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Improved Estimation of Population Mean Using Median and Coefficient of Variation of Auxiliary Variable

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Abstract
This manuscript deals with the estimation of population mean of the variable under study using an improved ratio type estimator utilizing the known values of median and coefficient of variation of auxiliary variable. The expressions for the bias and mean square error (MSE) of the proposed estimator are obtained up to the first order of approximation. The optimum estimator is also obtained for the optimum value of the constant of the estimator and its optimum properties are also studied. It is shown that the proposed estimator is better than the existing ratio estimators in the literature. For the justification of the improvement of the proposed estimator over others, an empirical study is also carried out.

Key words: Ratio estimator, Median, bias, mean squared error, efficiency.

I. INTRODUCTION

The simplest estimator for estimating population mean of the variable under study is the sample mean obtained by using simple random sampling without replacement, when the auxiliary information is not known in practice. The auxiliary information in sampling theory which is collected at some previous date when a complete count of the population was made is used for improved estimation of parameters thereby enhancing the efficiencies of the estimators. The variable which provides the auxiliary information is known as auxiliary variable which is highly correlated with the main variable under study. When the parameters of the auxiliary variable X such as Population Mean, Co-efficient of Variation, Co-efficient of Kurtosis, Co-efficient of Skewness, Median etc are known, a number of estimators such as ratio, product and linear regression estimators and their modifications have been proposed in the literature for improved estimation of the population mean of variable under study.

Let $(X_i, Y_i),\ i = 1, 2, ..., N$ be the N pair of observations for the auxiliary and study variables, respectively for the population having N distinct and identifiable units using Simple Random Sampling without Replacement technique of sampling. Let $\bar{X}$ and $\bar{Y}$ be the population means of auxiliary and study variables, respectively and $\bar{x}$ and $\bar{y}$ be the respective sample means. Ratio estimators are used when the line of regression of *y* on *x* passes through origin and the variables *X* and *Y* are positively correlated to each other, while product estimators are used when *X* and *Y* are negatively correlated to each other, otherwise regression estimators are used.

The variance of the sample mean ($t_0 = \bar{y}$) of the variable under study which is an unbiased estimator of population mean is given by,

$$MSE(t_0) = \frac{(1-f)}{n}\bar{Y}^2 C_y^2 = \frac{(1-f)}{n} S_y^2 \tag{1.0}$$

Where $C_y = \frac{S_y}{\bar{Y}}$, $C_x = \frac{S_x}{\bar{X}}$,

$$S_y^2 = \frac{1}{N-1}\sum_{i=1}^{N}(Y_i - \bar{Y})^2, \quad f = \frac{n}{N},$$

$$S_x^2 = \frac{1}{N-1}\sum_{i=1}^{N}(X_i - \bar{X})^2, \quad \rho = \frac{S_{yx}}{S_y S_x},$$

$$S_{yx} = \frac{1}{N-1}\sum_{i=1}^{N}(Y_i - \bar{Y})(X_i - \bar{X}).$$

Cochran (1940) was the first person to use auxiliary Information for the estimation of population mean of the variable under study and proposed the usual ratio estimator as,

$$t_R = \bar{y}\left[\frac{\bar{X}}{\bar{x}}\right] \tag{1.1}$$

The Bias and mean square error (MSE) of the estimator in (1.1) up to the first order of approximation are, respectively, as follows,

$$B(t_R) = \frac{(1-f)}{n}\bar{Y}[C_x^2 - \rho C_y C_x]$$

$$MSE(t_R) = \frac{(1-f)}{n}\bar{Y}^2[C_y^2 + C_x^2 - 2\rho C_y C_x)], \qquad (1.2)$$

As an improvement over the traditional ratio estimator, a large number of modified ratio estimators using known Co-efficient of Variation, Co-efficient of Kurtosis, Co-efficient of Skewness, Median etc of auxiliary variable have been given in the literature. The lists of existing modified ratio estimators to be compared with the proposed estimator, are divided into two classes namely Class 1 and Class 2, and are given respectively in Table 1.1. and Table 1.2. The existing modified ratio estimators together with their biases, mean squared errors and constants available in the literature are presented in the following tables as given by Subramani and Kumarapandiyan [18],

