CHAIN REGRESSION-TYPE ESTIMATOR USING MULTIPLE AUXILIARY INFORMATION IN SUCCESSIVE SAMPLING

HOUSILA P. SINGH[1], MANOJ KUMAR SRIVASTAVA[2], NAMITA SRIVASTAVA[3], TANVEER A. TARRAY[1], VIRENDRA SINGH[2], AND SHIVAM DIXIT[2]

Abstract. In successive sampling, the use of auxiliary information for estimation of population mean on current occasion is a well explored area. In the present work, the information on an auxiliary variable, which is available on both the occasions, is used along with the information on the study variable from the previous occasion and the current occasion. Consequently, chain regression-type estimator for estimating the population mean are proposed in two occasions successive sampling. The optimal replacement policy is also discussed. We have also given an empirical study along with pictorial representation to examine the merit of the proposed estimator.

Keywords: Successive sampling, Chain type ratio estimator, Optimal replacement policy, Rotation pattern, Auxiliary information, Double sampling.

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1. Introduction

When a population is subject to change over time, a survey on a single occasion does not provide information about the nature of change or the rate of change of the characteristics over different occasions and the average value of the characteristic for the most recent occasion or current occasion. To meet these objectives, sampling is done on successive occasions by retaining some units, drawn on the first occasion for its use on the second occasion and replacing the remaining by units drawn on fresh from the current occasion. The related theory and methods are called successive sampling which has drawn considerable attention of survey statisticians. This provides a strong mechanism to produce a reliable estimate of the population mean at the current occasion. In successive sampling over two occasions, the information on the study variable on the first occasion has been utilized as auxiliary information, which provides a strong mechanism to produce a reliable estimate of the population mean on the current occasion. Some of the reference in this area are Jessen (1942), Yates (1949), Patterson (1950), Tikkiwal (1951), Eckler (1955), Rao and Graham (1964), Singh and Kathuria (1969), Sen (1971, 1972, 1973a, 1973b), Cochran (1977) and Chaturvedi and Tripathi (1983).

[1] School of studies in Statistics, Vikram University, Ujjain-456010

[2] Institue of Social Sciences, Dr. B. R. A. University, Agra-282002,U.P.-India

[3] Department of Statistics, St. John,s College, Agra

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Sometimes, the information on auxiliary variables, which are strongly related to the study variable, is available so that their population means are known. The question arises that whether it is possible to utilize the information on the auxiliary variables, which are available on both the occasions, to increase the precision for estimating the population mean on the current occasion. For example in agriculture, the crop infestation due to a pest or disease during a week, in a particular area, may be associated with infestation and ancillary factors such as rainfall, temperature and humidity during the preceding week. Similarly, the yield of a crop during a season in a farm is known to depend to a great extend on the climatic factors, prevailing during the previous season. In biological populations we may be interested to estimate the kill of birds during a season by a hunter in a locality, which is known to be related to the hunter's kill and his disposable income during the previous season. Utilizing the auxiliary information on both the occasions, Feng and Zou (1997), Biradar and Singh (2001), Singh and Priyanka (2007) have proposed a variety of estimators of population mean on the current occasion.

Motivated by Chands (1975) chain technique, Singh and Priyanka (2008) used the auxiliary information on both the occasions and developed estimators for estimating the population mean on the current occasion in two occasions successive sampling and have discussed their properties.

In the present paper, a chain regression-type difference estimator is proposed for estimating the population mean on the current occasion. Through an empirical investigation the proposed estimator is shown to perform better than Singh and Priyanka (2008) estimator in terms of efficiency. It is noted that higher optimum value of (the fraction of the sample taken afresh on the second (current) occasion) is required for the proposed estimator than for Singh and Priyanka estimator when relationship between study variables over two occasions is weak, however, the proposed estimator reports high gain in efficiency. Thus, in case of efficiency is a priority and budget is not a limitation, it is shown that the proposed estimator is superior to Singh and Priyanka (2008) estimator more particularly when relationship between study variables over two occasions is weak.

