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ADVANCED ESTIMATOR IN STRATIFIED RANKED SET SAMPLING USING AUXILIARY INFORMATION

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ABSTRACT

In this article, we suggest an advanced estimator in Stratified Ranked Set Sampling (SRSS) based on the Prasad (1989) estimator. Theoretically, we obtain the mean square error (MSE) for this estimator and compare it with the MSE of estimator given by Kadilar and Cingi (2005). By this comparison, theoretically, it is shown that this suggested estimator using Stratified ranked set sampling is more efficient than the estimator given by Kadilar and Cingi(2005). A numerical illustration is also included to demonstrate the merits of the proposed estimator using SRSS over the corresponding estimators in SSRS.

KEYWORDS: Mean Squared Error, Ratio-Type Estimator, Stratified Ranked Set Sampling, Auxiliary Variable, Efficiency

I. INTRODUCTION

Ranked set sampling (RSS) was first suggested by McIntyre (1952) and its use in Stratified Sampling was introduced by Samawi (1996) to increase the efficiency of estimator of population mean. The performance of the combined and the separate ratio estimates using the stratified ranked set sampling (SRSS) was given by Samawi and Siam (2003). Kadilar et al. (2009) used ranked set sampling to improve ratio estimator given by Prasad (1989). A modified ratio estimators of finite population mean using information on coefficient of variation and co-efficient of kurtosis of auxiliary variable in Stratified Ranked Set Sampling were given by Mandowara and Mehta (2014). Here we shall propose a new ratio estimator based on Prasad's (1989) estimator by using Stratified ranked set sampling.

The usual combined ratio estimator given by Cochran (1977) for the population mean $\overline{Y}$ in stratified simple random sampling (SSRS) is defined by

$$\overline{y}_{SSRS} = \overline{y}_{st}\left(\frac{\overline{X}}{\overline{x}_{st}}\right) \tag{1.1}$$

where $\overline{y}_{st} = \sum_{h=1}^{L} W_h \overline{y}_h$ and $\overline{x}_{st} = \sum_{h=1}^{L} W_h \overline{x}_h$ are the unbiased estimators of population mean $\overline{Y}$ and $\overline{X}$

respectively, Y is the study variable and X is the auxiliary variable, L is the number of strata, $W_h = \frac{N_h}{N}$ is the weight of h^{th} stratum, N is the number of units in the population, N_h is the number of units in stratum h, $\bar{y}_h$ is the sample mean of study variate and $\bar{x}_h$ is the sample mean of auxiliary variate in stratum h.

The mean squared error (MSE) of the estimators $\bar{y}_{SSRS}$, on ignoring finite population correction (fpc) in each stratum, is given by

$$MSE(\bar{y}_{SSRS}) = \sum_{h=1}^{L} \frac{W_h^2}{n_h}\left(S_{y_h}^2 + R^2 S_{x_h}^2 - 2RS_{x_h y_h}\right) \tag{1.2}$$

Kadilar and Cingi (2005) suggested a modified estimator based on Prasad's (1989) estimator by using stratified simple random sampling as

$$\bar{y}_{stp} = k^* \left(\frac{\bar{y}_{st}}{\bar{x}_{st}}\right)\bar{X} = k^* \bar{y}_{SSRS} \tag{1.3}$$

The Mean Squared error (MSE) of the estimator $\bar{y}_{stp}$ was obtained as

$$MSE(\bar{y}_{stp}) = k^{*2} \sum_{h=1}^{L} \frac{W_h^2}{n_h}\left(S_{y_h}^2 + R^2 S_{x_h}^2 - 2RS_{x_h y_h}\right) + (k^* - 1)^2 \bar{Y}^2 \tag{1.4}$$

Where $k^* = \dfrac{\bar{Y}^2}{\bar{Y}^2 + \sum_{h=1}^{L} \frac{W_h^2}{n_h}\left(S_{y_h}^2 - 2RS_{x_h y_h} + R^2 S_{x_h}^2\right)}$ which makes MSE minimum, and $0 \le k^* \le 1$.

