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A Modified Dual to Ratio Cum Product Estimator Using Two Auxiliary Variables in Stratified Sampling for Estimating Population Mean

Asra Nazir[1*], Rafia Jan[2], Showkat Maqbool[3] and T.R. Jan[4]

[1,2,4]Department of Statistics, University of Kashmir, Srinagar, India
[3]Division of Agricultural Statistics and Economics, FOA, Wadura, Skuast, Kashmir, India

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Abstract- The estimator proposed in literature by Tailor (2012) and the work on dual to the existing estimator has been extended by introducing additional parameters for estimating the population mean. The expression for the Mean Square Error (MSE) is obtained and compared with the existing. Numerical illustration is used to verify the PRE'S of the estimators.

Keywords- *Auxiliary variable, Bias(B.),Mean Square Error(MSE), Stratified Sampling.*

I. INTRODUCTION

Hansen,Hurwitz and Gurney(1946) envisaged combined ratio estimator.Singh (1967) defined a ratio-cum-product estimator of population mean of two variates. Estimator by Singh (1967) was modified by Tailor and Chouhan (2012) in stratified random sampling. Kadilar and Cingi (2003) studied many ratio type estimators using known parameters of auxiliary variate in each stratum.Tailor and Lone (2012) developed two separate ratio-cum-product estimators.Tailor and Chouhan (2014), and Tailor and Lone (2014) contributed well in stratified random sampling. Clement (2016) suggested an improved ratio estimator in stratified random sampling.Etebong(2018) introduced Improved Family of Ratio Estimators using Population Variance in Stratified Random Sampling.

Suppose we take population $U = U_1, U_2, \underline{U_3} \ldots, U_N$ of size N, which is divided into L strata

of size N_h (h = 1, 2, 3, . . . , L). Let y be the study variate and x and z are the two auxiliary variates taking values y_{hi}, x_{hi} and z_{hi} (h = 1, 2, 3, . . . , L; i= 1, 2, 3, . . . ,N_h), respectively, on i^{th} unit of the h^{th} stratum. A sample of size n_h is drawn from each stratum which comprises a sample of size= $\sum_{h=1}^{l} n_h$.

II. NOTATIONS

$\bar{x}_h = \frac{1}{n_h}\sum_{i=1}^{n_h} x_{hi}$:sample mean of *hth*stratum for variate *x*,

$\bar{y}_h = \frac{1}{n_h}\sum_{i=1}^{n_h} y_{hi}$:sample mean of *hth*stratum for variate *y*,

$\bar{z}_h = \frac{1}{n_h}\sum_{i=1}^{n_h} z_{hi}$:sample mean of m *hth*stratum for variate *z*,

$\bar{X}_h = \frac{1}{N_h}\sum_{i=1}^{N_h} x_{hi}$: hth stratum mean for variate x,

$\bar{Y}_h = \frac{1}{N_h}\sum_{i=1}^{N_h} y_{hi}$: hth stratum mean for variate y,

$\bar{Z}_h = \frac{1}{N_h}\sum_{i=1}^{N_h} z_{hi}$: hth stratum mean for variate z, $\bar{X} = \sum_{h=1}^{L} W_h \bar{X}_h$: Population mean of variate x,

$\bar{Y} = \sum_{h=1}^{L} W_h \bar{Y}_h$: Population mean of variate y,

$\bar{Z} = \sum_{h=1}^{L} W_h \bar{Z}_h$: Population mean of variate z,

$\bar{x}_{st} = \sum_{h=1}^{l} W_h \bar{x}_h$:Unbiased estimator of $\bar{X}$,

$\bar{y}_{st} = \sum_{h=1}^{l} W_h \bar{y}_h$: Unbiased estimator of $\bar{Y}$,

$\bar{z}_{st} = \sum_{h=1}^{l} W_h \bar{z}_h$: Unbiased estimator of $\bar{Z}$,

$S_{xh} = \frac{1}{N_h - 1}\sum_{h=1}^{l}(x_{hi} - \bar{X}_h)^2$: Population mean square in hth stratum for variate x,

$S_{yh} = \frac{1}{N_h - 1}\sum_{h=1}^{l}(y_{hi} - \bar{Y}_h)^2$: Population mean square in hth stratum for variate y,