2. Formulation of Estimator

2.1. **Notations and Sampling scheme.** Consider a finite population $U = (U_1, U_2, \cdots, U_N)$ with $N(< \infty)$ identifiable units. Let the character under study be denoted by $x(y)$ on the first (second) occasion, respectively. It is assumed that information on an auxiliary variable z is known on the first and second occasions both. We assume that the variable z is closely and positively related with the study variable y . The objective of the present paper is to estimate population mean at the current occasion. For this a sample of size n is drawn from the population on the first occasion by simple random sampling without replacement (SRSWOR) scheme. The observations on z and x are taken for every unit selected in the sample. Out of this sample a subsample of size m is retained (matched subsample) for its use on the second occasion. The y observations are taken on the retained units of the matched subsample on the current occasion. Further, a fresh sample

of size $u = n - m = n\mu$ is drawn on the second occasion from the remaining $N - n$ units of the population by simple random sampling without replacement scheme so that total sample size on the second occasion is maintained at n . It is assumed that population is large enough so that finite population correction terms can be ignored. Following notations are used in the present work.
$\bar{X}, \bar{Y}, \bar{Z}$: Population mean of x, y and z respectively.
$\bar{x}_n, \bar{x}_m, \bar{y}_u, \bar{y}_m, \bar{z}_n, \bar{z}_m, \bar{z}_u$: Sample means of the respective variables based on sample sizes shown in suffices
$\rho_{yx}, \rho_{xz}, \rho_{yz}$: Correlation coefficient between the variables given in the subscript.
S_x^2, S_y^2, S_z^2 : Population variance for the variables and .

2.2. **Proposed Chain Regression-Type Estimator.** Two independent regression-type estimators are suggested for estimating the population mean $\bar{Y}$ on the current occasion. The first estimator is based on sample of size u drawn afresh on the second occasion. The first estimator is a regression estimator defined as

$$T_{1u} = \bar{y}_u + b_{yz}(u)(\bar{Z} - \bar{z}_u) \tag{2.1}$$

where $b_{yz}(u)$ is the sample regression coefficient of y on z based on sample of size u . The second estimator is based on matched subsample of size m which is the common to both the occasions. Motivated by Tripathi and Ahmed (1995) and Ahmad (1998) we define a regression-type estimator based on the sample of size $m = (n\lambda)$ common with both the occasions as ,

$$T_{2m} = \bar{y}_m + b_{yx\cdot z}(m)(\bar{x}_n - \bar{x}_m) + b_{yz\cdot x}(m)(\bar{z}_n - \bar{z}_m) + b_{yz}(n)(\bar{Z} - \bar{z}_n) \tag{2.2}$$

where $b_{yx\cdot z}(m)$ and $b_{yz\cdot x}(m)$ are the sample partial regression coefficients between the variables shown in suffices and based on sample of size m; and $b_{yz}(n)$ is the sample regression coefficient between the variables y and z based on sample of size n. The estimator $(i.e. T_{2m})$ can be also obtained from the equation (9.7.2) in , Sarndal Swensson and Wretman (1992). Combining the estimators T_{1u} and T_{2m}, we have the final estimator of the population mean $\bar{Y}$ as

$$T_c = \phi T_{1u} + (1 - \phi)T_{2m} \tag{2.3}$$

where ϕ is a constant to be determined such that the variance of T_c is minimum.

Adopted the standard techniques given in Cochran (1977, pp.193-194), the variance of the regressiontype estimators T_{1u} and T_{2m} to the first degree of approximation (ignoring finite population correction terms) can be easily obtained as

$$V(T_{1u}) = (S_y^2/u)(1 - \rho_{yz}^2) \tag{2.4}$$

and

$$V(T_{2m}) = (S_y^2/m)[1 - \rho_{y\cdot xz}^2 + (m/n)(\rho_{y\cdot xz}^2 - \rho_{yz}^2) \tag{2.5}$$

where

$$\rho^2_{y\cdot xz} = \frac{(\rho^2_{yx} + \rho^2_{yz} - 2\rho_{yz}\rho_{yx}\rho_{xz}}{(1-\rho^2_{xz})}$$