2. STRATIFIED RANKED SET SAMPLE

In Ranked set sampling (RSS), r independent random sets, each of size r and each unit in the set being selected with equal probability and without replacement , are selected from the population. The members of each random set are ranked with respect to the characteristic of the study variable or auxiliary variable. Then, the smallest unit is selected from the first ordered set and the second smallest unit is selected from the second ordered set. By this way, this procedure is continued until the unit with the largest rank is chosen from the r^{th} set. This cycle may be repeated m times, so $mr\ (= n)$ units have been measured during this process.

In Stratified ranked set sampling, for the h^{th} stratum of the population, first choose r_h independent samples each of size r_h $h = 1, 2, \ldots, L$. Rank each sample, and use RSS scheme to obtain L independent RSS samples of size r_h, one from each stratum. Let $r_1 + r_2 + \ldots\ldots + r_L = r$ .This complete one cycle of stratified ranked set sample. The cycle may be repeated m times until $n = Mr$ *Elements* have been obtained. A modification of the above procedure is suggested here to be used for the estimation of the ratio using stratified ranked set sample. For the h^{th} stratum, first choose r_h independent samples each of size r_h of bivariate elements from the h^{th} subpopulation (Stratum) , h = 1, 2, . . . , L. Rank each sample with respect to one of the variables say Y or X. Then use the RSS sampling scheme to obtain L independent RSS samples of size r_h, one from each stratum. This complete one cycle of stratified ranked set sample the cycle may be repeated m times until $n = mr$ bivariate elements have been obtained. We will use the following notation for the stratified ranked set sample when the ranking is on the variable X. For the k^{th} cycle and the h^{th} stratum, the SRSS is denoted by $\{(Y_{h[1]k}, X_{h(1)k})(Y_{h[2]k}, X_{h(2)k}),..........(Y_{h[r_h]k}, X_{h(r_h)k}) : k = 1,2,...m; h = 1,2,...L\}$, where $Y_{h[i]k}$ is the i^{th} Judgment ordering in the i^{th} set for the study variable and $X_{h(i)k}$ is the i^{th} order statistic in the i^{th} set for the auxiliary variable.

The combined ratio estimator of population mean $\overline{Y}$ given by Samawi and Siam (2003), using stratified ranked set sampling (SRSS) is defined as

$$\overline{y}_{SRSS} = \overline{y}_{[SRSS]}\left(\frac{\overline{X}}{\overline{x}_{(SRSS)}}\right) \tag{2.1}$$

where $\overline{y}_{[SRSS]} = \sum_{h=1}^{L} W_h \overline{y}_{h[r_h]}$ and $\overline{x}_{(SRSS)} = \sum_{h=1}^{L} W_h \overline{x}_{h(r_h)}$ are the stratified ranked set sample means for variables y and x respectively.

The Bias and MSE of the estimator $\overline{y}_{SRSS}$ to the first degree of approximation are respectively given by

$$B(\overline{y}_{SRSS}) = \overline{Y}\left[\sum_{h=1}^{L}\frac{W_h^2}{n_h}\left\{\frac{S_{x_h}^2}{\overline{X}^2} - \frac{S_{x_h y_h}}{\overline{X}\,\overline{Y}}\right\} - \sum_{h=1}^{L}\frac{W_h^2}{n_h}\left\{\frac{m}{n_h}\left(\sum_{i=1}^{r_h} D_{x_h(i)}^2 - \sum_{i=1}^{r_h} D_{x_h(i)y_h[i]}\right)\right\}\right] \tag{2.2}$$

and

$$MSE(\overline{y}_{SRSS}) = \sum_{h=1}^{L}\frac{W_h^2}{n_h}\left[\left\{S_{y_h}^2 + R^2 S_{x_h}^2 - 2RS_{x_h y_h}\right\} - \overline{Y}^2\left\{\frac{m}{n_h}\sum_{i=1}^{r_h}\left(D_{y_h[i]} - D_{x_h(i)}\right)^2\right\}\right] \tag{2.3}$$

