Initialize the weights  $w_j^{0,p} \leftarrow w_{1j}$ . Set  $D_0 = \infty$ . (This is a notation introduced for consistency with notation in step 9.)
2. Increment the outer cycle iteration counter  $k \leftarrow k + 1$ , and update the weights  $w_j^{k,0} \leftarrow w_j^{k-1,p}$ .
3. Initialize the inner cycle over control variables:  $v \leftarrow 1$ .
4. Update the weights using the  $v$ th variable as the poststratification variable:

$$w_j^{k,v} = \begin{cases} w_j^{k,v-1} \frac{T(X_v)}{\sum_{l \in \mathcal{S}} w_l^{k,v-1} x_{vl}}, & x_{vj} \neq 0 \\ w_j^{k,v-1}, & x_{vj} = 0 \end{cases}$$

5. If the `trimfrequency()` option is specified as `often`, perform weight trimming:

$$w_j^{k,v} \leftarrow \min(w_j^{k,v}, U, uw_j^{0,p})$$

$$w_j^{k,v} \leftarrow \max(w_j^{k,v}, L, lw_j^{0,p})$$

That is, trim the weights that are greater than  $U$  in absolute terms or have increased by more than a factor of  $u$  from the initial weight; reduce such weights to the largest allowed value. Likewise, trim the weights that are less than  $L$  in absolute terms or have dropped by more than a factor of  $l$  from the initial weight; increase such weights to the smallest allowed value.

6. Increment the internal cycle counter  $v \leftarrow v + 1$ .
7. If  $v \leq p$ , cycle back to step 4. Otherwise, the inner cycle over the control variables is completed; proceed to the next step.
8. If the `trimfrequency()` option is specified as `sometimes`, perform weight trimming:

$$w_j^{k,p} \leftarrow \min(w_j^{k,p}, U, uw_j^{0,p})$$

$$w_j^{k,p} \leftarrow \max(w_j^{k,p}, L, lw_j^{0,p})$$

9. If the largest change in weights,

$$D_k = \max_{j \in \mathcal{S}} \left| \frac{w_j^{k,p}}{w_j^{k-1,p}} - 1 \right|$$

is less than or equal to tolerance  $\delta_D$  (given in the `tolerance()` option), declare convergence of weights and go to step 11. If  $D_k > D_{k-1}$ ,  $k > 1$ , the algorithm may be diverging; stop the outer cycle iterations, issue a nonconvergence message, and go to step 11. Otherwise (that is, if  $\delta_D < D_k < D_{k-1}$ ), move to the next step: there is some room for weight improvement.

10. If the number of the outer cycle iterations  $k$  reaches a prespecified limit  $K$ , stop the outer cycle iterations, and issue a nonconvergence message. Otherwise, cycle back to step 2.
11. If the `trimfrequency()` option is specified as `once`, perform weight trimming:

$$w_j^{k,p} \leftarrow \min(w_j^{k,p}, U, uw_j^{0,p})$$

$$w_j^{k,p} \leftarrow \max(w_j^{k,p}, L, lw_j^{0,p})$$

12. If discrepancies between the weighted totals  $\sum_{j \in \mathcal{S}} w_j^{k,p} x_v$  and the target totals  $T(X_v)$  are greater than prespecified tolerances  $\delta_T$  (the `ctrltolerance()` option),

$$\left| \frac{T(X_v) - \sum_{j \in \mathcal{S}} w_j^{k,p} x_v}{T(X_v) + 1} \right| > \delta_T$$

for at least one  $v = 1, \dots, p$ , issue a warning message (see section 5).

13. Return the weights  $w_j^{k,p}$  as calibrated weights and exit.

The algorithm may be exited for three possible reasons: reaching the maximum number of iterations (indicative of lack of convergence), finding that the changes in weights started diverging, or reaching the state where the weights do not change from one iteration of poststratification and possibly trimming to the next. Even in the last case, convergence of the weights does not imply convergence of the weighted totals to their targets. Hence there are qualitatively three possible outcomes of running `ipfraking`:

1. The weights have converged as checked in step 9, and the weighted control totals are within tolerances from their targets, as checked in step 12. The raked weights are most likely safe to use, although additional quality control checks, including computation of the DEFF (11), histograms, and tabulations with the main variables of interest would be recommended.
2. The weights have converged as checked in step 9, but the weighted control totals are not sufficiently close to their targets, as checked in step 12. The raked weights should be reviewed and may not be safe to use. This often happens when the trimming options are too aggressive, when the data and the control totals are incompatible, or when the control totals themselves are poor (for example, the matrices sum to different values, for which `ipfraking` will issue an error message).
3. The weights have not converged after the prespecified number of iterations or started diverging. Again the resulting weights are likely to be unsatisfactory. The number of iterations should be increased, the tolerances should be decreased, or the `nodivergence` option can be specified if optimization aborted because the weight convergence criteria went up.

## 1.8 Other weight calibration programs

Several packages with similar functionality have been circulating in the Stata community. Winter's (2002) `survwgt` is the most robust and versatile of these, and its `survwgt rake` subcommand implements the same raking algorithm as the basic algorithm of `ipfraking`. The functionality of `survwgt` also includes valuable capabilities to create the balanced repeated replication and jackknife replicate weights (Kolenikov 2010) as well as nonresponse cell adjustments. One feature that `survwgt` does not have is trimming.

A more recent raking package is `ipfweight` (Bergmann 2011). It implements the basic raking and provides relative trimming similar to `trimfrequency(often)`.

Another user-contributed Stata package, `maxentropy` (Wittenberg 2010), implements case 4 of Deville and Särndal (1992) using Newton–Raphson optimization with analytical second derivatives and is much faster than `ipfraking`.

Compared with these packages, `ipfraking` was developed to work in the weight production environment of a survey company. To be an effective tool, the weight calibration procedure should not only produce the correct figures but also provide extensive diagnostics and robustness checks that can potentially be analyzed in semiautomated fashion and be robust and fail softly with incorrectly specified inputs. For instance, all the above packages rely on the user to match the variables and their targets, and some are relatively fragile numerically when the initial weights generate totals that are far off their targets. In `ipfraking`, as you will shortly see, the match between variables and their targets is implemented internally through metadata (variable names and values) stored in Stata target matrices as the necessary variables and their categories are picked up by `ipfraking` from the targets. Thus the number of necessary inputs and, hence,

the likelihood of user error (through incorrect ordering of variables and their categories) are reduced. The targets, in turn, can be easily obtained from calibration datasets such as the American Community Survey. Also `ipfraking` defines convergence in terms of the values of weights rather than the target discrepancies, which are used in other packages. It thus allows the possibility of the raking procedure converging computationally (weights stop changing from one iteration to the next) and then diagnoses the statistical convergence, that is, whether the targets are being satisfied.