Thus the variance of the combined estimator T_c is given by

$$V(T_c) = \phi^2 V(T_{1u}) + (1-\phi)^2 V(T_{2m}) \tag{2.6}$$

which is minimum when

$$\phi = \frac{V(T_{2m})}{V(T_{1u}) + V(T_{2m})} = \phi_{opt}(say)$$
$$= \frac{\mu(A+\mu B)}{A+\mu^2 B} \tag{2.7}$$

where, $\lambda = m/n, \mu = u/n, A = (1-\rho^2_{yz}), B = \frac{(\rho_{yx}-\rho_{yz}\rho_{xz})^2}{(1-\rho^2_{xz})}$.
Here we note that in the expression (2.6), we have not taken the term $\text{cov}(T_{1u}, T_{2m})$ into account because for large population size (i.e. N is very-very large), the term $\text{cov}(T_{1u}, T_{2m})$ is negligible. (i.e. $\lim_{N\to\infty} \text{cov}(T_{1u}, T_{2m}) \to 0$.

Substitution of (2.7) in (2.6) yields the variance of T_c as

$$V(T_c)_{opt} = \frac{V(T_{2u})V(T_{2m})}{V(T_{1u}) + V(T_{2m})}$$
$$= \frac{S^2_y}{n}\frac{A(A+\mu B)}{A+\mu^2 B} \tag{2.8}$$

. Under the assumption $\rho_{xz} = \rho_{yz}$, which has been earlier considered by Cochran (1977), Feng and Zou (1997) and Singh and Priyanka (2008); the expression in (2.8) reduces to

$$V(T_c)_{opt} = \frac{S^2_y}{n}\frac{A(A+\mu B^*)}{A+\mu^2 B^*} \tag{2.9}$$

where

$$B^* = -(\rho_{yx} - \rho^2_{yz})^2/(1-\rho^2_{yz})$$

2.3. **Comparison of T_c with chain regression-type estimator $T_c^{(1)}$ due to Singh and Priyanka (2008).** Using the technique due to Chand (1975), Singh and Priyanka (2008) proposed a chain type regression estimator of population mean on the current occasion by

$$T_c^{(1)} = \phi T_{1u}^{(1)} + (1-\phi)T_{2m}^{(1)} \tag{2.10}$$

with

$$T_{1u}^{(1)} = \bar{y}_u + b_{yz}(u)(\bar{Z} - \bar{z}_u) \tag{2.11}$$

$$T_{2m}^{(1)} = \bar{y}^*_m + b_{yx}(m)(\bar{x}^*_n - \bar{x}^*_m) \tag{2.12}$$

where

$$\bar{y}^*_m = \bar{y}_m + b_{yz}(m)(\bar{Z} - \bar{z}_m),$$
$$\bar{x}^*_n = \bar{x}_n + b_{xz}(n)(\bar{Z} - \bar{z}_n),$$
$$\bar{x}^*_m = \bar{x}_m + b_{xz}(m)(\bar{Z} - \bar{z}_m),$$

The variances of the estimators $T_{1u}^{(1)}$ and $T_{2m}^{(1)}$ to the first degree of approximation (ignoring finite population correction terms) are respectively given by .

$$V(T_{1u}^{(1)}) = \left(\frac{S_y^2}{u}\right)\left(1-\rho_{yz}^2\right)$$

$$V(T_{2m}^{(1)}) = S_y^2\left[\left(\frac{1}{m}\right)(1-\rho_{yz}^2) + \left(\frac{1}{m}-\frac{1}{n}\right)\{2\rho_{yz}^2\rho_{yx} - \rho_{yx}^2(1+\rho_{yz}^2)\}\right]$$

The variance of $V(T_{2m}^{(1)})$ is derived under the assumption that $\rho_{xz} = \rho_{yz}$ which has been earlier considered by Cochran (1977) and Feng and Zou (1997). Thus the variance of the estimator $T_c^{(1)}$ is given by

$$V(T_c^{(1)}) = \frac{1}{\mu(1-\mu)}[\phi^2(1-\mu)A + (1-\phi)^2\mu(A+\mu B_1)]\frac{S_y^2}{n} \tag{2.13}$$

where $B_1 = 2\rho_{yz}^2\rho_{yx} - \rho_{yx}^2(1+\rho_{yz}^2)$ and $\mu = u/n$ is the fraction of the sample taken a fresh on the second (current) occasion.

