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Research Article

# IMPROVED SAMPLING STRATEGIES FOR FINITE POPULATION USING AUXILIARY INFORMATION

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A B S T R A C T

This paper advocates the problem of estimating the finite population mean in sample surveys. We have suggested the generalized class of estimators under Midzuno (1950) - Lahiri - Sen (1952) type sampling scheme and its properties are studied up to the first degree of approximation. Further, we compare the proposed sampling strategy with the mean per unit estimator, classical ratio estimator, product estimator, linear regression estimator and the generalized ratio estimator (Walsh) under the simple random sampling without replacement. Also, we find out the unbiased estimate of the variance. On the basis of suitable range information, we give some concluding remarks related to proposed sampling strategy. An empirical study is given in support of the present study.

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## INTRODUCTION

Let the population consists of N units. Yi and Xi denote the $i^{th}$ characteristics of the population. The population mean of the study variable is denoted by $\bar{Y}$ and population mean of the auxiliary variable which

is known is denoted by $\bar{X}$ and it is given as

$\bar{Y} = \frac{1}{N}\sum_{i=1}^{N} Y_i$ and $\bar{X} = \frac{1}{N}\sum_{i=1}^{N} X_i$ respectively. The population variance of the study variable and the auxiliary variable is given as $\sigma_y^2 = \frac{1}{N}\sum_{i=1}^{N}\left(Y_i - \bar{Y}\right)^2$ and

$\sigma_x^2 = \frac{1}{N}\sum_{i=1}^{N}\left(X_i - \bar{X}\right)^2$ respectively.

Since the study variable and the auxiliary variable are correlated with each other and there exists a linear relationship between two variables. Thus $\rho$ be the correlation coefficient between the variable under study and auxiliary variable which measures the degree of linear relationship between two variables, it is given as

$$\rho = \frac{Cov\left(Y, X\right)}{\sigma_Y \sigma_X}$$

where $Cov\left(Y, X\right) = E\left(Y - \bar{Y}\right)\left(X - \bar{X}\right)$

$$V\left(Y\right) = E\left(Y - \bar{Y}\right)^2$$

$$V\left(X\right) = E\left(X - \bar{X}\right)^2$$

Also $C_y$ and $C_x$ be the coefficient of variation of 'Y' and 'X' respectively and it is given as

$C_y = \frac{\sigma_Y}{\bar{Y}}$ and $C_x = \frac{\sigma_X}{\bar{X}}$

where $\sigma_y$ and $\sigma_x$ are the standard deviation of the Y and X respectively.

Now let us take a random sample of size 'n'. $y_i$ be the $i^{th}$ characteristics of the study variable of the sample and $x_i$ be the $i^{th}$ characteristics of the auxiliary variable of the sample. Sample mean of study variable for estimating the population mean is denoted by $\bar{y}_s$ and it is given as

$$\bar{y}_s = \frac{1}{n}\sum_{i=1}^{n} y_i$$

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The sample mean of auxiliary variable is denoted by $\bar{x}_s$ and it is given as $\bar{x}_s = \frac{1}{n}\sum_{i=1}^{n} x_i$

When the random sample s is selected by simple random sampling without replacement, the generalized ratio for estimating population mean $\bar{Y}$ is

$$\bar{y}_{A\gamma} = \frac{\gamma\bar{y}\left(\alpha\bar{X}+\beta\right)}{\left(\alpha\bar{X}+\beta\right)+A\alpha\left(\bar{x}-\bar{X}\right)}$$

where A is the characterizing scalar to be chosen(1952) suitably.

We now consider the generalized ratio estimator $\bar{y}_A$ under Midzuno (1950) (1952)- Lahiri (1951)- Sen (1952) (1952) type sampling scheme and denote it by $\bar{y}_{A\gamma}$.