Table 1.1: Existing modified ratio type estimators (Class 1) with their biases, mean squared errors and their constants

Estimator	Bias	Mean Square Error	Constant θ_i
$t_{11} = \bar{y}\left[\frac{\bar{X}+C_x}{\bar{x}+C_x}\right]$ Sisodia and Dwivedi[12]	$\frac{(1-f)}{n}\bar{Y}[\theta_{11}^2 C_x^2 - \theta_{11}\rho C_y C_x]$	$\frac{(1-f)}{n}\bar{Y}^2[C_y^2 + \theta_{11}^2 C_x^2 - 2\theta_{11}\rho C_y C_y]$	$\theta_{11} = \frac{\bar{X}}{\bar{X}+C_x}$
$t_{12} = \bar{y}\left[\frac{\bar{X}+\beta_2}{\bar{x}+\beta_2}\right]$ Singh et.al[10]	$\frac{(1-f)}{n}\bar{Y}[\theta_{12}^2 C_x^2 - \theta_{12}\rho C_y C_x]$	$\frac{(1-f)}{n}\bar{Y}^2[C_y^2 + \theta_{12}^2 C_x^2 - 2\theta_{12}\rho C_y C_y]$	$\theta_{12} = \frac{\bar{X}}{\bar{X}+\beta_2}$
$t_{13} = \bar{y}\left[\frac{\bar{X}+\beta_1}{\bar{x}+\beta_1}\right]$ Yan and Tian[20]	$\frac{(1-f)}{n}\bar{Y}[\theta_{13}^2 C_x^2 - \theta_{13}\rho C_y C_x]$	$\frac{(1-f)}{n}\bar{Y}^2[C_y^2 + \theta_{13}^2 C_x^2 - 2\theta_{13}\rho C_y C_y]$	$\theta_{13} = \frac{\bar{X}}{\bar{X}+\beta_1}$
$t_{14} = \bar{y}\left[\frac{\bar{X}+\rho}{\bar{x}+\rho}\right]$ Singh and Tailor[9]	$\frac{(1-f)}{n}\bar{Y}[\theta_{14}^2 C_x^2 - \theta_{14}\rho C_y C_x]$	$\frac{(1-f)}{n}\bar{Y}^2[C_y^2 + \theta_{14}^2 C_x^2 - 2\theta_{14}\rho C_y C_y]$	$\theta_{14} = \frac{\bar{X}}{\bar{X}+\rho}$
$t_{15} = \bar{y}\left[\frac{\bar{X}C_x+\beta_2}{\bar{x}C_x+\beta_2}\right]$ Upadhyaya and Singh[19]	$\frac{(1-f)}{n}\bar{Y}[\theta_{15}^2 C_x^2 - \theta_{15}\rho C_y C_x]$	$\frac{(1-f)}{n}\bar{Y}^2[C_y^2 + \theta_{15}^2 C_x^2 - 2\theta_{15}\rho C_y C_y]$	$\theta_{15} = \frac{\bar{X}C_x}{\bar{X}C_x+\beta_2}$
$t_{16} = \bar{y}\left[\frac{\bar{X}\beta_2+C_x}{\bar{x}\beta_2+C_x}\right]$ Upadhyaya and Singh[19]	$\frac{(1-f)}{n}\bar{Y}[\theta_{16}^2 C_x^2 - \theta_{16}\rho C_y C_x]$	$\frac{(1-f)}{n}\bar{Y}^2[C_y^2 + \theta_{16}^2 C_x^2 - 2\theta_{16}\rho C_y C_y]$	$\theta_{16} = \frac{\bar{X}\beta_2}{\bar{X}\beta_2+C_x}$
$t_{17} = \bar{y}\left[\frac{\bar{X}\beta_1+\beta_2}{\bar{x}\beta_1+\beta_2}\right]$ Yan and Tian[20]	$\frac{(1-f)}{n}\bar{Y}[\theta_{17}^2 C_x^2 - \theta_{17}\rho C_y C_x]$	$\frac{(1-f)}{n}\bar{Y}^2[C_y^2 + \theta_{17}^2 C_x^2 - 2\theta_{17}\rho C_y C_y]$	$\theta_{17} = \frac{\bar{X}\beta_1}{\bar{X}\beta_1+\beta_2}$
$t_{18} = \bar{y}\left[\frac{\bar{X}\beta_2+\beta_1}{\bar{x}\beta_2+\beta_1}\right]$ Yan and Tian[20]	$\frac{(1-f)}{n}\bar{Y}[\theta_{18}^2 C_x^2 - \theta_{18}\rho C_y C_x]$	$\frac{(1-f)}{n}\bar{Y}^2[C_y^2 + \theta_{18}^2 C_x^2 - 2\theta_{18}\rho C_y C_y]$	$\theta_{18} = \frac{\bar{X}\beta_2}{\bar{X}\beta_2+\beta_1}$
$t_{19} = \bar{y}\left[\frac{\bar{X}+M_d}{\bar{x}+M_d}\right]$ Subramani and	$\frac{(1-f)}{n}\bar{Y}[\theta_{19}^2 C_x^2 - \theta_{19}\rho C_y C_x]$	$\frac{(1-f)}{n}\bar{Y}^2[C_y^2 + \theta_{19}^2 C_x^2 - 2\theta_{19}\rho C_y C_y]$	$\theta_{19} = \frac{\bar{X}}{\bar{X}+M_d}$

