

# Some details on two-phase variances

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This document explains the computation of variances for totals in two-phase designs. Variances for other statistics are computed by the delta-method from the variance of the total of the estimating functions.

The variance formulas come from conditioning on the sample selected in the first phase

$$\text{var}[\hat{T}] = E \left[ \text{var} \left[ \hat{T} | \text{phase 1} \right] \right] + \text{var} \left[ E \left[ \hat{T} | \text{phase 1} \right] \right]$$

The first term is estimated by the variance of  $\hat{T}$  considering the phase one sample as the fixed population, and so uses the same computations as any single-phase design. The second term is the variance of  $\hat{T}$  if complete data were available for the phase-one sample. This takes a little more work.

The variance computations for a stratified, clustered, multistage design involve recursively computing a within-stratum variance for the total over sampling units at the next stage. That is, we want to compute

$$s^2 = \frac{1}{n-1} \sum_{i=1}^n (X_i - \bar{X})^2$$

where  $X_i$  are  $\pi$ -expanded observations, perhaps summed over sampling units. A natural estimator of  $s^2$  when only some observations are present in the phase-two sample is

$$\hat{s}^2 = \frac{1}{n-1} \sum_{i=1}^n \frac{R_i}{\pi_i} (X_i - \hat{\bar{X}})^2$$

where  $\pi_i$  is the probability that  $X_i$  is available and  $R_i$  is the indicator that  $X_i$  is available. We also need an estimator for  $\bar{X}$ , and a natural one is

$$\hat{\bar{X}} = \frac{1}{n} \sum_{i=1}^n \frac{R_i}{\pi_i} X_i$$

This is not an unbiased estimator of  $s^2$  unless  $\hat{\bar{X}} = \bar{X}$ , but the bias is of order  $O(n_2^{-1})$  where  $n_2 = \sum_i R_i$  is the number of phase-two observations.

If the phase-one design involves only a single stage of sampling then  $X_i$  is  $Y_i/p_i$ , where  $Y_i$  is the observed value and  $p_i$  is the phase-one sampling probability. For multistage phase-one designs (not yet implemented)  $X_i$  will be more complicated, but still feasible to automate.

This example shows the unbiased phase-one estimate (from Takahiro Tsuchiya) and the estimate I use, in a situation where the phase two sample is quite small.

First we read the data

```
rei<-read.table(textConnection(
" id  N n.a h n.ah n.h  sub  y
1  1 300 20 1  12  5  TRUE  1
2  2 300 20 1  12  5  TRUE  2
3  3 300 20 1  12  5  TRUE  3
4  4 300 20 1  12  5  TRUE  4
5  5 300 20 1  12  5  TRUE  5
6  6 300 20 1  12  5 FALSE NA
7  7 300 20 1  12  5 FALSE NA
8  8 300 20 1  12  5 FALSE NA
9  9 300 20 1  12  5 FALSE NA
10 10 300 20 1  12  5 FALSE NA
11 11 300 20 1  12  5 FALSE NA
12 12 300 20 1  12  5 FALSE NA
13 13 300 20 2   8  3  TRUE  6
14 14 300 20 2   8  3  TRUE  7
15 15 300 20 2   8  3  TRUE  8
16 16 300 20 2   8  3 FALSE NA
17 17 300 20 2   8  3 FALSE NA
18 18 300 20 2   8  3 FALSE NA
19 19 300 20 2   8  3 FALSE NA
20 20 300 20 2   8  3 FALSE NA
"), header=TRUE)
```

Now, construct a two-phase design object and compute the total of y

```
> des.rei <- twophase(id = list(~id, ~id), strata = list(NULL,
+ ~h), fpc = list(~N, NULL), subset = ~sub, data = rei)
> tot <- svytotal(~y, des.rei)
```

The unbiased estimator is given by equation 9.4.14 of Särndal, Swensson, & Wretman.

```
> rei$w.ah <- rei$n.ah/rei$n.a
> a.rei <- aggregate(rei, by = list(rei$h), mean, na.rm = TRUE)
> a.rei$S.ysh <- tapply(rei$y, rei$h, var, na.rm = TRUE)
> a.rei$y.u <- sum(a.rei$w.ah * a.rei$y)
> a.rei$f <- with(a.rei, n.a/N)
> a.rei$delta.h <- with(a.rei, (1/n.h) * (n.a - n.ah)/(n.a - 1))
> Vphase1 <- with(a.rei, sum(N * N * ((1 - f)/n.a) * (w.ah * (1 -
+ delta.h) * S.ysh + ((n.a)/(n.a - 1)) * w.ah * (y - y.u)^2)))
```

The phase-two contributions (not shown) are identical. The phase-one contributions are quite close

```
> Vphase1
[1] 24072.63
> attr(vcov(tot), "phases")$phase1
[,1]
[1,] 23461.05
```