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Assessing the Efficiencies of Different Ratio Estimators for Estimating Average Production of Sugarcane Yield

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Abstract
In this research paper, we conducted a thorough examination of various existing ratio estimators utilizing a single auxiliary variable by analyzing real population data. The study systematically compares their efficiencies, employing a robust methodology. The experimental setup involves the selection of a sample from a real population, utilizing the simple random sampling without replacement method. Unlike simulations, our approach involves direct application to actual population data, enhancing the external validity of the findings. We evaluate the performance of different ratio estimators concerning bias, mean square error, providing valuable insights into their real-world applicability. The results revealed that, the estimator t_{13} is the most efficient and t_2 is the least efficient estimator of population mean. This comprehensive analysis contributes valuable insights into the comparative efficiency and performance characteristics of various ratio estimators under the given conditions, providing a detailed understanding of their applicability in estimating population parameters.

Keywords: Sampling, Main Variable, Auxiliary Variable, Bias, MSE.

Introduction

Sample surveys serve as a widely employed and cost-effective means of gathering data to draw valid inferences about the population parameters. Within the realm of sample surveys, it becomes feasible to not only measure the specific characteristic under study but also to assess other relevant attributes that exhibit a high correlation with the study variable. This supplementary data, known as auxiliary information, contributes valuable insights to the overall understanding of the subject matter. Numerous sample surveys have been conducted both in India and internationally, leveraging auxiliary information that demonstrates a significant correlation with the variable of interest. This strategic utilization of additional information enhances the precision and comprehensiveness of the findings, enabling researchers and policymakers to derive more nuances insights into the intricacies of the studied phenomena. Consequently, the incorporation of auxiliary information in sample surveys becomes a private tool in enhancing the accuracy and reliability of the conclusions drawn from the collected data.

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Tripathi (1978) employed auxiliary information from one or more variables in sample surveys through three fundamental approaches Muhammad *et al.* (2019), Kumar and Kumar (2020), Ahuja *et al.* (2021) and others have extensively employed auxiliary information in various forms. This application of auxiliary information aims to enhance the performance of estimators for the study variable. Particularly, the ratio estimator tends to exhibit robust performance when a positive correlation exists between the study variable and auxiliary variables.

The effectiveness of the ratio method of estimation has been further refined by Sisodia and Dwivedi (1981), Bahl and Tuteja (1991), Upadhyaya and Singh (1991), and Kadilar and Cingi (2004). Noteworthy contributions to different aspects of the ratio method of estimation include works by Subramani and Kumarapandiyan (2012), Abid *et al.* (2016), Kanwai *et al.* (2016), Singh *et al.* (2019), Yadav *et al.* (2020), Baghel and Yadav (2020), Singh and Yadav (2020) , Tiwari *et al.* (2021) Nderitu *et al.* (2022), Ali *et al.* (2023) and Adejumobi *et al.* (2023). These studies collectively contribute to the ongoing development and refinement of ratio-based estimation methods in sample surveys. In statistical research, obtaining authentic real-world data sets for the purpose of comparing estimators under practical conditions can be a complex endeavour. Recognizing the inherent challenges in sourcing genuine data, this study deviates from conventional approaches and relies on an actual data set for the assessment of estimators. Unlike simulation-based methods, which generate synthetic data, the methodology employed here involves scrutinizing the properties of estimators using a bona fide data set.

Drawing inspiration from the need for empirical relevance, this research endeavours to contribute insights based on the analysis of estimators applied to a real data set. This departure from simulation-based studies ensures that the findings are grounded in the complexities and nuances present in the actual data, providing a more authentic basis for assessing the performance of the estimators under examination.

Materials and Method

Table 1: List of different ratio estimators of population mean with their bias and mean squared errors

Estimator	Bias	Mean Square Error
$t_r = \bar{y}\left(\frac{\bar{X}}{\bar{x}}\right)$ Cochran (1940)	$\frac{(1-f)}{n}\bar{Y}[C_x^2 - \rho C_y C_x]$	$\frac{(1-f)}{n}\bar{Y}^2[C_y^2 + C_x^2 - 2\rho C_y C_x]$
$t_1 = \bar{y}\left(\frac{\bar{X}+C_x}{\bar{x}+C_x}\right)$ Sisodia and Dwivedi (1981)	$\frac{(1-f)}{n}\bar{Y}[\theta_1^2 C_x^2 - \theta_1 \rho C_y C_x]$	$\frac{(1-f)}{n}\bar{Y}^2[C_y^2 + \theta_1^2 C_x^2 - 2\theta_1 \rho C_y C_x]$