Kumarpandiyan [15]			
$t_{110} = \bar{y}\left[\frac{\bar{X}C_x + M_d}{\bar{x}C_x + M_d}\right]$ Subramani and Kumarpandiyan [18]	$\frac{(1-f)}{n}\bar{Y}[\theta_{110}^2 C_x^2 - \theta_{110}\rho C_y C_x]$	$\frac{(1-f)}{n}\bar{Y}^2[C_y^2 + \theta_{110}^2 C_x^2 - 2\theta_{110}\rho C_y C_y]$	$\theta_{110} = \frac{\bar{X}C_x}{\bar{X}C_x + M_d}$

Table 1.2: Existing modified ratio type estimators (Class 2) with their biases, mean squared errors and their constants

Estimator	Bias	Mean Square Error	Constant R_i
$t_{21} = \frac{\bar{y} + b(\bar{X} - \bar{x})}{\bar{x}}\bar{X}$ Kadilar and Cingi [2]	$\frac{(1-f)}{n}\frac{S_x^2}{\bar{Y}}R_{21}^2$	$\frac{(1-f)}{n}[R_{21}^2 S_x^2 + S_y^2(1-\rho^2)]$	$R_{21} = \frac{\bar{Y}}{\bar{X}}$
$t_{22} = \frac{\bar{y} + b(\bar{X} - \bar{x})}{(\bar{x} + C_x)}(\bar{X} + C_x)$ Kadilar and Cingi [2]	$\frac{(1-f)}{n}\frac{S_x^2}{\bar{Y}}R_{22}^2$	$\frac{(1-f)}{n}[R_{22}^2 S_x^2 + S_y^2(1-\rho^2)]$	$R_{22} = \frac{\bar{Y}}{\bar{X} + C_x}$
$t_{23} = \frac{\bar{y} + b(\bar{X} - \bar{x})}{(\bar{x} + \beta_2)}(\bar{X} + \beta_2)$ Kadilar and Cingi [2]	$\frac{(1-f)}{n}\frac{S_x^2}{\bar{Y}}R_{23}^2$	$\frac{(1-f)}{n}[R_{23}^2 S_x^2 + S_y^2(1-\rho^2)]$	$R_{23} = \frac{\bar{Y}}{\bar{X} + \beta_2}$
$t_{24} = \frac{\bar{y} + b(\bar{X} - \bar{x})}{(\bar{x}\beta_2 + C_x)}(\bar{X}\beta_2 + C_x)$ Kadilar and Cingi [2]	$\frac{(1-f)}{n}\frac{S_x^2}{\bar{Y}}R_{24}^2$	$\frac{(1-f)}{n}[R_{24}^2 S_x^2 + S_y^2(1-\rho^2)]$	$R_{24} = \frac{\bar{Y}\beta_2}{\bar{X}\beta_2 + C_x}$
$t_{25} = \frac{\bar{y} + b(\bar{X} - \bar{x})}{(\bar{x}C_x + \beta_2)}(\bar{X}C_x + \beta_2)$ Kadilar and Cingi [2]	$\frac{(1-f)}{n}\frac{S_x^2}{\bar{Y}}R_{25}^2$	$\frac{(1-f)}{n}[R_{25}^2 S_x^2 + S_y^2(1-\rho^2)]$	$R_{25} = \frac{\bar{Y}C_x}{\bar{X}C_x + \beta_2}$