Aside from the internal convergence diagnostics, the weights produced by `ipfraking` were compared with those produced by `survwgt` and `ipfweight` as a certification step (Gould 2001), and were found to be identical within numerical accuracy.

## 2 The ipfraking command

### 2.1 Syntax

```
ipfraking [if] [in] [pw=varname], ctotal(matname [matname ...])
  {generate(newvar)|replace} [tolerance(#) iterate(#) nodivergence
  ctrltolerance(#) trace alpha(#) trimhiabs(#) trimhirel(#)
  trimloabs(#) trimlorel(#) trimfrequency(keyword) double meta nograph
  loglevel(#)]
```

Note that the weight statement [*pw=varname*] is required and must contain the initial weights.

### 2.2 Options

#### Required options

`ctotal`(*matname* [*matname* ...]) supplies the names of the matrices that contain the control totals as well as metadata about the variables to be used in calibration. `ctotal()` is required.

#### □ Technical note

The row and column names of the control total matrices (see [P] **matrix rownames**) should be formatted as follows:

- **rownames**: the names of the control variables.
- **colnames**: the values the control variables take.
- **coleq**: the name of the variable for which the total is computed; typically, it is identically equal to 1.

See examples in section 4.

□

`generate(newvar)` specifies the name of the new variable to contain the raked weights. `generate()` or `replace` is required.

`replace` indicates that the weight variable supplied in the `[pw=varname]` expression should be overwritten with the new weights. `replace` or `generate()` is required.

### Options to control convergence

#### □ Technical note

Convergence in `ipfraking` is defined in terms of the maximum relative change in weights:

$$D_k = \max_{j \in \mathcal{S}} \frac{|w_j^{k,p} - w_j^{k-1,p}|}{w_j^{k-1,p}} \quad (12)$$

When  $D_k$  is small,  $D_k < \delta_D$ , it means that the weights stop changing between iterations; that is, the algorithm came to its steady state. On the other hand, if  $D_k > D_{k-1}$ , it means that the algorithm may start diverging, at which point it might be reasonable to terminate it. See step 9 of algorithm 2 in section 1.7.

Once the algorithm terminates, it also checks whether the control totals are satisfied. Specifically, for each of the control total matrices  $M_1, \dots, M_p$ , the relative difference versus the corresponding weighted sample totals  $\widehat{M}_1, \dots, \widehat{M}_p$  is computed with

$$m_c = \text{mreldif}(\widehat{M}_c, M_c)$$

where the maximum relative difference of two matrices is

$$\text{mreldif}(A, B) = \max_{ij} \frac{|a_{ij} - b_{ij}|}{1 + |b_{ij}|}$$

as defined in [D] **functions**. A control relation is satisfied if  $m_c < \delta_T$ ; otherwise, a warning is issued. See step 12 of algorithm 2 in section 1.7.

Iterations continue until one of the following:  $k = K$ , a specified number of iterations,  $D_k < \delta_D$ , or  $D_k > D_{k-1}$ . □

`tolerance(#)` defines the  $D_k$ -convergence criterion, that is,  $\delta_D$ . Convergence will be declared if the largest relative difference of the weights in two successive iterations (a full cycle over all raking variables) does not exceed this value. The default is `tolerance(0.000001)`.

`iterate(#)` specifies the maximum number of iterations for the algorithm. The default is `iterate(2000)`.

`nodivergence` overrides the check that  $D_k > D_{k-1}$ , that is, ignores this termination condition.

`ctrltolerance(#)` defines the criterion  $\delta_T$  to assess the accuracy of the control totals. If, upon convergence of the algorithm (see the `tolerance()` option), the relative difference of the weighted totals and means and the control totals and means is greater than this value, an error message will be issued. The default is `ctrltolerance(0.000001)`.

`trace` produces the trace plot to show how the control total discrepancy changes with the iteration number; see section 4.4.

`alpha(#)` changes the adjustment factor to  $(\text{factor})^\alpha$ .

### Trimming options

`trimhiabs(#)` specifies the upper bound  $U$  on the greatest value of the raked weights.

The weights that exceed this value will be trimmed down so that  $w_{3j} \leq U$  for every  $j \in \mathcal{S}$ .

`trimhirel(#)` specifies the upper bound  $u$  on the adjustment factor over the baseline weight. The weights that exceed the baseline times this value will be trimmed down so that  $w_{3j} \leq uw_{1j}$  for every  $j \in \mathcal{S}$ .

`trimloabs(#)` specifies the lower bound  $L$  on the smallest value of the raked weights. The weights that are smaller than this value will be increased so that  $w_{3j} \geq L$  for every  $j \in \mathcal{S}$ .

`trimlorel(#)` specifies the lower bound  $l$  on the adjustment factor over the baseline weight. The weights that are smaller than the baseline times this value will be increased so that  $w_{3j} \geq lw_{1j}$  for every  $j \in \mathcal{S}$ .

`trimfrequency(keyword)` specifies when the trimming operations are to be performed. *keyword* can be one of the following:

**often** means that trimming will be performed after each marginal adjustment, that is, within each iteration of the inner cycle inside step 5 of algorithm 2.

**sometimes** means that trimming will be performed after a full set of variables has been used for poststratification, that is, at the end of each outer cycle iteration at step 8 of algorithm 2. The default is `trimfrequency(sometimes)`.

**once** means that trimming will be performed after the outer loop converges at step 11 of algorithm 2.

The numeric trimming options `trimhiabs(#)`, `trimhirel(#)`, `trimloabs(#)`, and `trimlorel(#)` can be specified in any combination or can be entirely omitted to produce untrimmed weights. By default, there is no trimming. See section 4.3 for examples.

### Miscellaneous options

`double` specifies that the new variable named in the `generate()` option should be generated as a double type (see [D] **data types**).

`meta` puts the names of the control vectors and the achieved control accuracies  $m_c$  as characteristics stored with the variable specified in the `generate()` option; see section 4.5.

`nograph` omits the histogram of the calibrated weights, which can be used to speed up `ipfraking` once the diagnostics on the weights are completed (for example, in replicate-weight production).

`loglevel(#)` specifies the level of detail in the output. `#` can be one of the following:

0 specifies that only the iteration log will be produced. The default is `loglevel(0)`.