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$t_2 = \bar{y}\left(\frac{\bar{X}C_x + \beta_2}{\bar{x}C_x + \beta_2}\right)$ Upadhyaya and Singh (1999)	$\frac{(1-f)}{n}\bar{Y}[\theta_2^2 C_x^2 - \theta_2 \rho C_y C_x]$	$\frac{(1-f)}{n}\bar{Y}^2[C_y^2 + \theta_2^2 C_x^2 - 2\theta_2 \rho C_y C_x]$
$t_3 = \bar{y}\left(\frac{\bar{X}\beta_2 + C_x}{\bar{x}\beta_2 + C_x}\right)$ Upadhyaya and Singh (1999)	$\frac{(1-f)}{n}\bar{Y}[\theta_3^2 C_x^2 - \theta_3 \rho C_y C_x]$	$\frac{(1-f)}{n}\bar{Y}^2[C_y^2 + \theta_3^2 C_x^2 - 2\theta_3 \rho C_y C_x]$
$t_4 = \bar{y}\left(\frac{\bar{X} + \rho}{\bar{x} + \rho}\right)$ Singh and Tailor (2003)	$\frac{(1-f)}{n}\bar{Y}[\theta_4^2 C_x^2 - \theta_4 \rho C_y C_x]$	$\frac{(1-f)}{n}\bar{Y}^2[C_y^2 + \theta_4^2 C_x^2 - 2\theta_4 \rho C_y C_x]$
$t_5 = \bar{y}\left(\frac{\bar{X} + \beta_2}{\bar{x} + \beta_2}\right)$ Singh *et al.* (2004)	$\frac{(1-f)}{n}\bar{Y}[\theta_5^2 C_x^2 - \theta_5 \rho C_y C_x]$	$\frac{(1-f)}{n}\bar{Y}^2[C_y^2 + \theta_5^2 C_x^2 - 2\theta_5 \rho C_y C_x]$
$t_6 = \bar{y}\left(\frac{\bar{X} + \beta_1}{\bar{x} + \beta_1}\right)$ Yan and Tian (2010)	$\frac{(1-f)}{n}\bar{Y}[\theta_6^2 C_x^2 - \theta_6 \rho C_y C_x]$	$\frac{(1-f)}{n}\bar{Y}^2[C_y^2 + \theta_6^2 C_x^2 - 2\theta_6 \rho C_y C_x]$
$t_7 = \bar{y}\left(\frac{\bar{X}C_x + \beta_1}{\bar{x}C_x + \beta_1}\right)$ Yan and Tian (2010)	$\frac{(1-f)}{n}\bar{Y}[\theta_7^2 C_x^2 - \theta_7 \rho C_y C_x]$	$\frac{(1-f)}{n}\bar{Y}^2[C_y^2 + \theta_7^2 C_x^2 - 2\theta_7 \rho C_y C_x]$
$t_8 = \bar{y}\left(\frac{\bar{X}C_x + M_d}{\bar{x}C_x + M_d}\right)$ Subramani and Kumarpandiyan (2012)	$\frac{(1-f)}{n}\bar{Y}[\theta_8^2 C_x^2 - \theta_8 \rho C_y C_x]$	$\frac{(1-f)}{n}\bar{Y}^2[C_y^2 + \theta_8^2 C_x^2 - 2\theta_8 \rho C_y C_x]$
$t_9 = \bar{y}\left(\frac{\bar{X}\beta_1 + Q_d}{\bar{x}\beta_1 + Q_d}\right)$ Jeelani *et al.* (2013)	$\frac{(1-f)}{n}\bar{Y}[\theta_9^2 C_x^2 - \theta_9 \rho C_y C_x]$	$\frac{(1-f)}{n}\bar{Y}^2[C_y^2 + \theta_9^2 C_x^2 - 2\theta_9 \rho C_y C_x]$
$t_{10} = \bar{y}\left(\frac{\bar{X} + n}{\bar{x} + n}\right)$ Jerajuddin and Kishun (2016)	$\frac{(1-f)}{n}\bar{Y}[\theta_{10}^2 C_x^2 - \theta_{10} \rho C_y C_x]$	$\frac{(1-f)}{n}\bar{Y}^2[C_y^2 + \theta_{10}^2 C_x^2 - 2\theta_{10} \rho C_y C_x]$