$t_{26} = \frac{\bar{y} + b(\bar{X} - \bar{x})}{(\bar{x} + \beta_1)}(\bar{X} + \beta_1)$ Yan and Tian [20]	$\frac{(1-f)}{n}\frac{S_x^2}{\bar{Y}}R_{26}^2$	$\frac{(1-f)}{n}[R_{26}^2 S_x^2 + S_y^2(1-\rho^2)]$	$R_{26} = \frac{\bar{Y}}{\bar{X} + \beta_1}$
$t_{27} = \frac{\bar{y} + b(\bar{X} - \bar{x})}{(\bar{x} + \rho)}(\bar{X} + \rho)$ Kadilar and Cingi [3]	$\frac{(1-f)}{n}\frac{S_x^2}{\bar{Y}}R_{27}^2$	$\frac{(1-f)}{n}[R_{27}^2 S_x^2 + S_y^2(1-\rho^2)]$	$R_{27} = \frac{\bar{Y}}{\bar{X} + \rho}$
$t_{28} = \frac{\bar{y} + b(\bar{X} - \bar{x})}{(\bar{x}C_x + \rho)}(\bar{X}C_x + \rho)$ Kadilar and Cingi [3]	$\frac{(1-f)}{n}\frac{S_x^2}{\bar{Y}}R_{28}^2$	$\frac{(1-f)}{n}[R_{28}^2 S_x^2 + S_y^2(1-\rho^2)]$	$R_{28} = \frac{\bar{Y}C_x}{\bar{X}C_x + \rho}$
$t_{29} = \frac{\bar{y} + b(\bar{X} - \bar{x})}{(\bar{x}\rho + C_x)}(\bar{X}\rho + C_x)$ Kadilar and Cingi [3]	$\frac{(1-f)}{n}\frac{S_x^2}{\bar{Y}}R_{29}^2$	$\frac{(1-f)}{n}[R_{29}^2 S_x^2 + S_y^2(1-\rho^2)]$	$R_{29} = \frac{\bar{Y}\rho}{\bar{X}\rho + C_x}$
$t_{210} = \frac{\bar{y} + b(\bar{X} - \bar{x})}{(\bar{x}\beta_2 + \rho)}(\bar{X}\beta_2 + \rho)$ Kadilar and Cingi [3]	$\frac{(1-f)}{n}\frac{S_x^2}{\bar{Y}}R_{210}^2$	$\frac{(1-f)}{n}[R_{210}^2 S_x^2 + S_y^2(1-\rho^2)]$	$R_{210} = \frac{\bar{Y}\beta_2}{\bar{X}\beta_2 + \rho}$
$t_{211} = \frac{\bar{y} + b(\bar{X} - \bar{x})}{(\bar{x}\rho + \beta_2)}(\bar{X}\rho + \beta_2)$ Kadilar and Cingi [3]	$\frac{(1-f)}{n}\frac{S_x^2}{\bar{Y}}R_{211}^2$	$\frac{(1-f)}{n}[R_{211}^2 S_x^2 + S_y^2(1-\rho^2)]$	$R_{211} = \frac{\bar{Y}\rho}{\bar{X}\rho + \beta_2}$