The proposed Midzuno (1950)-Lahiri-Sen(1952) type sampling scheme for selecting a sample 's ' of size n is given as selecting the first unit of the sample by probability proportional to $\left(\alpha\bar{X}+\beta\right)+A\alpha\left(x_i-\bar{X}\right)$, where $x_i$ is the size of first selected unit.

$$P(i)=\frac{\left(\alpha\bar{X}+\beta\right)+A\alpha\left(x_i-\bar{X}\right)}{{}^{N}C_n\left(\alpha\bar{X}+\beta\right)}$$

and selecting the remaining (n-1) units in the sample from (N-1) units in the population by simple random sampling without replacement. Thus,

$$P(s)=\sum_{i=1}^{n}\{\text{probability of selecting } i\text{th sample unit at first draw}\}\{\text{probability of selecting } (n-1) \text{ units out of } (N-1) \text{ units by SRSWOR}\}$$

$$P(s)=\sum_{i=1}^{n}\frac{\left(\alpha\bar{X}+\beta\right)+A\alpha\left(x_i-\bar{X}\right)}{{}^{N-1}C_{n-1}\left(\alpha\bar{X}+\beta\right)}$$

$$P(s)=\frac{\left(\alpha\bar{X}+\beta\right)+A\alpha\left(\bar{x}-\bar{X}\right)}{{}^{N}C_n\left(\alpha\bar{X}+\beta\right)}$$

## 2 BIASEDNESS OF $\left(\bar{y}_{A\gamma}\right)$

The formula for calculating biasness of $\left(\bar{y}_{A\gamma}\right)$ is given as

$$\bar{y}_{A\gamma} = \frac{\gamma\bar{y}\left(\alpha\bar{X}+\beta\right)}{\left(\alpha\bar{X}+\beta\right)+A\alpha\left(\bar{x}-\bar{X}\right)}$$

Taking expectation on both the sides,

$$E\left(\bar{y}_{A\gamma}\right)=E\left[\frac{\gamma\bar{y}\left(\alpha\bar{X}+\beta\right)}{\left(\alpha\bar{X}+\beta\right)+A\alpha\left(\bar{x}-\bar{X}\right)}\right]$$

$$=\sum_{s=1}^{{}^{N}C_n}\left[\frac{\gamma\bar{y}\left(\alpha\bar{X}+\beta\right)}{\left(\alpha\bar{X}+\beta\right)+A\alpha\left(\bar{x}-\bar{X}\right)}\right]P(s)$$

$$=\sum_{s=1}^{{}^{N}C_n}\left[\frac{\gamma\bar{y}\left(\alpha\bar{X}+\beta\right)}{\left(\alpha\bar{X}+\beta\right)+A\alpha\left(\bar{x}-\bar{X}\right)}\right]\frac{\left\{\left(\alpha\bar{X}+\beta\right)+A\alpha\left(\bar{x}-\bar{X}\right)\right\}}{{}^{N}C_n\left(\alpha\bar{X}+\beta\right)}$$

$$=\gamma\sum_{s=1}^{{}^{N}C_n}\left[\frac{\bar{y}}{{}^{N}C_n}\right]$$

$$=\gamma E\left(\bar{y}\right)$$

$$=\gamma\bar{Y}$$

$$\text{Bias}\left(\bar{y}_{A\gamma}\right)=E\left(\bar{y}_{A\gamma}\right)-\gamma\bar{Y}$$

Therefore, $\left(\bar{y}_{A\gamma}\right)$ is not an unbiased estimator of population mean.

**Mean Square Error Of $\left(\bar{y}_{A\gamma}\right)$**

$$MSE\left(\bar{y}_{A\gamma}\right)=E\left[\bar{y}-\bar{Y}\right]^2$$

$$=E\left[\frac{\gamma\bar{y}\left(\alpha\bar{X}+\beta\right)}{\left(\alpha\bar{X}+\beta\right)+A\alpha\left(\bar{x}-\bar{X}\right)}-\bar{Y}\right]^2$$

$$=E\left[\frac{\gamma\bar{y}\left(\alpha\bar{X}+\beta\right)-\bar{Y}\left(\alpha\bar{X}+\beta\right)-\bar{Y}A\alpha\left(\bar{x}-\bar{X}\right)}{\left(\alpha\bar{X}+\beta\right)+A\alpha\left(\bar{x}-\bar{X}\right)}\right]^2$$