1 provides additional output on the intermediate trimming steps.

2 provides a lot of detailed (and not always useful) output.

## 3 Utility programs

Aside from the main weight calibration program, the `ipfraking` package also provides two utility programs to create and manipulate `ipfraking`-compatible matrices.

### 3.1 The `mat2do` command

#### Syntax

```
mat2do matrix_name using filename [, replace append list type]
```

#### Description

`mat2do` stores the values and the attributes (row and column names) of a Stata matrix as a do-file. By running this do-file, one can fully reproduce the matrix. The names of the matrix and the do-file are required.

#### Options

`replace` overwrites the existing do-file.

`append` adds the code to the existing do-file.

`list` adds the `matrix list` command to the end of the do-file so that when *filename* is executed, the listing is provided for verification.

`type` lists the matrix and the resulting do-file.



## 3.2 The xls2row command

### Syntax

```
xls2row matrix_name using filename, cellrange(start:end) sheet(name)
      over(varname) [ scale(#) ]
```

### Description

The utility program `xls2row` reads the calibration totals from the specified Excel file and stores them in the matrix *matrix\_name*. The name of the Excel file, the range of cells, and the name of the sheet from which to take the values are required; they are specified in the same way as in `import excel` (see [D] `import excel`). Mathematically, `xls2row` performs a vector transformation of the matrix read from an Excel sheet, that is, stores the result by columns. The `matrix coleq` of the resulting matrix is the naming convention `_one`.

To optimize performance, `xls2row` relies on `preserve` as an intermediate step. It is thus advisable to run `xls2row` up front before loading potentially large datasets that would otherwise be written to disk and restored several times.

### Options

`cellrange(start:end)` specifies a range of cells in an Excel file, for example, `B2:D15`. `cellrange()` is required.

`sheet(name)` specifies the name of a sheet from which to take values in an Excel file. `sheet()` is required.

`over(varname)` is the variable corresponding to the control total being imported from Excel. The columns of the resulting row vector *matrix\_name* will be labeled with the values of *varname* (that is, as the `matrix colname` of the matrix *matrix\_name*), and *varname* itself will appear as the `matrix rowname` of the matrix *matrix\_name*. If the number of categories of *varname* does not match the number of nonmissing imported values, an error message will be issued, and the target matrix will not be created. `over()` is required.

`scale(#)` scales the entries of the resulting row vector so that they sum to *#*.

## 4 Examples

### 4.1 Basic syntax and input requirements

In this very simple example, I will demonstrate the basic mechanics of `ipfraking`, its input requirements, and its output. The following examples are intended to demonstrate only the syntax and the output of `ipfraking`; they may or may not provide substantively meaningful results.

#### ► Example 1

We will work with the standard example of `svy` data, an excerpt from the Second National Health and Nutrition Examination Survey (NHANES II) dataset available from the StataCorp website. We will introduce some small changes to the data so that `ipfraking` will have some work to do.

```
. use http://www.stata-press.com/data/r13/nhanes2
. generate byte _one = 1
. svy: total _one, over(sex, nolabel)
(running total on estimation sample)
Survey: Total estimation
Number of strata =      31      Number of obs   =      10351
Number of PSUs  =      62      Population size = 117157513
                                   Design df      =          31

      1: sex = 1
      2: sex = 2
```

	Over	Total	Linearized Std. Err.	[95% Conf. Interval]	
<code>_one</code>					
	1	5.62e+07	1377465	5.34e+07	5.90e+07
	2	6.10e+07	1396159	5.82e+07	6.38e+07

```
. matrix NHANES2_sex = e(b)
. matrix rownames NHANES2_sex = sex
```

```
. svy: total _one, over(race, nolabel)
(running total on estimation sample)
Survey: Total estimation
Number of strata =      31      Number of obs   =      10351
Number of PSUs  =      62      Population size = 117157513
                                   Design df      =          31

      1: race = 1
      2: race = 2
      3: race = 3
```

Over	Linearized				
	Total	Std. Err.	[95% Conf. Interval]		
_one	1	1.03e+08	2912042	9.71e+07	1.09e+08
	2	1.12e+07	1458814	8213964	1.42e+07
	3	2968728	1252160	414930.1	5522526

```
. matrix NHANES2_race = e(b)
. matrix rownames NHANES2_race = race
. matrix NHANES2_sex[1,1] = NHANES2_sex[1,1]*1.25
. matrix NHANES2_race[1,1] = NHANES2_race[1,1]*1.4
```

Let us now look at the matrices that will serve as an input to the raking procedure:

```
. matrix list NHANES2_sex, f(%12.0g)
NHANES2_sex[1,2]
      _one:      _one:
        1         2
sex  70199350  60998033
. matrix list NHANES2_race, f(%12.0g)
NHANES2_race[1,3]
      _one:      _one:      _one:
        1         2         3
race 144199368.6  11189236  2968728
```

These input matrices are organized as follows. Input matrices always have a single row, just as estimation results  $e(b)$  do. The column names follow the naming conventions of  $e(b)$ , namely, the name of the variable for which the total is being computed (here `_one`) and the numeric categories of the variable that was used in the `over()` option (here `sex`, with values 1 for male and 2 for female, and `race`, with values 1 for white, 2 for black, and 3 for other). These values must be in an increasing order. Because that variable is not stored in  $e(b)$  per se, it needs to be added to this matrix, which is done in the form of the row name. The entries of the matrix are the totals to which the weights in the categories of the control variables need to sum. In this example, they are scaled to be the population totals. Alternatively, these can be made to sum to the sample size, as is done sometimes in public opinion research, or to 1, which is what the `proportion` estimation command would produce.

The input requirements in terms of control totals are thus made as simple as possible. If a higher-quality survey is available, the survey statistician simply needs to obtain the

totals for the categories of the control variables by using `svy: total ... , over(..., nolabel)` and save the name of that variable along with the matrix. Note that the `total` is computed with the `over(..., nolabel)` suboption to suppress the otherwise informative labeling of the categories; `ipfraking` expects the numeric values of the categories to be column names (see [P] `matrix rownames`). The name of the matrix itself is immaterial, but it is a good programming practice to have informative names (McConnell 2004). Thus the names of the matrices in the examples generally follow the naming convention `data_source.variable`.