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$t_{11} = \bar{y}\left(\frac{\bar{X}n+\rho}{\bar{x}n+\rho}\right)$ Yadav *et al.* (2019)	$\frac{(1-f)}{n}\bar{Y}[\theta_{11}^2 C_x^2 - \theta_{11}\rho C_y C_x]$	$\frac{(1-f)}{n}\bar{Y}^2[C_y^2 + \theta_{11}^2 C_x^2 - 2\theta_{11}\rho C_y C_x]$
$t_{12} = \bar{y}\left(\frac{\bar{X}n+C_x}{\bar{x}n+C_x}\right)$ Yadav *et al.* (2019)	$\frac{(1-f)}{n}\bar{Y}[\theta_{12}^2 C_x^2 - \theta_{12}\rho C_y C_x]$	$\frac{(1-f)}{n}\bar{Y}^2[C_y^2 + \theta_{12}^2 C_x^2 - 2\theta_{12}\rho C_y C_x]$
$t_{13} = \bar{y}\left(\frac{\bar{x}}{\bar{X}}\right)^{\alpha}[\beta exp\{\frac{(a\bar{X}+b)-(a\bar{x}+b)}{(a\bar{X}+b)+(a\bar{x}+b)}\} + (1-\beta)\{1 + log\frac{(a\bar{x}+b)}{(a\bar{X}+b)}\}]$ Ali *et al.* (2023)	$\frac{(1-f)}{n}\bar{Y}(\frac{7}{8}\beta\theta^2 C_x^2 - \frac{1}{2}\theta^2 C_x^2 - \frac{3}{2}\alpha\beta\theta C_x^2 + \alpha\theta C_x^2 + \frac{\alpha(\alpha-1)}{2!}C_x^2 - \frac{3}{2}\beta\theta C_{yx} + \theta C_{yx} + \alpha C_{yx})$	$\bar{Y}^2(A + \alpha^2 B + \alpha C + \beta^2 D - \beta F - \alpha\beta F)$

Where,

$A = \lambda(\theta^2 C_x^2 + C_F^2 + 2\theta C_{yx}), B = \lambda C_x^2$

$C = 2\lambda(\theta C_x^2 + C_{yx})$

$D = \frac{9}{4}\lambda\theta^2 C_x^2$

$F = 3\lambda\theta^2 C_x^2 + 3\lambda\theta C_{yx})$

$G = 3\lambda\theta C_x^2$

and the optimum values of α and β respectively are,

$\alpha = \frac{(FG-2DC)}{(4BD-G^2)}$, $\beta = \frac{(2BF-CG)}{(4BD-G^2)}$

$\theta_1 = \frac{\bar{X}}{\bar{X}+C_x}$, $\theta_2 = \frac{\bar{X}C_x}{\bar{X}C_x+\beta_2}$, $\theta_3 = \frac{\bar{X}\beta_2}{\bar{X}\beta_2+C_x}$, $\theta_4 = \frac{\bar{X}}{\bar{X}+\rho}$, $\theta_5 = \frac{\bar{X}}{\bar{X}+\beta_2}$, $\theta_6 = \frac{\bar{X}}{\bar{X}+\beta_1}$

$\theta_7 = \frac{\bar{X}C_x}{\bar{X}C_x+\beta_1}$, $\theta_8 = \frac{\bar{X}C_x}{\bar{X}C_x+M_d}$, $\theta_9 = \frac{\bar{X}\beta_1}{\bar{X}\beta_1+Q_d}$, $\theta_{10} = \frac{\bar{X}}{\bar{X}+n}$, $\theta_{11} = \frac{\bar{X}n}{\bar{X}n+\rho}$, $\theta_{12} = \frac{\bar{X}n}{\bar{X}n+C_x}$

$\theta = \frac{a\bar{X}}{a\bar{X}+b}$, where, a and b can be either a constant or any of the auxiliary variable's parameters, such as n, C_x, β_1, β_2, **ρ**, Q_d, MR, M_d, and fourth and sixth decile of the secondary variable or quartiles of auxiliary variable but here we have considered $a = n$, $b = \beta_1$.