$$=\sum_{S=1}^{{}^{N}C_n}\left[\frac{\gamma\bar{y}\left(\alpha\bar{X}+\beta\right)-\bar{Y}\left(\alpha\bar{X}+\beta\right)-\bar{Y}A\alpha\left(\bar{x}-\bar{X}\right)}{\left(\alpha\bar{X}+\beta\right)+A\alpha\left(\bar{x}-\bar{X}\right)}\right]^2 P(s)$$

$$=\sum_{S=1}^{{}^{N}C_n}\left[\frac{\gamma\bar{y}\left(\alpha\bar{X}+\beta\right)-\bar{Y}\left(\alpha\bar{X}+\beta\right)-\bar{Y}A\alpha\left(\bar{x}-\bar{X}\right)}{\left(\alpha\bar{X}+\beta\right)+A\alpha\left(\bar{x}-\bar{X}\right)}\right]^2\frac{\left\{\left(\alpha\bar{X}+\beta\right)+A\alpha\left(\bar{x}-\bar{X}\right)\right\}}{{}^{N}C_n\left(\alpha\bar{X}+\beta\right)}$$

$$=\sum_{S=1}^{{}^{N}C_n}\left[\frac{\left\{\gamma\bar{y}\left(\alpha\bar{X}+\beta\right)-\bar{Y}\left(\alpha\bar{X}+\beta\right)-\bar{Y}A\alpha\left(\bar{x}-\bar{X}\right)\right\}^2}{\left(\alpha\bar{X}+\beta\right)+A\alpha\left(\bar{x}-\bar{X}\right)}\right]\frac{1}{{}^{N}C_n\left(\alpha\bar{X}+\beta\right)}$$

$$=\sum_{S=1}^{{}^{N}C_n}\left[\frac{\left\{\gamma\bar{y}\left(\alpha\bar{X}+\beta\right)-\bar{Y}\left(\alpha\bar{X}+\beta\right)-\bar{Y}A\alpha\left(\bar{x}-\bar{X}\right)\right\}^2}{\left\{1+\frac{A\alpha\left(\bar{x}-\bar{X}\right)}{\left(\alpha\bar{X}+\beta\right)}\right\}}\right]\frac{1}{{}^{N}C_n\left(\alpha\bar{X}+\beta\right)^2}$$

$$=\sum_{S=1}^{{}^{N}C_n}\left[\left\{\gamma\bar{y}\left(\alpha\bar{X}+\beta\right)-\bar{Y}\left(\alpha\bar{X}+\beta\right)-\bar{Y}A\alpha\left(\bar{x}-\bar{X}\right)\right\}^2\left\{1+\frac{A\alpha\left(\bar{x}-\bar{X}\right)}{\left(\alpha\bar{X}+\beta\right)}\right\}^{-1}\right]\frac{1}{{}^{N}C_n\left(\alpha\bar{X}+\beta\right)^2}$$

$$=E\left[\left\{\gamma\bar{y}\left(\alpha\bar{X}+\beta\right)-\bar{Y}\left(\alpha\bar{X}+\beta\right)-\bar{Y}A\alpha\left(\bar{x}-\bar{X}\right)\right\}^2\left\{1+\frac{A\alpha\left(\bar{x}-\bar{X}\right)}{\left(\alpha\bar{X}+\beta\right)}\right\}^{-1}\right]\frac{1}{\left(\alpha\bar{X}+\beta\right)^2}$$

(1)

Let $\varepsilon_o=\frac{\left(\bar{y}-\bar{Y}\right)}{\bar{Y}}$ and $\varepsilon_1=\frac{\left(\bar{x}-\bar{X}\right)}{\bar{X}}$

Such that E( $\varepsilon_o$ )=E( $\varepsilon_1$ )=0

and V( $\varepsilon_o$ )=E( $\varepsilon_0^2$ )= $\frac{\left(N-n\right)}{Nn}\frac{S_y^2}{\bar{Y}^2}$

V( $\varepsilon_1$ )= E( $\varepsilon_1^2$ )= $\frac{\left(N-n\right)}{Nn}\frac{S_x^2}{\bar{X}^2}$