We are now ready to run `ipfraking` and see what it produces:

```
. ipfraking [pw=finalwgt], ctotal(NHANES2_sex NHANES2_race) generate(rakedwgt1)
Warning: the totals of the control matrices are different:
  Target 1 (NHANES2_sex) total      =      131197383
  Target 2 (NHANES2_race) total     =      158357332.6
Iteration 1, max rel difference of raked weights = .56227988
Iteration 2, max rel difference of raked weights = .00073288
Iteration 3, max rel difference of raked weights = 2.356e-07
Warning: the controls NHANES2_sex did not match

Summary of the weight changes
```

	Mean	Std. dev.	Min	Max	CV
Orig weights	11318	7304	2000	79634	.6453
Raked weights	15299	10274	1914	90831	.6716
Adjust factor	1.3490		0.8846	1.5614	

In this simple case with just two control variables and the control totals that are not very different from the existing sample totals, the procedure converged very quickly in three iterations. A diagnostic message was produced up front by `ipfraking` that informed about apparent differences in total population counts as obtained from the different control total matrices. As a result, the control totals for the variable that was adjusted first (`sex`) could not match the required control totals even after the weights converged in the sense of differing little between iterations. Both of these warnings are produced only when problems are encountered.

The summary table is always produced and shows some relevant characteristics of the original weights  $w_{1j}$ , the raked weights  $w_{3j}$ , and the raking ratios  $w_{3j}/w_{1j}$ . As expected, the CV went up from 0.645 to 0.672.

The graphic output produced by `ipfraking` is shown in figure 1. Generally, we want to inspect these graphs to see whether there are any unexpected patterns, such as highly outlying values, gaps in the distribution (here there are only 6 distinct values of the adjustment factor corresponding to the  $2 \times 3$  combinations of the control variables), or concentration near the limits of the weight range, as is typical for trimmed weights (see section 4.3 below). These graphs also may inform later trimming decisions: the trimming limits can be chosen to conform to the breaks in the distributions of the untrimmed raked weights.

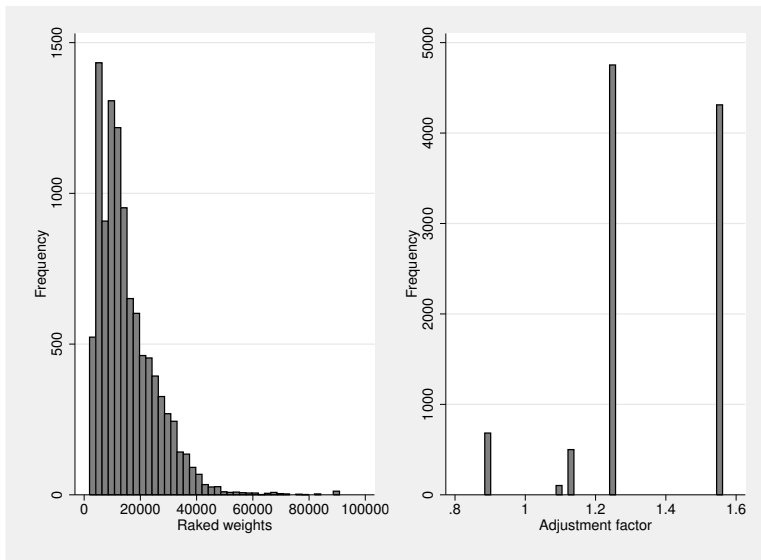


Figure 1. Histograms of the raked weights and calibration ratios, example 1

◀

## 4.2 Preparing control matrices from scratch

In many situations, the control totals will be obtained from outside Stata and need to be prepared to work with `ipfraking`.

### ► Example 2

Suppose we wanted to calibrate the NHANES II dataset to the latest control totals available from the U.S. Census Bureau website. Using the tables S0101 from the 2011 American Community Survey 1-year estimates and NST-EST2011 from the U.S. Census Bureau population projections, the latest available at the time of writing this article, we can obtain the figures displayed in table 1.

Table 1. Control totals for the 2011 U.S. population

Group	Population
American Community Survey 2011 1-year estimates, table S0101	
Male, total	153,267,860
Ages 20–39	27.4%
Ages 40–59	27.5%
Ages 60+	17.3%
Female, total	158,324,057
Ages 20–39	26.0%
Ages 40–59	27.6%
Ages 60+	20.7%
U.S. Census Bureau 2011 projections, table NST-EST2011-01	
Northeast	55,521,598
Midwest	67,158,835
South	116,046,736
West	72,864,748
U.S. Census Bureau 2011 projections, table NC-EST2011-03	
White	243,470,497
Black	40,750,746
Other	27,370,674
Total	311,591,917

Thus we have information in the two-way age-by-sex table as well as two additional margins. We will need an additional sex-by-age group variable, and we will try to make its values somewhat informative (for example, the value 12 of the variable `sex_age` means the first group of sex and the second group of age):

```
. generate byte age_grp = 1 + (age>=40) + (age>=60) if !mi(age)
. generate sex_age = sex*10 + age_grp
```

With that, the matrices will have to be defined explicitly, and their labels need to be hand coded, too (see [P] **matrix rownames**). Note that the U.S. Census Bureau 2011 projections relate to the total population, while the target population of the study is the population age 20+. Assuming that the age structure is the same across regions and races, the control totals for region and race need to be rescaled to the adult population to avoid the warning messages. (More accurate figures can be obtained from American Community Survey microdata, which can be downloaded from the U.S. Census Bureau website.)

```

. matrix ACS2011_sex_age = (
> 153267860*0.274, 153267860*0.275, 153267860*0.173, // males
> 158324057*0.260, 158324057*0.276, 158324057*0.207 // females
> )

. matrix colnames ACS2011_sex_age = 11 12 13 21 22 23
. matrix coleq ACS2011_sex_age = _one
. matrix rownames ACS2011_sex_age = sex_age
. scalar ACS2011_total_pop = 311591917
. matrix ACS2011_adult_pop = ACS2011_sex_age * J(colsof(ACS2011_sex_age),1,1)
. matrix Census2011_region = (55521598, 67158835, 116046736, 72864748)
. matrix Census2011_region = Census2011_region * ACS2011_adult_pop /
> ACS2011_total_pop

. matrix colnames Census2011_region = 1 2 3 4
. matrix coleq Census2011_region = _one
. matrix rownames Census2011_region = region
. matrix Census2011_race = (243470497, 40750746, 27370674)
. matrix Census2011_race = Census2011_race * ACS2011_adult_pop /
> ACS2011_total_pop

. matrix colnames Census2011_race = 1 2 3
. matrix coleq Census2011_race = _one
. matrix rownames Census2011_race = race