where $n_h = mr_h$, $D_{y_h[i]}^2 = \frac{\tau_{y_h[i]}^2}{\overline{Y}^2}$, $D_{x_h(i)}^2 = \frac{\tau_{x_h(i)}^2}{\overline{X}^2}$ and $D_{x_h(i)y_h[i]} = \frac{\tau_{x_h(i)y_h[i]}}{\overline{Y}\,\overline{X}}$. Here we would also like to remind that $\tau_{x_h(i)} = \mu_{x_h(i)} - \overline{X}_h$, $\tau_{y_h[i]} = \mu_{y_i[i]} - \overline{Y}_h$ and $\tau_{x_h(i)y_h[i]} = (\mu_{x_h(i)} - \overline{X}_h)\,(\mu_{y_h[i]} - \overline{Y}_h)$ where $\mu_{x_h(i)} = E[x_{h(i)}]$, $\mu_{y_h(i)} = E[y_{h(i)}]$, $\overline{X}_h$ and $\overline{Y}_h$ are the means of the h^{th} stratum for variables X and Y respectively.

3. THE PROPOSED RATIO-TYPE ESTIMATOR IN SRSS

In stratified ranked set sampling, we propose a new estimator as

$$\bar{y}_{MM,str} = k * \left(\frac{\bar{y}_{[SRSS]}}{\bar{\bar{x}}_{(SRSS)}} \right) \bar{X} = k * \bar{y}_{SRSS} \quad (3.1)$$

To obtain bias and Mean squared error of $\bar{y}_{MM,str}$, we define

Now $V(\delta_0) = E(\delta_0^2) = \dfrac{V(\bar{y}_{[SRSS]})}{\bar{Y}^2}$

$$= \sum_{h=1}^{L} W_h^2 \frac{1}{mr_h} \frac{1}{\bar{Y}^2} \left[S_{y_h}^2 - \frac{m}{n_h} \sum_{i=1}^{r_h} \tau_{y_h[i]}^2 \right] = \sum_{h=1}^{L} \frac{W_h^2}{n_h} \left[\frac{S_{y_h}^2}{\bar{Y}^2} - \frac{m}{n_h} \sum_{i=1}^{r_h} D_{y_h[i]}^2 \right]$$

Similarly, $E(\delta_1^2) = \displaystyle\sum_{h=1}^{L} \frac{W_h^2}{n_h} \left[\frac{S_{x_h}^2}{\bar{X}^2} - \frac{m}{n_h} \sum_{i=1}^{r_h} D_{x_h(i)}^2 \right]$

and $E(\delta_0, \delta_1) = \displaystyle\sum_{h=1}^{L} \frac{W_h^2}{n_h} \left[\frac{S_{x_h y_h}}{\bar{X}\bar{Y}} - \frac{m}{n_h} \sum_{i=1}^{r_h} D_{x_h(i) y_h[i]} \right]$

Therefore, the Bias of this estimator is obtained as

$$B(\bar{y}_{MM,str}) = E(\bar{y}_{MM,str}) - \bar{Y}$$

$$= E\left(k * \bar{y}_{SRSS} - \bar{Y}\right)$$

$$= E\left(k * \frac{\bar{y}_{[SRSS]}}{\bar{\bar{x}}_{(SRSS)}} \bar{X} - \bar{Y} \right)$$

$$= \bar{X} E\left(\frac{k * \bar{y}_{[SRSS]} - R\bar{x}_{(SRSS)}}{\bar{\bar{x}}_{(SRSS)}} \right) \quad (3.2)$$

where E symbolizes expected value. We can rewrite $\left(\dfrac{1}{\bar{\bar{x}}_{(SRSS)}} \right)$ as

$$\frac{1}{\bar{\bar{x}}_{(SRSS)}} = \frac{1}{\bar{\bar{X}} + \left(\bar{x}_{(SRSS)} - \bar{\bar{X}}\right)} = \left(\bar{X} + (\bar{x}_{(SRSS)} - \bar{X})\right)^{-1} = \frac{1}{\bar{\bar{X}}} \left(1 + \frac{\bar{x}_{(SRSS)} - \bar{X}}{\bar{\bar{X}}} \right)^{-1}$$