Thus (1) becomes,

$$=E\left[\left\{\gamma\bar{Y}\left(1+\varepsilon_o\right)\left(\alpha\bar{X}+\beta\right)-\bar{Y}\left(\alpha\bar{X}+\beta\right)-\bar{Y}\bar{X}A\alpha\varepsilon_1\right\}^2\left\{1+\frac{A\alpha\bar{X}\varepsilon_1}{\left(\alpha\bar{X}+\beta\right)}\right\}^{-1}\right]\frac{1}{\left(\alpha\bar{X}+\beta\right)^2}$$

$$=\frac{1}{\left(\alpha\bar{X}+\beta\right)^2}E\left[\left\{(\gamma-1)\bar{Y}\left(\alpha\bar{X}+\beta\right)+\gamma\varepsilon_0\bar{Y}\left(\alpha\bar{X}+\beta\right)-\bar{Y}A\alpha\varepsilon_1\bar{X}\right\}^2\left\{1-\frac{A\alpha\varepsilon_1\bar{X}}{\left(\alpha\bar{X}+\beta\right)}+\frac{A^2\alpha^2\varepsilon_1^2\bar{X}^2}{\left(\alpha\bar{X}+\beta\right)^2}-...\right\}\right]$$

$$=\frac{1}{\left(\alpha\bar{X}+\beta\right)^2}E\Big[\Big\{(\gamma-1)^2\bar{Y}^2\left(\alpha\bar{X}+\beta\right)^2+\gamma^2\varepsilon_0{}^2\bar{Y}^2\left(\alpha\bar{X}+\beta\right)^2+\bar{Y}^2A^2\alpha^2\varepsilon_1{}^2\bar{X}^2$$

$$+2(\gamma-1)\gamma\bar{Y}^2\left(\alpha\bar{X}+\beta\right)^2\varepsilon_0-2(\gamma-1)\bar{Y}^2\bar{X}\left(\alpha\bar{X}+\beta\right)A\alpha\varepsilon_1-2\gamma\bar{Y}^2\bar{X}\left(\alpha\bar{X}+\beta\right)A\alpha\varepsilon_1\varepsilon_0\Big\}$$

$$\left\{1-\frac{A\alpha\varepsilon_1\bar{X}}{\left(\alpha\bar{X}+\beta\right)}+\left\{\frac{A\alpha\varepsilon_1\bar{X}}{\left(\alpha\bar{X}+\beta\right)}\right\}^2-...\right\}$$

(ignoring higher power terms)

$$=\frac{1}{\left(\alpha\bar{X}+\beta\right)^2}E\Big[\Big\{(\gamma-1)^2\bar{Y}^2\left(\alpha\bar{X}+\beta\right)^2+\bar{Y}^2(\gamma-1)^2A^2\alpha^2\varepsilon_1{}^2\bar{X}^2+\bar{Y}^2\gamma^2\left(\alpha\bar{X}+\beta\right)^2\varepsilon_0{}^2+\bar{Y}^2A^2\alpha^2\varepsilon_1{}^2\bar{X}^2$$

$$-2\gamma(\gamma-1)\bar{Y}^2\bar{X}\left(\alpha\bar{X}+\beta\right)A\alpha\varepsilon_0\varepsilon_1+2\bar{Y}^2(\gamma-1)\bar{X}^2A^2\alpha^2\varepsilon_1{}^2-2\gamma\bar{Y}^2\bar{X}\left(\alpha\bar{X}+\beta\right)A\alpha\varepsilon_0\varepsilon_1\Big\}\Big]$$

$$=\frac{1}{\left(\alpha\bar{X}+\beta\right)^2}\Big[\Big\{(\gamma-1)^2\bar{Y}^2\left(\alpha\bar{X}+\beta\right)^2+\bar{Y}^2(\gamma-1)^2A^2\alpha^2\bar{X}^2E\left(\varepsilon_1{}^2\right)+\bar{Y}^2\gamma^2\left(\alpha\bar{X}+\beta\right)^2E\left(\varepsilon_0{}^2\right)$$