$t_{212}=\dfrac{\bar{y}+b(\bar{X}-\bar{x})}{(\bar{x}+M_d)}(\bar{X}+M_d)$ Subramani and Kumarpandiyan [18]	$\dfrac{(1-f)}{n}\dfrac{S_x^2}{\bar{Y}}R_{212}^2$	$\dfrac{(1-f)}{n}[R_{212}^2S_x^2+S_y^2(1-\rho^2)]$	$R_{212}=\dfrac{\bar{Y}\rho}{\bar{X}\rho+\beta_2}$
$t_{213}=\dfrac{\bar{y}+b(\bar{X}-\bar{x})}{(\bar{x}C_x+M_d)}(\bar{X}C_x+M_d)$ Subramani and Kumarpandiyan [18]	$\dfrac{(1-f)}{n}\dfrac{S_x^2}{\bar{Y}}R_{213}^2$	$\dfrac{(1-f)}{n}[R_{213}^2S_x^2+S_y^2(1-\rho^2)]$	$R_{213}=\dfrac{\bar{Y}\rho}{\bar{X}\rho+\beta_2}$

II. PROPOSED ESTIMATOR

Motivated by Prasad (1989) and Subramani and Kumarapandiyan (2012), we have proposed an efficient ratio estimator of population mean utilizing the known values of coefficient of variation and the median of auxiliary variable as,

$$\eta=\kappa\bar{y}\left(\frac{\bar{X}C_x+M_d}{\bar{x}C_x+M_d}\right) \quad (2.1)$$

where κ is a suitable constant to be determined later such that the mean squared error of η is minimum.

In order to study the large sample properties of the proposed estimator η, let us define $e_0=\dfrac{\bar{y}-\bar{Y}}{\bar{Y}}$ and $e_1=\dfrac{\bar{x}-\bar{X}}{\bar{X}}$. Using these notations,

$E(e_0)=E(e_0)=0$, $E(e_0^2)=\dfrac{(1-f)}{n}C_y^2$,

$E(e_1^2)=\dfrac{(1-f)}{n}C_x^2$,

$E(e_0e_1)=\dfrac{(1-f)}{n}C_{yx}=\dfrac{(1-f)}{n}\rho C_yC_x$, the estimators (2.1) may be expressed as,

$\eta=\kappa\bar{Y}(1+e_0)(1+\theta_{110}e_1)^{-1}$,

After simplifying and retaining terms up to the first order of approximation, we have,

$\eta=\kappa\bar{Y}(1+e_0-\theta_{110}e_1-\theta_{110}e_0e_1+\theta_{110}^2e_1^2)$

On subtracting $\bar{Y}$ both the sides of above equation, we obtain,

$$\eta-\bar{Y}=\kappa\bar{Y}(1+e_0-\theta_{110}e_1-\theta_{110}e_0e_1+\theta_{110}^2e_1^2)-\bar{Y} \quad (2.2)$$

Taking expectation along with using above results of (2.2), we have the bias of proposed estimator t as,

$B(\eta)=\lambda\kappa\bar{Y}[\theta_{110}^2C_x^2-\theta_{110}C_{yx}]+\bar{Y}(\kappa-1)$,

where $\lambda=\dfrac{(1-f)}{n}$.

Squaring both sides of (2.2), simplifying and taking expectation on both sides, up to the first order of approximation, we get the mean squared error of the proposed estimator as,

$$MSE(\eta)=\bar{Y}^2\left[\kappa^2\lambda C_y^2+(3\kappa^2-2\kappa)\theta_{110}^2\lambda C_x^2-2(2\kappa^2-\kappa)\theta_{110}\lambda C_{yx}+(\kappa-1)^2\right], \quad (2.3)$$