and let this expression expand to Taylor series. If we use first degree approximation (omit the terms after the second term, i.e., square, cubic, etc., terms) in Taylor series expansion, the equation will be

$$\frac{1}{\overline{\overline{x}}_{(SRSS)}} \cong \frac{1}{\overline{\overline{X}}}\left(1-\frac{\overline{x}_{(SRSS)}-\overline{X}}{\overline{\overline{X}}}\right)$$

From Eq. (3.2), we have

$$B(\overline{y}_{MM,str}) = E\left\{\left(k*\overline{y}_{[SRSS]}-R\overline{x}_{(SRSS)}\right)\left(1-\frac{\overline{x}_{(SRSS)}-\overline{X}}{\overline{\overline{X}}}\right)\right\}$$

$$= k*E\left(\overline{y}_{[SRSS]}\right)-RE\left(\overline{x}_{(SRSS)}\right)-\frac{k*}{\overline{\overline{X}}}E\left[\overline{y}_{[SRSS]}\left(\overline{x}_{(SRSS)}-\overline{X}\right)\right]+\frac{R}{\overline{\overline{X}}}E\left[\overline{x}_{(SRSS)}\left(\overline{x}_{(SRSS)}-\overline{X}\right)\right]$$

$$= k*\overline{Y}-\frac{\overline{Y}}{\overline{\overline{X}}}\overline{X}-\frac{k*}{\overline{\overline{X}}}E\left[\left(\overline{y}_{[SRSS]}-\overline{Y}\right)\left(\overline{x}_{(SRSS)}-\overline{X}\right)\right]+\frac{R}{\overline{\overline{X}}}E\left[\left(\overline{x}_{(SRSS)}-\overline{X}\right)^2\right]$$

$$= (k*-1)\overline{Y}+\frac{R}{\overline{\overline{X}}}\sum_{h=1}^{L}\frac{W_h^2}{n_h}\left\{S_{x_h}^2-\frac{m}{n_h}\sum_{i=1}^{r_h}D_{x_h(i)}^2\right\}-\frac{k*}{\overline{\overline{X}}}\sum_{h=1}^{L}\frac{W_h^2}{n_h}\left\{S_{x_hy_h}-\frac{m}{n_h}\sum_{i=1}^{r_h}D_{x_h(i)y_h[i]}\right\}$$

$$\Rightarrow B(\overline{y}_{MM,str}) = (k*-1)\overline{Y}+\frac{1}{\overline{\overline{X}}}\sum_{h=1}^{L}\frac{W_h^2}{n_h}\left[\left\{RS_{x_h}^2-k*S_{x_hy_h}\right\}-\frac{m}{n_h}\left\{\sum_{i=1}^{r_h}D_{x_h(i)}^2-\sum_{i=1}^{r_h}D_{x_h(i)y_h[i]}\right\}\right] \quad (3.3)$$

Now, MSE of this estimator is obtained as

$$MSE\left(\overline{y}_{MM,str}\right)=E\left(\overline{y}_{MM,str}-\overline{Y}\right)^2$$

$$= E\left(k*\overline{y}_{SRSS}-\overline{Y}\right)^2$$

$$= E\left(k*^2\,\overline{y}_{SRSS}^2-2k*\overline{y}_{SRSS}\overline{Y}+\overline{Y}^2\right)$$

$$= k*^2\,E\left(\overline{y}_{SRSS}^2\right)-2k*\overline{Y}E\left(\overline{y}_{SRSS}\right)+\overline{Y}^2$$

$$= k*^2\,E\left(\overline{y}_{SRSS}^2\right)-2k*\overline{Y}^2+\overline{Y}^2+k*^2\,\overline{Y}^2-k*^2\left[E\left(\overline{y}_{SRSS}\right)\right]^2$$