$S_{zh} = \frac{1}{N_h - 1}\sum_{h=1}^{l}(z_{hi} - \bar{Z}_h)^2$: Population mean square in hth stratum for variate z,

$W_h = \frac{N_h}{N}$ Stratum weight of the hth stratum

The separate ratio and product estimators for $\bar{Y}$ are defined, respectively as

$$\hat{\bar{Y}}_{RS} = \sum_{h=1}^{L} W_h \bar{y}_h \left(\frac{\bar{X}_h}{\bar{x}_h}\right), \tag{1}$$

and

$$\bar{Y}_{PS} = \sum_{h=1}^{L} W_h \bar{y}_h \left(\frac{\bar{z}_h}{\bar{Z}_h}\right) \tag{2}$$

(2)

The biases(B.) andmean-squared errors(MSE) of $\hat{\bar{Y}}_{RS}$ and $\bar{Y}_{PS}$

$$B(\hat{\bar{Y}}_{RS}) = \sum_{h=1}^{L} W_h \bar{Y}_h \gamma_h \left(C_{xh} - \rho_{xyh} C_{xh} C_{yh}\right) \tag{3}$$

$$B(\hat{\bar{Y}}_{PS}) = \sum_{h=1}^{L} W_h \bar{Y}_h \gamma_h \rho_{yzh} C_{yh} C_{zh} \quad (4)$$

$$MSE(\hat{\bar{Y}}_{RS}) = \sum_{h=1}^{L} W_h^{\,2} \gamma_h \begin{pmatrix} S_{xh}^{\,2} + R_{1h} S_{xh}^{\,2} \\ -2R_{1h} S_{yxh} \end{pmatrix} \quad (5)$$

And
$$MSE(\hat{\bar{Y}}_{PS}) = \sum_{h=1}^{L} W_h^{\,2} \gamma_h \begin{pmatrix} S_{xh}^{\,2} + R_{2h} S_{zh}^{\,2} \\ +2R_{1h} S_{yzh} \end{pmatrix} \quad (6)$$

Where $R_{1h} = \dfrac{\bar{Y}_h}{\bar{X}_h}$ and $R_{2h} = \dfrac{\bar{Y}_h}{\bar{Z}_h}$

The Tailor et al. (2012) estimator can be written as

$$\hat{\bar{Y}}_1 = \sum_{h=1}^{L} W_h \bar{y}_h \left(\frac{\bar{X}_h}{\bar{x}_h}\right)\left(\frac{\bar{z}_h}{\bar{Z}_h}\right) \quad (7)$$

The biases(B.)and mean-squared errors(MSE) of $\hat{\bar{Y}}_1$ are obtained as:

$$B(\hat{\bar{Y}}_1) = \sum_{h=1}^{L} W_h \bar{Y}_h \gamma_h \begin{pmatrix} C_{xh} - \rho_{xyh} C_{xh} C_{yh} \\ +\rho_{yzh} C_{yh} C_{zh} - \rho_{xzh} C_{xh} C_{zh} \end{pmatrix} \quad (8)$$

$$MSE(\hat{\bar{Y}}_1) = \sum_{h=1}^{L} W_h^{\,2} \gamma_h \begin{pmatrix} S_{xh}^{\,2} + R_{1h} S_{xh}^{\,2} + \\ R_{2h} S_{zh}^{\,2} - 2R_{1h} S_{yxh} \\ +2R_{2h} S_{yzh} - 2R_{1h} R_{2h} S_{xzh} \end{pmatrix} \quad (9)$$

III. PROPOSED ESTIMATOR

We suggested a generalized class of dual to ratio cum product estimator for estimating the population mean $\bar{Y}$

$$\hat{\bar{Y}}_t^{*} = \sum_{h=1}^{L} W_h \bar{y}_h \left(\frac{a_h \bar{x}^{*}_h + b_h}{a_h \bar{X}_h + b_h}\right)^{\alpha} \left(\frac{c_h \bar{Z}_h + d_h}{c_h \bar{z}_h^{*} + d_h}\right)^{\beta} \quad (10)$$

Where a_h, b_h, c_h and d_h are either known parameters or a functions of known parameters

where $x_h^{*} = \dfrac{N\bar{X}_h - nx_h}{N-n}$, $z_h^{*} = \dfrac{N\bar{Z}_h - nz_h}{N-n}$