Numerical Study

In this segment, comparison of various estimators has been made using a real population dataset. The parameters and constants pertinent to the study are elucidated in Table 2.

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Table 2: Parameters of population under inspection

N =181	$n = 25$	$S_x = 0.519118$	S_y=453.9736
$C_x = 0.526141$	$C_y = 0.500406$	$\bar{Y}$= 907.210	$\bar{X}$= 0.987
D6 =0.961	$\beta_1 = 3.4641$	$\beta_2 = 19.49481$	$M_d = 0.890$
$QD = 0.204$	$Q_1 = 0.71$	$Q_3 = 1.118$	$\rho = 0.923328$

Table 3: Bias and MSEs of different estimators

Estimator	Bias	MSE	PRE
t_0	1.055	1164.341	1
t_1	-1.276	1448.507	0.8038
t_2	-0.191	6752.394	0.1724
t_3	-1.640	2190.552	0.5315
t_4	-1.617	2074.212	0.5613
t_5	-0.346	6458.505	0.1803
t_6	-1.260	4432.24	0.2627
t_7	-0.844	5440.093	0.2140
t_8	-1.626	3088.21	0.3770
t_9	-0.582	1104.108	1.0546
t_{10}	-0.276	6592.426	0.1766
t_{11}	0.716	1105.525	1.0532
t_{12}	0.856	1127.806	1.0324
t_{13}	-0.0096	1047.762	1.1113

The results in Table 3 have also been presented in the form of graph in Figure 1.

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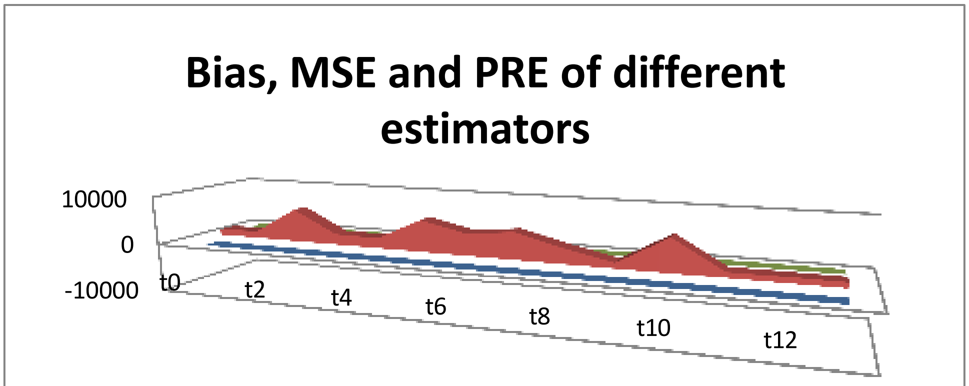

	t0	t1	t2	t3	t4	t5	t6	t7	t8	t9	t10	t11	t12	t13
Bias	1.06	-1.3	-0.2	-1.6	-1.6	-0.3	-1.3	-0.8	-1.6	-0.6	-0.3	0.72	0.86	-0
MSE	1164	1449	6752	2191	2074	6459	4432	5440	3088	1104	6592	1106	1128	1048
PRE	1	0.8	0.17	0.53	0.56	0.18	0.26	0.21	0.38	1.05	0.18	1.05	1.03	1.11

Figure 1: Bias, MSE and PRE of different estimators

Table 3 provides the bias, MSE and PRE of different estimators. Correlation coefficient between the auxiliary variable and main variable was 0.9233 and the sample size taken was 25. It is concluded from the table that the estimator by Ali *et al.* (t_{13}) was the best estimator and estimator by Upadhyaya and Singh (t_2) was the least performing estimator.

Result and Conclusion

Table 3 presents the bias, Mean Squared Error (MSE), and Percent Relative Efficiencies (PRE) values for various estimators. With a correlation coefficient of 0.9233 between the auxiliary and main variables, and a sample size of 25, the analysis indicates that the estimator proposed by Ali et al. (t_{13}) emerged as the most effective, while the estimator by Upadhyaya and Singh (t_2) demonstrated the lowest performance among the considered estimators. This thorough examination enhances our understanding of the relative efficiency and performance attributes of diverse ratio estimators across varying conditions. The findings offer valuable insights, shedding light on the practical suitability of these estimators for accurately estimating population parameters with real-world data.

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