$MSE(\eta)$ is minimum for,

$$\kappa=\frac{A}{B}=\kappa^*, \quad (2.4)$$

Where,

$A=\theta_{110}^2\lambda C_x^2-\theta_{110}\lambda C_{yx}+1$ and

$B=\lambda C_y^2+3\theta_{110}^2\lambda C_x^2-4\theta_{110}\lambda C_{yx}+1$,

The minimum MSE of the estimator t, for this optimum value of κ, is,

$$MSE_{\min}(\eta)=\bar{Y}^2\left[1-\frac{A^2}{B}\right], \quad (2.5)$$

III. EFFICIENCY COMPARISON

From (2.5) and (1.0), we have,

$MSE_{\min}(\eta)-V(t_0)=\bar{Y}^2\left[1-\dfrac{A^2}{B}-\lambda C_y^2\right]$

$$<0,\ \text{if}\ \frac{A^2}{B}+\lambda C_y^2>1, \quad (3.1)$$

From (2.5) and (1.2), we have,

$MSE_{\min}(\eta)-MSE(t_R)=$

$\dfrac{(1-f)}{n}\bar{Y}^2[1-\dfrac{A^2}{B}-(C_y^2+C_x^2-2\rho C_yC_x)]$

$$<0,\ \text{if}\ 1-\frac{A^2}{B}<(C_y^2+C_x^2-2\rho C_yC_x), \quad (3.2)$$

From (2.5) and the estimators of class 1, we have,

$MSE_{\min}(\eta)-MSE(\mathrm{t}_{1i})$

$=\bar{Y}^2\left[1-\dfrac{A^2}{B}-\lambda[C_y^2+\theta_{1i}^2C_x^2-2\theta_{1i}\rho C_yC_y]\right]$,

$i=1,2,...,11$

$$<0,\ \text{if}\ \frac{A^2}{B}+\lambda[C_y^2+\theta_{1i}^2C_x^2-2\theta_{1i}\rho C_yC_y]>1,\quad i=1,2,...,11 \quad (3.3)$$

From (2.5) and the estimators of class 2, we have,

$MSE_{\min}(\eta) - MSE(t_{2i})$

$= \bar{Y}^2\left[1 - \frac{A^2}{B}\right] - \lambda[R_{2j}^2 S_x^2 + S_y^2(1-\rho^2)]$,

$j = 1, 2, ..., 14$

< 0, if $\bar{Y}^2\left[1 - \frac{A^2}{B}\right] < \lambda[R_{2j}^2 S_x^2 + S_y^2(1-\rho^2)]$,

$j = 1, 2, ..., 14$ (3.4)

IV. NUMERICAL ILLUSTRATION

To study the performances of the existing mentioned ratio type estimators given in class 1 and class 2 along with the proposed estimator, the following population, given in Murthy[5] at page 228 has been take into account. The population parameters are as follows:

Table 3: Parameters of different populations

$N = 80$, $n = 20$, $\bar{Y} = 51.8264$, $\bar{X} = 2.8513$, $\rho = 0.9150$, $S_y = 18.3569$, $C_y = 0.3542$, $S_x = 2.7042$, $C_x = 0.9484$, $\beta_1 = 1.3005$, $\beta_2 = 0.6978$, $M_d = 1.4800$

Table 4: Comparative representation of Biases and Mean Squared Errors of various estimators

Estimator		Bias	MSE	Estimator		Bias	MSE
Class-1	t_0	0	12.6366	Class-2	t_{21}	1.7481	92.6563
	t_R	1.1507	41.3150		t_{22}	0.9844	53.0736
	t_{11}	0.5361	17.1881		t_{23}	0.8245	44.7874
	t_{12}	0.4142	12.8426		t_{24}	1.1086	59.5095
	t_{13}	0.6484	21.3660		t_{25}	0.7971	43.3674
	t_{14}	0.5497	17.6849		t_{26}	1.1283	60.5325
	t_{15}	0.3937	12.1351		t_{27}	1.0019	53.9825
	t_{16}	0.6328	20.7801		t_{28}	0.9759	52.6365
	t_{17}	0.7355	24.6969		t_{29}	0.9403	50.7876
	t_{18}	0.6297	20.6613		t_{210}	1.1246	60.3426
	t_{19}	0.3643	11.1366		t_{211}	0.7785	42.4051
	t_{110}	0.3441	10.4605		t_{212}	0.7680	41.3191
Proposed	η	**-0.1959**	**10.1798**		t_{213}	0.7540	39.8990

V. RESULTS AND CONCLUSION

It has been shown theoretically as well as empirically that the proposed improved ratio type estimator of population mean of the study variable utilizing the known values of the coefficient of variation and the median of the auxiliary variable has lesser mean squared error than the existing estimators mentioned under class 1 and class 2, given in table 1 and table 2 respectively. Therefore the proposed estimator should be preferred over above estimators given in table-1.1 and table-1.2 for the estimation of population mean in simple random sampling.

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