The associated sample mean is obtained as

$$\bar{x}_h^{*} = (1+g)\bar{X}_{h_h} - g\bar{x}_h \text{ and } g = \frac{n}{N-n}$$

$$\bar{z}_h^{*} = (1+g)\bar{Z}_{h_h} - g\bar{z}_h$$

To examine the mean-squared error(MSE) of the suggested estimator we write. $\hat{\bar{Y}}_t^*$

$$\bar{y}_h = \bar{Y}_h(1+e_{0h}), \bar{x}_h = \bar{X}_h(1+e_{1h}),$$
$$\bar{z}_h = \bar{Z}_h(1+e_{2h}) \quad ,$$

such that

$$E(e_{oh}) = E(e_{1h}) = E(e_{2h}) = 0$$
$$E(e_{oh}{}^2) = \gamma_h C_{yh} = E(e_{1h}{}^2) = \gamma_h C_{xh}$$
$$E(e_{2h}{}^2) = \gamma_h C_{zh}$$
$$E(e_{oh}e_{1h}) = \gamma_h \rho_{yxh} C_{yh} C_{xh},$$
$$E(e_{1h}e_{2h}) = \gamma_h \rho_{xzh} C_{xh} C_{zh},$$
$$E(e_{2h}e_{oh}) = \gamma_h \rho_{yzh} C_{zh} c_{yh}$$

Expressing equation (10) in terms of e's we have

$$\hat{\bar{Y}}_t^* = \sum_{h=1}^{L} W_h \bar{Y}_h (1+e_{0h})$$
$$\left(\frac{a_h \bar{X}_h - a_h g \bar{X}_h e_{1h} + b_h}{a_h \bar{X}_h + b_h}\right)^{\alpha}$$
$$\left(\frac{c_h \bar{Z}_h + d_h}{c_h \bar{Z}_h - c_h g \bar{Z}_h e_{2h} + d_h}\right)^{\beta}$$

$$\hat{\bar{Y}}_t^* = \sum_{h=1}^{L} W_h \bar{Y}_h (1+e_{0h})(1-\theta_1 e_{1h})^{\alpha}(1-\theta_2 e_{2h})^{-\beta}$$
$$= \sum_{h=1}^{L} W_h \bar{Y}_h (1+e_{0h})(1-\alpha\theta_1 e_{1h})(1+\beta\theta_2 e_{2h}) \qquad (11)$$

Where $\theta_1 = \frac{a_h g \bar{X}_h}{a_h \bar{X}_h + b_h} =, \theta_2 = \frac{c_h g \bar{Z}_h}{c_h \bar{Z}_h + d_h}$

Now expanding the right-hand side of (11) and ignoring power than two,we obtain

$$= \sum_{h=1}^{L} W_h \bar{Y}_h (1 + e_{0h} - \alpha\theta_1 e_{1h} + \beta\theta_2 e_{2h} - \alpha\theta_1 e_{1h} e_{oh} + \beta\theta_2 e_{2h} e_{oh}) \quad \hat{\bar{Y}}_t^* - \sum_{h=1}^{L} W_h \bar{Y}_h = \sum_{h=1}^{L} W_h \bar{Y}_h (e_{0h} - \alpha\theta_1 e_{1h} + \beta\theta_2 e_{2h} - \alpha\theta_1 e_{1h} e_{oh} + \beta\theta_2 e_{2h} e_{oh})$$

(12)

Taking expectation and squaring on both sides of equation (12), the mean square error(MSE)is as

$$E(\hat{\bar{Y}}_t^* - \sum_{h=1}^{L} W_h \bar{Y}_h)^2 = \sum_{h=1}^{L} W_h \bar{Y}_h E(e_{0h} - \alpha\theta_1 e_{1h} + \beta\theta_2 e_{2h})^2$$

$$\mathrm{MSE}(\hat{\hat{Y}}_t^{*}) = \sum_{h=1}^{L} W_h \bar{Y}_h E(e_{0h}^{2} + \alpha^2\theta_1^2 e_{1h}^{2} + \beta^2\theta_2^{2} e_{2h}^{2} - 2\alpha\theta_1 e_{1h} e_{oh} - 2\alpha\beta\theta_1\theta_2 e_{1h} e_{2h} + 2\beta\theta_2 e_{2h} e_{oh})$$