```

Let us check the matrix entries and labels once again before producing the weights. Note that the values of the control variable categories are given in an increasing order.

```

. matrix list ACS2011_sex_age, f(%10.0g)
ACS2011_sex_age[1,6]
      _one:      _one:      _one:      _one:      _one:      _one:
      11      12      13      21      22      23
sex_age 41995394 42148662 26515340 41164255 43697440 32773080
. matrix list Census2011_region, f(%10.0g)
Census2011_region[1,4]
      _one:      _one:      _one:      _one:
      1      2      3      4
region 40679030 49205289 85024007 53385843
. matrix list Census2011_race, f(%11.0g)
Census2011_race[1,3]
      _one:      _one:      _one:
      1      2      3
race 178383622 29856864.7 20053682.2

```

The labels appear to be in place, so let us run `ipfraking`:

```
. ipfraking [pw=finalwgt], generate(rakedwgt2)
> cttotal(ACS2011_sex_age Census2011_region Census2011_race)

Iteration 1, max rel difference of raked weights = 14.95826
Iteration 2, max rel difference of raked weights = .19495004
Iteration 3, max rel difference of raked weights = .02204455
Iteration 4, max rel difference of raked weights = .00315355
Iteration 5, max rel difference of raked weights = .00043857
Iteration 6, max rel difference of raked weights = .00006061
Iteration 7, max rel difference of raked weights = 8.365e-06
Iteration 8, max rel difference of raked weights = 1.154e-06
Iteration 9, max rel difference of raked weights = 1.593e-07
```

Summary of the weight changes

	Mean	Std. dev.	Min	Max	CV
Orig weights	11318	7304	2000	79634	.6453
Raked weights	22055	19227	4050	338675	.8717
Adjust factor	2.1464		0.9264	18.3694	

The diagnostic plots for these weights are given in figure 2. They do appear to have some outlying cases (which are not very clearly seen on these plots, because they are single-count observations with outlying weights), and we will address them in the next section with trimming.

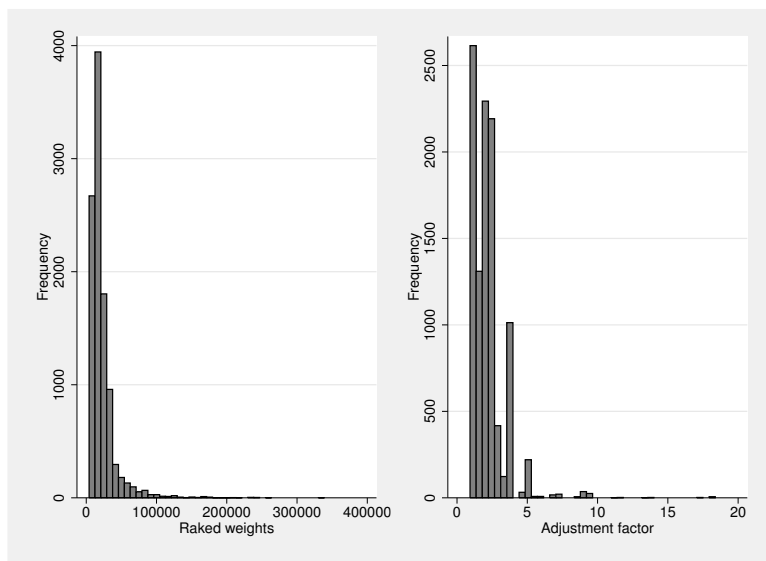


Figure 2. Histograms of the raked weights and calibration ratios, example 2



### 4.3 Trimming options

As discussed in section 1.7 above, if variability of the weights becomes excessive, the weights can be trimmed by restricting the extremes. When one uses `ipfraking` trimming options, upper and lower limits can be defined for either the absolute values of the weights or the relative changes from the base weights. The frequency of the trimming operations can also be controlled. Trimming can be applied once to the final data (`trimfreq(once)`) at step 11 of algorithm 2. Alternatively, trimming can be applied after every full cycle over variables at step 8 of algorithm 2. Finally, trimming can be applied after each subiteration at step 5 of the algorithm.

#### ► Example 3

When we inspect the histograms in figure 2, it appears reasonable to restrict the upper tail of the raked weights. A more detailed investigation of the histogram reveals a somewhat greater concentration of the raked weights around the value of 160,000 and sparse bars beyond 200,000. This latter number will be used as the top cutoff point for trimming and is provided as an input to `ipfraking` via the `trimhiabs()` option. Let us also specify the absolute lower bound of 2,000, which is the minimum of the original weights; however, as the output in the previous example suggested, the calibrated weights tend to run above 4,000, so specifying the lower limit as `trimloabs(2000)` may not really affect the calibration procedure.

```
. ipfraking [pw=finalwgt], generate(rakedwgt3)
> cttotal(ACS2011_sex_age Census2011_region Census2011_race)
> trimhiabs(200000) trimloabs(2000)

Iteration 1, max rel difference of raked weights = 14.95826
Iteration 2, max rel difference of raked weights = .21474256
Iteration 3, max rel difference of raked weights = .02754514
Iteration 4, max rel difference of raked weights = .00511347
Iteration 5, max rel difference of raked weights = .00095888
Iteration 6, max rel difference of raked weights = .00018036
Iteration 7, max rel difference of raked weights = .00003391
Iteration 8, max rel difference of raked weights = 6.377e-06
Iteration 9, max rel difference of raked weights = 1.199e-06
Iteration 10, max rel difference of raked weights = 2.254e-07

Summary of the weight changes
```

	Mean	Std. dev.	Min	Max	CV
Orig weights	11318	7304	2000	79634	.6453
Raked weights	22055	18908	4033	200000	.8573
Adjust factor	2.1486		0.9220	18.9828	

The resulting CV of weights, 0.857, is slightly better than that with unrestricted range of weights, 0.872. The summary also shows that the weights were capped at 200,000, as requested.