$$= k*^2\left[E\left(\overline{y}_{SRSS}^2\right)-E\left(\overline{y}_{SRSS}\right)\right]^2+\overline{Y}^2(k*-1)^2$$

$$= k*^2\,Var\left(\overline{y}_{SRSS}\right)+\overline{Y}^2(k*-1)^2$$

From this equation, we obtain the MSE of the suggested estimate as follows:

$$MSE\left(\overline{y}_{MM,str}\right)=k*^2\sum_{h=1}^{L}\frac{W_h^2}{n_h}\left[\left\{S_{y_h}^2+R^2S_{x_h}^2-2RS_{x_hy_h}\right\}-\overline{Y}^2\frac{m}{n_h}\sum_{i=1}^{r_h}\left(D_{y_h[i]}-D_{x_h(i)}\right)^2\right]+(k*-1)^2\overline{Y}^2 \quad (3.4)$$

In order to find the optimum value of $k*$ which makes the MSE minimum. We take the derivative of the MSE with respect to $k*$ and equating it to zero, gives us

$$\frac{\partial MSE(\bar{y}_{MM,strp})}{\partial k*} = 2k*\sum_{h=1}^{L}\frac{W_h^2}{n_h}\left[\left\{S_{y_h}^2 + R^2 S_{x_h}^2 - 2RS_{x_h y_h}\right\} - \bar{Y}^2 \frac{m}{n_h}\sum_{i=1}^{r_h}\left(D_{y_h[i]} - D_{x_h(i)}\right)^2\right] + 2(k*-1)\bar{Y}^2 = 0$$

From this equation, we obtain

$$k* = \frac{\bar{Y}^2}{\bar{Y}^2 + \sum_{h=1}^{L}\frac{W_h^2}{n_h}\left[\left(S_{y_h}^2 + R^2 S_{x_h}^2 - 2RS_{x_h y_h}\right) - \bar{Y}^2 \frac{m}{n_h}\sum_{i=1}^{r_h}\left(D_{y_h[i]} - D_{x_h(i)}\right)^2\right]}$$

Where $0 \le k* \le 1$

4. EFFICIENCY COMPARISON

If we compare the MSE of estimator $\bar{y}_{stp}$ given by Kadilar and Cingi (2005) with the MSE of proposed estimator, we will have the condition as follows:

$$MSE(\bar{y}_{stp}) - MSE(\bar{y}_{MM,str}) = A \ge 0$$, where $A = \bar{Y}^2 \sum_{h=1}^{L}\frac{W_h^2}{n_h}\frac{m}{n_h}\sum_{i=1}^{r_h}\left(D_{y_h[i]} - D_{x_h(i)}\right)^2$

$$\Rightarrow MSE(\bar{y}_{stp}) \ge MSE(\bar{y}_{MM,str})$$

It is easily seen that the MSE of the proposed estimator $\bar{y}_{MM,str}$ is always smaller than the MSE of estimator $\bar{y}_{stp}$, given by Kadilar and Cingi(2005), because A is a non-negative value. Therefore we can say that the proposed estimator $\bar{y}_{MM,str}$ using Stratified ranked set sampling is more efficient than the estimator $\bar{y}_{stp}$, given by Kadilar and Cingi(2005).

5. NUMERICAL ILLUSTRATION

To compare efficiencies of various proposed estimators of our study, here, we take a Stratified population with 3 strata with sizes 12,30 & 17 respectively on page 1119(Appendix) of the book entitled "Advanced Sampling Theory with Applications", Vol.2 , by Sarjinder Singh published from Kluwer Academic Publishers. The example considers the data of Tobacco for Area and Production in specified countries during 1998, where y is production (study variable) in metric tons and x is area (auxiliary variable) in hectares.

For the above population, the parameters are summarized as below:

Total population size $N = 59$, $\bar{Y} = 76485.42$, $\bar{X} = 26942.29$.