$$\mathrm{MSE}(\hat{\hat{Y}}_t^{*}) = \sum_{h=1}^{L} W_h \gamma_h \bar{Y}_h^{2} \begin{pmatrix} C_{yh}^{2} + \alpha^2\theta_1^2 C_{xh}^{2} + \beta^2\theta_2^{2} C_{zh}^{2} \\ -2\alpha\theta_1\rho_{yxh} C_{xh} C_{yh} \\ -2\alpha\beta\theta_1\theta_2\rho_{xzh} C_{xh} C_{zh} \\ +2\beta\theta_2\rho_{yzh} C_{yh} C_{zh} \end{pmatrix} \tag{13}$$

$$\mathrm{MSE}(\hat{\hat{Y}}_t^{*}) = \sum_{h=1}^{L} W_h \gamma_h \begin{pmatrix} S_{yh}^{2} + \alpha^2 R_{1h}^{2}\theta_1^2 S_{xh}^{2} \\ +\beta^2 R_{2h}^{2}\theta_2^{2} C_{zh}^{2} \\ -2\alpha R_{1h}\theta_1\rho_{yxh} S_{xh} S_{yh} \\ -2\alpha\beta R_{1h} R_{2h}\theta_1\theta_2\rho_{xzh} S_{xh} S_{zh} \\ +2R_{2h}\beta\theta_2\rho_{yzh} S_{yh} S_{zh} \end{pmatrix}$$

Now differentiating the equation (13) with respect to α and β ,we get the minimum mean square error (MSE) of the proposed estimator

$$\left.\begin{aligned} \alpha &= \frac{S_{yh}(\rho_{yxh} - \rho_{yzh}\rho_{xzh})}{R_{1h}\theta_1 S_{xh}(1-\rho_{zh}^{2})} \\ \beta &= \frac{S_{yh}(\rho_{yxh}\rho_{xzh} - \rho_{yzh})}{R_{2h}\theta_2 S_{zh}(1-\rho_{zh}^{2})} \end{aligned}\right\} \tag{14}$$

Substituting the value of equation no (14) in (13) we get the minimum mean square error (MSE)of the proposed estimator

$$\mathrm{MSE}(\hat{\hat{Y}}_t^{*}) = \sum_{h=1}^{l} W_h^{2}\gamma_h S_{yh}^{2}\left[1 - \frac{\rho_{yxh}^{2} - \rho_{xzh}^{2} + 2\rho_{yxh}\rho_{xzh}\rho_{yzh}}{(1-\rho_{xzh}^{2})}\right] \tag{15}$$

Table 1: New members of the Modified estimators

Estimators	**Constants**			
	a_h	**b_h**	**c_h**	**d_h**
$\hat{\hat{Y}}_{t1}^{*} = \sum_{h=1}^{L} W_h \bar{y}_h \left(\frac{\bar{x}^{*}_h + \rho_{yxh}}{\bar{X}_h + \rho_{yxh}}\right)^{\alpha}\left(\frac{\bar{Z}_h + \rho_{yzh}}{\bar{z}_h^{*} + \rho_{yzh}}\right)^{\beta}$	1	ρ_{yxh}	1	ρ_{yzh}
$\hat{\hat{Y}}_{t2}^{*} = \sum_{h=1}^{L} W_h \bar{y}_h \left(\frac{\bar{x}^{*}_h}{\bar{X}_h}\right)^{\alpha}\left(\frac{\bar{Z}_h}{\bar{z}_h^{*}}\right)^{\beta}$	1	0	1	0
$\hat{\hat{Y}}_{t3}^{*} = \sum_{h=1}^{L} W_h \bar{y}_h \left(\frac{\bar{x}^{*}_h + C_{xh}}{\bar{X}_h + C_{xh}}\right)^{\alpha}\left(\frac{\bar{Z}_h + C_{zh}}{\bar{z}_h^{*} + C_{zh}}\right)^{\beta}$	1	C_{xh}	1	C_{zh}