Setting the absolute limits on the range of the raked weights is often very subjective. A somewhat better plan might be to set limits in terms of the range of the adjustment factors, as shown in the next example. The relative change in the weights can be

bounded with the `trimlorel()` and `trimhirel()` options. We also demonstrate here how to use the results of `summarize` to feed into `ipfraking`. While ensuring that accurate numbers are being carried over in the context of the code, the approach is fragile for interactive work: simply running the single line with the sole `ipfraking` command that refers to the `r()` return values may break down if `summarize` was not the immediately preceding command.

```
. summarize finalwgt
```

Variable	Obs	Mean	Std. Dev.	Min	Max
finalwgt	10351	11318.47	7304.04	2000	79634

```
. ipfraking [pw=finalwgt], generate(rakedwgt4)
> ctototal(ACS2011_sex_age Census2011_region Census2011_race)
> trimhiabs(`=2.5*r(max)` ) trimloabs(`=r(min)` ) trimhirel(6)
Iteration 1, max rel difference of raked weights = 5
Iteration 2, max rel difference of raked weights = .25592859
Iteration 3, max rel difference of raked weights = .0626759
Iteration 4, max rel difference of raked weights = .0158786
Iteration 5, max rel difference of raked weights = .00299304
Iteration 6, max rel difference of raked weights = .00070812
Iteration 7, max rel difference of raked weights = .00016401
Iteration 8, max rel difference of raked weights = .00003734
Iteration 9, max rel difference of raked weights = 8.434e-06
Iteration 10, max rel difference of raked weights = 1.898e-06
Iteration 11, max rel difference of raked weights = 4.265e-07
Warning: the controls ACS2011_sex_age did not match
Warning: the controls Census2011_region did not match
Warning: the controls Census2011_race did not match

Summary of the weight changes
```

	Mean	Std. dev.	Min	Max	CV
Orig weights	11318	7304	2000	79634	.6453
Raked weights	21830	18115	4113	199085	.8298
Adjust factor	2.1323		0.8973	6.0000	

◀

Setting the trimming options too aggressively may lead to adverse consequences. First, it may bias the estimates, as discussed in section 1.6. Second, as this example demonstrates, it can impede (statistical) convergence: the output contains multiple warnings about targets not being achieved within desired accuracy, while no problems were encountered without trimming.

#### 4.4 Tracking convergence

Let us now examine the issue of trimming frequency and demonstrate another diagnostic plot that can be produced by `ipfraking`.

► **Example 4**

We return to the first set of options of example 3 and rerun the raking procedure.

```
. capture drop rakedwgt3
. ipfraking [pw=finalwgt], generate(rakedwgt3)
> ctotals(ACS2011_sex_age Census2011_region Census2011_race)
> trimhiabs(200000) trimloabs(2000) trimfreq(sometimes) trace

Iteration 1, max rel difference of raked weights = 14.95826
Iteration 2, max rel difference of raked weights = .21474256
Iteration 3, max rel difference of raked weights = .02754514
Iteration 4, max rel difference of raked weights = .00511347
Iteration 5, max rel difference of raked weights = .00095888
Iteration 6, max rel difference of raked weights = .00018036
Iteration 7, max rel difference of raked weights = .00003391
Iteration 8, max rel difference of raked weights = 6.377e-06
Iteration 9, max rel difference of raked weights = 1.199e-06
Iteration 10, max rel difference of raked weights = 2.254e-07
```

Summary of the weight changes

	Mean	Std. dev.	Min	Max	CV
Orig weights	11318	7304	2000	79634	.6453
Raked weights	22055	18908	4033	200000	.8573
Adjust factor	2.1486		0.9220	18.9828	

The `trace` option requests that trace plots be added to the diagnostic plots, as shown in figure 3. The trace plots are presented on the absolute scale and on the log scale. The exponentially declining discrepancy appears to be a general phenomenon. In other words, after the first few iterations, discrepancy between the currently weighted totals and the control totals roughly follows the rate of  $\text{const} \times \alpha^k$  for some  $\alpha < 1$ , where  $k$  is the (outer cycle) iteration number. When convergence is very slow or the sample size is very large, this rule may be helpful in determining the number of iterations necessary to achieve the required accuracy and, hence, the expected computing time. Zero cross-cells and collinearity between the control variables may make the convergence factor  $\alpha$  close to 1, thus hampering convergence. This happens when the control variables have very similar meaning, such as age and grade of children: it is impossible to have children of age 8 in grade 10. Also sets of interactions of categorical variables, such as interactions of age group and education along with age group and race, are guaranteed to produce zero cells in the cross-tabulation: it is impossible to have any observations in the cells defined by, say, “age under 40 interacted with higher education” on one margin against “age above 60 interacted with white race” on the other.

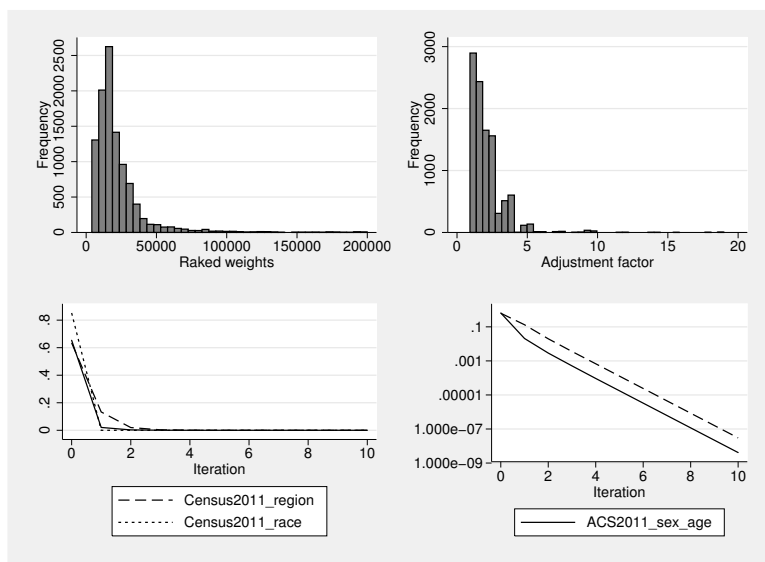


Figure 3. Diagnostic plots for example 4

While `trimfreq(sometimes)` is the default in the presence of other trimming options, the behavior can be changed with explicit specification of trimming frequency. Note that slightly different weights will be produced that way.

```
. ipfraking [pw=finalwgt], generate(rakedwgt5)
> cttotal(ACS2011_sex_age Census2011_region Census2011_race)
> trimhiabs(200000) trimloabs(2000) trimfreq(often) trace
```

```
Iteration 1, max rel difference of raked weights = 14.95826
Iteration 2, max rel difference of raked weights = .21613885
Iteration 3, max rel difference of raked weights = .02673316
Iteration 4, max rel difference of raked weights = .00480164
Iteration 5, max rel difference of raked weights = .00086195
Iteration 6, max rel difference of raked weights = .00015444
Iteration 7, max rel difference of raked weights = .00002762
Iteration 8, max rel difference of raked weights = 4.940e-06
Iteration 9, max rel difference of raked weights = 8.832e-07
```

Summary of the weight changes

	Mean	Std. dev.	Min	Max	CV
Orig weights	11318	7304	2000	79634	.6453
Raked weights	22055	18905	4033	200000	.8572
Adjust factor	2.1487		0.9220	18.9844	

```
. compare rakedwgt3 rakedwgt5
```

	count	minimum	difference average	maximum
rakedwgt3<rakedwgt5	3638	-15.28125	-1.226752	-.0126953
rakedwgt3=rakedwgt5	12			
rakedwgt3>rakedwgt5	6701	.0009766	.6660518	2471.578
jointly defined	10351	-15.28125	.000028	2471.578
total	10351			

In this example, trimming the weights after adjusting each of the margins led to fewer iterations. This may or may not translate to lower overall computing times because more computing is performed within each iteration.