Table 1

Stratum-1	Stratum-2	Stratum-3
$N_1 = 12$	$N_2 = 30$	$N_3 = 17$
$n_1 = 9$	$n_2 = 15$	$n_3 = 12$
$W_1 = 0.2034$	$W_2 = 0.5085$	$W_3 = 0.2881$
$\overline{X}_1 = 5987.83$	$\overline{X}_2 = 11682.73$	$\overline{X}_3 = 68662.29$
$\overline{Y}_1 = 11788$	$\overline{Y}_2 = 16862.27$	$\overline{Y}_3 = 227371.53$
$S_{x_1}^2 = 27842810.5$	$S_{x_2}^2 = 760238523$	$S_{x_3}^2 = 12187889050$
$S_{y_1}^2 = 153854583$	$S_{y_2}^2 = 2049296094$	$S_{y_3}^2 = 372428238550$
$S_{y_1x_1} = 62846173.1$	$S_{y_2x_2} = 1190767859$	$S_{y_3x_3} = 27342963562$
$C_{x_1} = 0.8812$	$C_{x_2} = 2.3601$	$C_{x_3} = 1.6079$
$\beta_{21}(x) = 1.8733$	$\beta_{22}(x) = 10.7527$	$\beta_{21}(x) = 8.935$
$R_1 = 1.97$	$R_2 = 1.44$	$R_3 = 3.31$

From this population we took 25 ranked set samples of sizes $r_1 = 3$, $r_2 = 5$ & $r_3 = 4$ from stratum 1st , 2nd and 3rd respectively. Further each ranked set sample from each stratum were repeated with number of cycles $m = 3$. Hence sample sizes of stratified ranked set samples equivalent to stratified simple random samples of sizes $n_h (= mr_h)$ on considering arbitrary allocation.

The estimated MSE values with their respective relative efficiencies of proposed Stratified ranked set estimator in comparison with corresponding Stratified SRS estimator given by Kadilar and Cingi (2005) in the following table for 25 Stratified ranked set samples (SRSS).

Table 2

MSE of Stratified SRS Estimator →	Kadilar and Cingi (2005)($\overline{y}_{stp}$) 1623272104	Relative Efficiencies in %
Stratified Ranked Set Sample Nos.	**MSE of Proposed Stratified Ranked Set Sampling Estimator ($\overline{y}_{MM,str}$)**	
1	1456175009	111.4751
2	1567762231	103.5407
3	1161020319	139.8143
4	1500935038	108.1507
5	1222216766	132.8138
6	1604484149	101.171
7	1376170466	117.9557
8	1084720351	149.6489
9	1486323922	109.2139
10	1504754683	107.8762
11	1344542896	120.7304
12	991713095.4	163.6836
13	1434447789	113.1636
14	1412019201	114.9611
15	1518554150	106.8959
16	1042536446	155.7041

17	1456854226	111.4231
18	1409346059	115.1791
19	1165756188	139.2463
20	1126603122	144.0855
21	1501557775	108.1059
22	1367913186	118.6678
23	1401055519	115.8607
24	1212511653	133.8768
25	1157266254	140.2678

In the table above, we see that for all Stratified ranked set samples, the estimator relative efficiencies are more than 100%. Thus, our proposed Stratified ranked set estimator $\bar{y}_{MM,str}$ is more efficient than corresponding Stratified SRS estimator $\bar{y}_{stp}$, given by Kadilar and Cingi (2005).

6. CONCLUSIONS

We have proposed a new estimator for Stratified ranked set sampling from the estimator of Prasad (1989) and obtained its MSE equation. By this equation, the MSE of proposed estimator has been compared with corresponding stratified simple random sampling estimator given by Kadilar and Cingi (2005) and it has been found that the proposed estimator has a smaller MSE than the corresponding estimator. This theoretical result has been supported by the above example and thus it is concluded that the proposed new estimator $\bar{y}_{MM,str}$ for the population mean using stratified ranked set sampling is more efficient than the usual estimator $\bar{y}_{stp}$, given by Kadilar and Cingi (2005). With this conclusion, we hope to develop new estimators in other sampling methods in the forthcoming studies.

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