$\hat{\bar{Y}}_{t4}^{*}=\sum_{h=1}^{L}W_h\bar{y}_h\left(\frac{\beta_{2h}(x)\bar{x}^{*}{}_h+C_{xh}}{\beta_{2h}(x)\bar{X}_h+C_{xh}}\right)^{\alpha}\left(\frac{\beta_{2h}(z)\bar{Z}_h+C_{zh}}{\beta_{2h}(z)\bar{z}_h^{*}+C_{zh}}\right)^{\beta}$	$\beta_{2h}(x)$	C_{xh}	$\beta_{2h}(z)$	C_{zh}
$\hat{\bar{Y}}_{t5}^{*}=\sum_{h=1}^{L}W_h\bar{y}_h\left(\frac{\beta_{2h}(x)\bar{x}^{*}{}_h+C_{xh}}{\beta_{2h}(x)\bar{X}_h+C_{xh}}\right)^{\alpha}\left(\frac{\beta_{2h}(z)\bar{Z}_h+C_{zh}}{\beta_{2h}(z)\bar{z}_h^{*}+C_{zh}}\right)^{\beta}$	C_{xh}	$\beta_{2h}(x)$	C_{zh}	$\beta_{2h}(z)$

IV. EFFICIENCY COMPARISON

We have compared the mean square error(MSE) of the proposed estimator $\hat{\bar{Y}}_t^{*}$ with the MSE of the $\bar{y}_{st}$, $\bar{y}_{RS}$ and $\bar{y}_{PS}$ is given as

Table 2

Existing estimator	**Conditions**
$\bar{y}_{st}$	$\sum_{h=1}^{L}W_h\gamma_h\left(\begin{matrix}\alpha^2\theta_1^2R_1^2S_{xh}^2+\beta^2\theta_2^2R_2^2S_{zh}^2\\-2\alpha\theta_1R_1S_{xyh}-2\alpha\beta\theta_1\theta_2R_1R_2S_{xzh}+2\beta\theta_2R_2S_{yzh}\end{matrix}\right)>0$
$\bar{y}_{RS}$	$\sum_{h=1}^{L}W_h\gamma_h\left(\begin{matrix}R_{1h}^2S_{xh}^2(\alpha^2\theta_1^2-1)+\beta^2\theta_2^2R_{2h}^2S_{zh}^2\\-2R_{1h}S_{xyh}(\alpha\theta_1-1)-2\alpha\beta\theta_1\theta_2R_{1h}R_2hS_{xzh}+2\beta\theta_2R_{2h}S_{yzh}\end{matrix}\right)>0$
$\bar{y}_{PS}$	$\sum_{h=1}^{L}W_h\gamma_h\left(\begin{matrix}R_{2h}^2S_{zh}^2(\beta^2\theta_2^2-1)+\alpha^2\theta_1^2R_{1h}^2S_{xh}^2\\-2R_{2h}S_{yzh}(\beta\theta_2-1)-2\alpha\beta\theta_1\theta_2R_1R_2S_{xzh}-2\alpha\theta_1R_{1h}S_{yzh}\end{matrix}\right)>0$
$\hat{\bar{Y}}_1$	$\sum_{h=1}^{L}W_h\gamma_h\left(\begin{matrix}R_{1h}^2S_{xh}^2(\alpha^2\theta_1^2-1)+R_2^2S_{zh}^2(\beta^2\theta_2^2-1)\\-2R_1S_{xyh}(\alpha\theta_1-1)-2R_1R_2S_{xzh}(\alpha\beta\theta_1\theta_2-1)+2R_2S_{yzh}(\beta\theta_2-1)\end{matrix}\right)>0$

V. NUMERICAL ILLUSTRATION

we use the data set in Koyuncu and Kadilar [4]. The data statistics given in Table 2. In this data set (Y) is the number of teachers, (X) is the number of students and (Z) is the number of classes in both primary and secondary schools.