◀

## 4.5 Metadata

The results of raking operations can be stored with the newly created weight variables for later review and reproduction of the results. Let us reproduce the example in the previous section, adding all the metadata available:

### ▶ Example 5

```
. capture drop rakedwgt3
. ipfraking [pw=finalwgt], generate(rakedwgt3)
> ctotals(ACS2011_sex_age Census2011_region Census2011_race)
> trimhiabs(200000) trimloabs(2000) meta

Iteration 1, max rel difference of raked weights = 14.95826
(output omitted)

Iteration 10, max rel difference of raked weights = 2.254e-07

Summary of the weight changes
```

	Mean	Std. dev.	Min	Max	CV
Orig weights	11318	7304	2000	79634	.6453
Raked weights	22055	18908	4033	200000	.8573
Adjust factor	2.1486		0.9220	18.9828	

```

. char li rakedwgt3[]
rakedwgt3[command]:      [pw=finalwgt], generate(rakedwgt3)
> cttotal(ACS2011_sex_age C..
rakedwgt3[trimloabs]:    trimloabs(2000)
rakedwgt3[trimhiabs]:    trimhiabs(200000)
rakedwgt3[trimfrequency]: sometimes
rakedwgt3[objfcn]:       2.25435521164e-07
rakedwgt3[maxctrl]:      3.00266819571e-08
rakedwgt3[converged]:    1
rakedwgt3[Census2011_race]: 7.48567522438e-09
rakedwgt3[Census2011_region]:
                          3.00266819571e-08
rakedwgt3[ACS2011_sex_age]: 4.13778301743e-09
rakedwgt3[notel]:        Raking controls used: ACS2011_sex_age
> Census2011_regio..
rakedwgt3[note0]:        1

```

◀

The following characteristics are stored with the newly created weight variable (see [P] **char**):

<code>command</code>	the full command as typed by the user
<code>matrix name</code>	the relative matrix difference from the corresponding control total; see [D] <b>functions</b>
<code>trimhiabs()</code> , <code>trimloabs()</code> , <code>trimhirel()</code> , <code>trimlorel()</code> , <code>trimfrequency()</code>	corresponding trimming options, if specified
<code>maxctrl</code>	the greatest <code>mreldif</code> between the targets and the achieved weighted totals
<code>objfcn</code>	the value of the relative weight change $D_k$ (12) at exit
<code>converged</code>	whether <code>ipfraking</code> exited because of convergence (1) or whether because of an increase in the objective function or reaching the limit on the number of iterations (0)

Also `ipfraking` stores the notes regarding the control matrices used and which of the margins did not match the control totals, if any (see [D] **notes**).

## 4.6 Replicate weights

As discussed in section 1.5, one of the greater challenges of weight calibration is ensuring that variance estimates take into account the greater precision achieved by adjusting the sample toward the fixed population quantities. Because estimating the variances using linearization is cumbersome, replicate variance estimation may be more attractive.

### ▶ Example 6

The simplest code for calibrated replicate weights is obtained by calling `ipfraking` from within `bsweights` (Kolenikov 2010), which can pass the name of a replicate-weight

variable to an arbitrary calibration routine. In this example, we will use the same settings as in section 4.2; thus we will use the calibrated weight `rakedwgt2`, which was produced in that example, as the main weight for which the bootstrap weights provide the measure of sampling variability.

```
. set rmsg on
r; t=0.00 9:51:00
. set seed 2013
r; t=0.00 9:51:00
. bsweights bsw, reps(310) n(-1) balanced dots
> calibrate(ipfraking [pw=@], replace nograph meta
> ctotat(ACS2011_sex_age Census2011_region Census2011_race))
Balancing within strata:
.....
Rescaling weights
..... 50
..... 100
..... 150
..... 200
..... 250
..... 300
.....
r; t=265.05 9:55:25
. forvalues k=1/310 {
2.   _dots `k' 0
3.   assert `: char bsw`k'[converged]' == 1
4.   assert `: char bsw`k'[maxctrl]' < 10*c(epsfloat)
5. }
..... 50
..... 100
..... 150
..... 200
..... 250
..... 300
.....r; t=0.37 9:55:25
. svyset [pw=rakedwgt2], vce(bootstrap) bsrw(bsw*) dof(31)
    pweight: rakedwgt2
      VCE: bootstrap
      MSE: off
    bsrweight: bsw1 bsw2 bsw3 bsw4 bsw5 bsw6 bsw7 bsw8 bsw9 bsw10 bsw11 bsw12
(output omitted)
          bsw301 bsw302 bsw303 bsw304 bsw305 bsw306 bsw307 bsw308 bsw309
          bsw310
    Design df: 31
    Single unit: missing
      Strata 1: <one>
        SU 1: <observations>
          FPC 1: <zero>
r; t=0.01 9:55:25
. set rmsg off
```

The options of `bsweights` request 310 replicate weights (a multiple of 31 strata), resample one fewer PSU than available in a given stratum, and obtain the first-order balance within a stratum. With the two PSU/stratum design and these options, `bsweights`







## 5 Error messages and troubleshooting

### 5.1 Critical errors

The following critical errors will stop execution of `ipfraking`:

- **pweight is required**  
The `[pweight=...]` component of `ipfraking` syntax is required. Probability weights must be specified as inputs to `ipfraking`.
- **ctotal() is required**  
The `ctotal()` option of `ipfraking` syntax is required. Names of the matrices containing the control totals must be specified.
- **one and only one of generate() or replace must be specified**  
Either the `generate()` option with the name of the new variable must be supplied to `ipfraking` or `replace` to replace the variable specified in the `[pw=...]` statement must be supplied to `ipfraking`. Both may not be specified.
- **raking procedure appears diverging**  
The maximum relative difference of weights,  $D_k$ , has increased from the previous iteration. This may or may not indicate a problem. Rerun `ipfraking` with the `nodivergence` option to override the warning.
- **cannot process matrix *matrix\_name***  
For whatever reason, `ipfraking` could not process this matrix. The matrix may not have been defined or the variables in this matrix cannot be found.
- **variable *varname* corresponding to the control matrix *matrix\_name* not found**  
The variables contained in row or column names of this matrix cannot be found.
- ***varname1* and *varname2* variables are not compatible**  
When `total varname1, over(varname2)` was run, an error was encountered. One of the variables may be a string variable or have missing values resulting in an empty estimation sample.
- **categories of *varname* do not match in the control *matrix\_name* and in the data (nolab option)**  
There was a mismatch in the categories of *varname* found in the data and in the control matrix *matrix\_name*. This could happen for any of the following reasons: 1) there were more categories in one than in the other; 2) the entries are in the wrong order in the control matrix; 3) the labels in the control matrix do not correspond to the category values in the dataset; or 4) the control matrix was obtained via `total varname2, over(varname)`, but the `nolabel` suboption

of `over()` was omitted, and the labels of the control matrix may include some unexpected text. Tabulate *varname* without labels, and compare the results with the matrix listing of the *matrix\_name*.

- `cannot compute controls for matrix_name over varname with the current weights`

This is a generic error message that something bad happened while `ipfraking` was computing the totals for the current set of weights. This error message is generally rare, but because computing the totals may be the slowest operation of the iterative optimization process, stopping `ipfraking` with a `Ctrl+Break` combination or the **Break** graphical user interface button may produce this error message.

- `trimhiabs|trimloabs|trimhirel|trimlorel must be a positive number`  
One or more of the trimming options are given as a nonpositive number or a nonnumber.
- `trimhiabs must be greater than trimloabs`  
`trimhirel must be greater than trimlorel`

The trimming parameters are illogical (the lower bound is greater than the upper bound). Respecify the values of the trimming parameters.

## 5.2 Other errors and warnings

The following warning messages may be produced by `ipfraking`. The program will continue running, but you must double-check the results for potential problems.

- `the totals of the control matrices are different`

The sums of values of the control matrices are different. These sums will be listed for review. Convergence is still possible, but some of the control total checks are likely to fail.

- `trimfrequency() option is specified without numeric settings; will be ignored`

The option `trimfrequency()` was specified without any numeric trimming options. There is no way to interpret this, and `ipfraking` will proceed without trimming.

- `trimfrequency() option is specified incorrectly, assume default value (sometimes)`

The `trimfrequency()` option contains something other than `often`, `sometimes`, or `once`, and the default value is being used instead.

- **raking procedure did not converge**

The maximum number of iterations was reached, but weights never met the convergence criteria (see step 9 of algorithm 2 in section 1.7). The user may want to increase the number of iterations or relax convergence criteria.

- **the controls *matrix\_name* did not match**

After convergence of weights was declared, `ipfraking` checked the control totals again and found that the results differed from the target for one or more of the control total matrices. Any of the following can cause this: 1) the sum of entries of this particular matrix differs from the others; 2) the trimming options are too restrictive and do not allow the weights to adjust enough; or 3) the problem may not have a solution because of incompatible control totals or a bad sample.

- **division by zero weighted total encountered with *matrix\_name* control**

The weights for a category of the control variable summed to 0. `ipfraking` will skip the calibration of this variable and proceed to the next one.

- **# missing values of *varname* encountered; convergence will be impaired**

A control variable has missing values in the calibration sample. `ipfraking` cannot figure out how to deal with the weights for the observations with missing values. The user would need to restrict the sample to nonmissing values of all control variables, to impute the missing values, or to create a separate category for the missing values of a given control variable (which may lead to difficulties in defining valid population control totals for it).

## 6 Acknowledgments

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**About the author**

Stanislav (Stas) Kolenikov is a principal survey scientist at Abt SRBI. His research interests include application of statistical methods in public opinion, behavioral, and health survey research, such as advanced sampling techniques, survey weighting, calibration, missing-data imputation, and variance estimation. Aside from survey statistics, Stas has extensive experience developing and applying statistical methods in social sciences, with focus on structural equation modeling and microeconometrics. He has been writing Stata programs since 1998, when Stata was version 5.

## Appendix: Common notation

$\mathcal{C}_k$	Section 1.3	Calibration cell
$D_k$	(12)	Maximum relative difference of weights from iteration $k - 1$ to iteration $k$
$\delta_D$	Section 1.7	Convergence criteria for $D_k$
$\delta_T$	Section 1.7	Quality control criteria for control totals
$i$	Section 1.1	Subscript $i$ usually applies to units in population
$j$	Section 1.1	Subscript $j$ usually applies to units in sample
$k$	Section 1.7	The outer cycle iteration number
$K$	Section 1.7	The maximum number of the outer cycle iterations
$l$	Section 1.7	Relative limit on weights: all the weights will be made $\geq (l \times \text{the input weight})$
$l$		Summation index, where I run out of other traditional integer letters
$L$	Section 1.7	Absolute limit on weights: all the weights will be made $\geq L$
$n$		Sample size; number of sampled units
$N$		Population size; number of units in population or frame
$\pi_i$		Probability of selection of unit $i$ specified by the sampling design
$\mathcal{S}$	Section 1.1	Sample; set of sampled units
$T(y)$	(1)	Population-based total of variable ( $y$ )
$t_m(y)$	(3)	Sample-based weighted estimate of the total $T(y)$ ; subscript $m = 1, 2, 3$ indicates the type of weights used in computing the total
$u$	Section 1.7	Relative upper limit on weights: all the weights will be made $\leq (u \times \text{the input weight})$
$U$	Section 1.7	Absolute upper limit on weights: all the weights will be made $\leq U$
$\mathcal{U}$	Section 1.1	Universe or population; set of units in population
$w_{1i}$	(2)	Probability (design) weights; inverse probability of selection
$w_{2j}$	(4)	Poststratified weights; random; depend on group sizes in sample; analytically computable
$w_{3j}$	Section 1.3	Calibrated (raked) weights; random; require iterative optimization
$x_v$	Section 1.4	The $v$ th calibration (control) variable, $v = 1, \dots, p$ ; population total $T(x_v)$ known