$$+\bar{Y}^2\bar{X}^2A^2\alpha^2E\left(\varepsilon_1{}^2\right)-2\gamma(\gamma-1)\bar{Y}^2\bar{X}\left(\alpha\bar{X}+\beta\right)A\alpha E\left(\varepsilon_0\varepsilon_1\right)+2\bar{Y}^2(\gamma-1)\bar{X}^2A^2\alpha^2E\left(\varepsilon_1{}^2\right)$$

$$-2\gamma\bar{Y}^2\bar{X}\left(\alpha\bar{X}+\beta\right)A\alpha E\left(\varepsilon_0\varepsilon_1\right)\Big\}\Big]$$

$$=\frac{1}{\left(\alpha\bar{X}+\beta\right)^2}\Big[\Big\{(\gamma-1)^2\bar{Y}^2\left(\alpha\bar{X}+\beta\right)^2+\bar{Y}^2(\gamma-1)^2A^2\alpha^2S_x^2+\gamma^2\left(\alpha\bar{X}+\beta\right)^2S_y^2+\bar{Y}^2A^2\alpha^2S_x^2$$

$$-2\gamma(\gamma-1)\bar{Y}\left(\alpha\bar{X}+\beta\right)A\alpha S_{xy}+2\bar{Y}^2(\gamma-1)A^2\alpha^2S_x^2-2\gamma\bar{Y}\left(\alpha\bar{X}+\beta\right)A\alpha S_{xy}\Big\}\Big]$$

$$=\frac{1}{\left(\alpha\bar{X}+\beta\right)^2}\left[(\gamma-1)^2\bar{Y}^2\left(\alpha\bar{X}+\beta\right)^2+\bar{Y}^2\gamma^2A^2\alpha^2S_x^2+\gamma^2\left(\alpha\bar{X}+\beta\right)^2S_y^2-2\gamma^2\bar{Y}A\alpha\left(\alpha\bar{X}+\beta\right)S_{xy}\right]$$

$$=\frac{1}{\left(\alpha\bar{X}+\beta\right)^2}\left[(\gamma-1)^2\bar{Y}^2\left(\alpha\bar{X}+\beta\right)^2+\gamma^2\left\{\bar{Y}^2A^2\alpha^2S_x^2+\left(\alpha\bar{X}+\beta\right)^2S_y^2-2\bar{Y}A\alpha\left(\alpha\bar{X}+\beta\right)S_{xy}\right\}\right]$$

$$=\left[(\gamma-1)^2\bar{Y}^2+\gamma^2\left\{S_y^2+\frac{\bar{Y}^2A^2\alpha^2S_x^2}{\left(\alpha\bar{X}+\beta\right)^2}-\frac{2\bar{Y}A\alpha S_{xy}}{\left(\alpha\bar{X}+\beta\right)}\right\}\right] \tag{2.1}$$

which is the mean square error of the estimator under the proposed sampling strategy.

Differentiating (2.1) with respect to constants and equating to zero, we get the optimum values of these constant by solving the two normal equations i.e.

$$\left[(\gamma-1)\bar{Y}^2+\gamma\left\{S_y^2+\frac{\bar{Y}^2A^2\alpha^2S_x^2}{\left(\alpha\bar{X}+\beta\right)^2}-\frac{2\bar{Y}A\alpha}{\left(\alpha\bar{X}+\beta\right)}S_{xy}\right\}\right]=0 \tag{2.2}$$

$$=\left\{2\gamma^2\bar{Y}^2A\alpha^2S_x^2-2\bar{Y}\gamma^2\alpha\left(\alpha\bar{X}+\beta\right)S_{xy}\right\}=0 \tag{2.3}$$

From (2.2) we get

$$\gamma=\frac{\bar{Y}^2}{\bar{Y}^2+\left\{S_y^2+\frac{\bar{Y}^2A^2\alpha^2S_x^2}{\left(\alpha\bar{X}+\beta\right)^2}-\frac{2\bar{Y}A\alpha}{\left(\alpha\bar{X}+\beta\right)}S_{xy}\right\}} \tag{2.4}$$