Table no 3:Data Statistics

N_1=127	N_2=117	N_3=103	N_4=170	N_5=205	N_6=201
n_1=31	n_2 =21	n_3=29	n_4=38	n_5 =22	n_6 =39
$S_{y1}=883.835$	$S_{y2}=644$	$S_{y3}=1033.467$	$S_{y4}=810.585$	$S_{y5}=403.654$	$S_{y6}=$ 711.723
$\bar{Y}_1=703.74$	$\bar{Y}_2=413$	$\bar{Y}_3=573.17$	$\bar{Y}_4=424.66$	$\bar{Y}_5=267.03$	$\bar{Y}_6=393.84$
$S_{x1}=30486.751$	$S_{x2}=15180.760$	$S_{x3}=27549.697$	$S_{x4}=18218.931$	$S_{x5}=8997.776$	$S_{x6}=23094.141$
$\bar{X}_1=20804.59$	$\bar{X}_2=9211.79$	$\bar{X}_3=14309.30$	$\bar{X}_4=9478.85$	$\bar{X}_5=5569.95$	$\bar{X}_6=12997.59$

S_{z1} = 555.5816	S_{z2} = 365.4576	S_{z3} = 612.9509	S_{z4} = 458.0282	S_{z5} = 260.8511	S_{z6} = 397.0481
$\bar{Z}_1$ = 498.28	$\bar{Z}_2$ = 318.33	$\bar{Z}_3$ = 431.36	$\bar{Z}_4$ = 498.28	$\bar{Z}_5$ = 227.20	$\bar{Z}_6$ = 313.71
S_{yx1} = 25237153.52	S_{yx2} = 9747942.85	S_{yx3} = 28294397.04	S_{yx4} = 1452885.53	S_{yx5} = 3393591.75	S_{yx6} = 15864573.97
S_{xz1} = 15914648	S_{xz2} = 5379190	S_{xz3} = 164900674.56	S_{xz4} = 8041254	S_{xz5} = 214457	S_{xz6} = 8857729
S_{yz1} = 480688.2	S_{yz2} = 230092.8	S_{yz3} = 623019.3	S_{yz4} = 36493.4	S_{yz5} = 101539	S_{yz6} = 277696.1
ρ_{yx1} = 0.936	ρ_{yx2} = 0.996	ρ_{yx3} = 0.994	ρ_{yx4} = 0.983	ρ_{yx5} = 0.989	ρ_{yx6} = 0.965
ρ_{xz1} = 0.939	ρ_{xz2} = 0.969	ρ_{xz3} = 0.036	ρ_{xz4} = 0.043	ρ_{xz5} = 0.045	ρ_{xz6} = 0.030
ρ_{yz1} = 0.978	ρ_{yz2} = 0.976	ρ_{yz3} = 0.983	ρ_{yz4} = 0.982	ρ_{yz5} = 0.964	ρ_{yz6} = 0.982

Data set 2: [Source: National Horticulture Board (2010)]

y : Productivity *(*MT*/*hectare*).*
x : Production *(*000 tons*).*
z :Area *(*000 hectare*)*

N=20	n=8	N_1=10	N_2=10	n_1=4	n_2 =4
S_{y1} = 0.504	S_{y2} = 1.4128	S_{yx1} = 1.608	S_{yx2} = 144.88	ρ_{yx1} = 0.903	ρ_{yx2} = 0.918
$\bar{Y}_1$ = 1.70	$\bar{Y}_2$ = 3.67	S_{xz1} = 1.3838	S_{xz2} = -92.09	ρ_{xz1} = 0.3322	ρ_{xz2} = -0.076
S_{x1} = 3.53	S_{x2} = 111.69	S_{yz1} = -0.056	S_{yz2} = -7.046	ρ_{yz1} = -0.094	ρ_{yz2} = -0.46
$\bar{X}_1$ = 10.41	$\bar{X}_2$ = 289.14	S_{z1} = 1.18	S_{z2} = 10.81	$\bar{Z}_1$ = 6.32	$\bar{Z}_2$ = 80.67

Table no: 4 PRE'S of the modified Estimators

Estimators	**Data 1**	**Data 2**
$\bar{y}_{st}$	100.00	100.00
$\bar{y}_{RS}$	1730.66	223.84
$\bar{y}_{PS}$	32.19	26.62
$\hat{\bar{Y}}_1$	163.59	158.19
$\hat{\bar{Y}}_t^*$	**4683.33**	**356.12**

VI. CONCLUSION

From the above table, it is clear that the suggestedclass of Dual to Ratio cum Product estimators has shown higher Relative Percent efficiency as compared to the existing estimators. So, the recommended estimator is more proficient than the existing estimator.

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