From (2.3) we get

$$A_{opt}=\frac{S_{xy}}{\bar{Y}\alpha S_x} \tag{2.5}$$

Substituting (2.5) in (2.4), we get

$$\gamma_{opt}=\frac{\bar{Y}^2}{\bar{Y}^2+\left\{S_y^2\left(1-\rho^2\right)\right\}} \tag{2.6}$$

Now minimum mean square error under the proposed sampling strategy is obtained by putting (2.5) and (2.6) in (2.1) we get

$$MSE\left(\bar{y}_{A\gamma}\right)_{opt}=\frac{\bar{Y}^2S_y^2\left(1-\rho^2\right)}{\bar{Y}^2+\left\{S_y^2\left(1-\rho^2\right)\right\}} \tag{2.7}$$

***Efficiency Comparison***

***Comparison with mean per unit estimator***

$$MSE\left(\bar{y}_{A\gamma}\right)<MSE\left(\bar{y}\right)_{wor} \tag{3.1.1}$$

***Comparison with ratio estimator***

$$MSE\left(\bar{y}_{A\gamma}\right)<MSE\left(\bar{y}\right)_{ratio} \tag{3.2.1}$$

***Comparison with product estimator***

$$MSE\left(\bar{y}_{A\gamma}\right)<MSE\left(\bar{y}\right)_{pro} \tag{3.3.1}$$

***Comparison with linear regression estimator***

$$MSE\left(\bar{y}_{A\gamma}\right)_{opt}<MSE\left(\bar{y}_{lr}\right) \tag{3.4.1}$$

***Comparison with generalized ratio estimator***

$$MSE\left(\bar{y}_{A\gamma}\right)_{opt}<MSE\left(\bar{y}_{A}\right)_{opt} \tag{3.5.1}$$

***Empirical study***

Population 1 is taken from the book 'Singh & Chaudhary' from page number 107. Population 2 is taken from the book 'Singh & Chaudhary Singh' from page number 176. Population 3 is taken from the book 'P. V. Sukhatme' from page number 51. Population 4 is taken from the book 'Singh & Chaudhary' from page number 141.

**Table 1** Summary of the data

| Population 1 | | Population 2 | | Population 3 | | Population 4 | |
|---|---|---|---|---|---|---|---|
| N | 12 | N | 20 | N | 25 | N | 22 |
| n | 5 | n | 8 | n | 12 | n | 8 |
| $\overline{X}$ | 27.33 | $\overline{X}$ | 641.05 | $\overline{X}$ | 927.36 | $\overline{X}$ | 22.62 |
| $\overline{Y}$ | 550.33 | $\overline{Y}$ | 816.45 | $\overline{Y}$ | 735.8 | $\overline{Y}$ | 1467.55 |
| $\sigma_y^2$ | 429.59 | $\sigma_y^2$ | 562.21 | $\sigma_y^2$ | 785 | $\sigma_y^2$ | 2503.23 |
| $\sigma_x^2$ | 19.92 | $\sigma_x^2$ | 517.11 | $\sigma_x^2$ | 568.97 | $\sigma_x^2$ | 32.29 |
| $\rho$ | 0.93 | $\rho$ | 0.89 | $\rho$ | 0.96 | $\rho$ | 0.90 |

**Table 2** Mean square error (M) of various estimators

| Estimator | Pop 1 | Pop 2 | Pop 3 | Pop 4 |
|---|---|---|---|---|
| M( $\overline{y}$ ) | 21530.53 | 23706.39 | 26703.08 | 498447.4 |
| M( $\overline{y}_R$ ) | 2876.249 | 6621.88 | 5929.65 | 94906.49 |
| M( $\overline{y}_P$ ) | 77726.36 | 105852.8 | 65139.19 | 1600009 |
| M( $\overline{y}_{lr}$ ) | 2876.07 | 4788.30 | 1892.50 | 92776.46 |
| $M_{min}$( $\overline{y}_{A\gamma}$ ) | **2659.59** | **4369.77** | **1751.23** | **60183.83** |

## CONCLUSION

For all the population, the minimum mean square error of the proposed sampling strategy is less than the mean square error of the mean per unit estimator, ratio estimator, product estimator and the linear regression estimator. Thus the proposed sampling strategy is the best among mean per unit, ratio, product and regression estimator.

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