The variance of the estimator $T_c^{(1)}$ in (2.13) is minimum for

$$\phi^* = \frac{\mu(A+\mu B_1)}{A+\mu^2 B_1} \tag{2.14}$$

Thus, the resulting variance of $T_c^{(1)}$ is given by

$$\min V(T_c^{(1)}) = \frac{S_y^2}{n}\frac{A(A+\mu B_1)}{A+\mu^2 B_1} \tag{2.15}$$

From (2.9) and (2.15), we have

$$\min V(T_c^{(1)}) - \min V(T_c) = \left(\frac{S_y^2}{n}\right)\frac{A\mu(1-\mu)\rho_{yz}^4(1-\rho_{yx})^2}{(A+\mu^2 B_1)(A+\mu^2 B^*)} \tag{2.16}$$

which is always positive.
It follows that the proposed chain regression- type estimator T_c is superior to the chain regression-type estimator $T_c^{(1)}$ due to Singh and Priyanka (2008).

3. Optimum Replacement Policy for T_c

To determine the optimum value of the sample fraction for the required sample to be drawn afresh on the second occasion to estimate population mean $\bar{Y}$ we minimize the minimum variance of the combined estimator in equation (2.9) with respect to μ . The resulting quadratic equation in μ is given by

$$B^*\mu^2 + 2A\mu - A = 0 \tag{3.1}$$

Solving equation (3.1) we get the optimum value for μ

$$\hat{\mu} = \frac{-A \pm \sqrt{A(A+B^*)}}{B^*} \tag{3.2}$$

provided $A(A+B^*) \geq 0$.

Only those value of μ are admissible for which $0 \leq \mu \leq 1$. Otherwise, it is stated that μ does not exist. With this optimum value of μ say μ_0 the minimum $M(T_c)_{opt}$ is given by

$$M(T_c)_{opt} = \frac{S_y^2}{n}\frac{A[A+\mu_0 B^*]}{[A+\mu_0^2 B^*]} \tag{3.3}$$

4. Efficiency Comparison

The proposed estimator T_c is compared with the two estimators namely $\bar{y}_n$, and combined regression-type estimator $\bar{y}_{CD}$. The estimator $\bar{y}_n$ refers to a situation when there is no matching, and , $\bar{y}_{CD} = \psi\bar{y}_u + (1-\psi)\bar{y}_{ld}$, refers to a situation when no auxiliary information is used at any occasion. Here, $\bar{y}_{ld}$ is the regression estimator defined by $\bar{y}_{ld} = \bar{y}_m + b_{yx}(m)(\bar{x}_n - \bar{x}_m)$.

The variance of $\bar{y}_n$ (ignoring fpc terms) is given by

$$V(\bar{y}_n) = \frac{S_y^2}{n} \tag{4.1}$$

and the variance of the estimator $\bar{y}_{CD}$ to the first degree of approximation (ignoring fpc terms) under optimum condition is given by

$$V_{opt}(\bar{y}_C D) = \frac{S_y^2}{n}[1+\sqrt{1-\rho_{yx}^2}] \tag{4.2}$$

The percent relative efficiencies of the proposed estimator T_c and $T_c^{(1)}$ with respect to $\bar{y}_n$ and $\bar{y}_{CD}$ have been calculated for different values of ρ_{yx} and ρ_{yz}

$$E_1(T_c) = \frac{V\bar{y}_n}{V(T_c)_{opt}|_{\mu_0}} \times 100 \quad and\ E_2(T_c) = \frac{V_{opt}\bar{y}_{CD}}{V(T_c)_{opt}|_{\mu_0}} \times 100$$

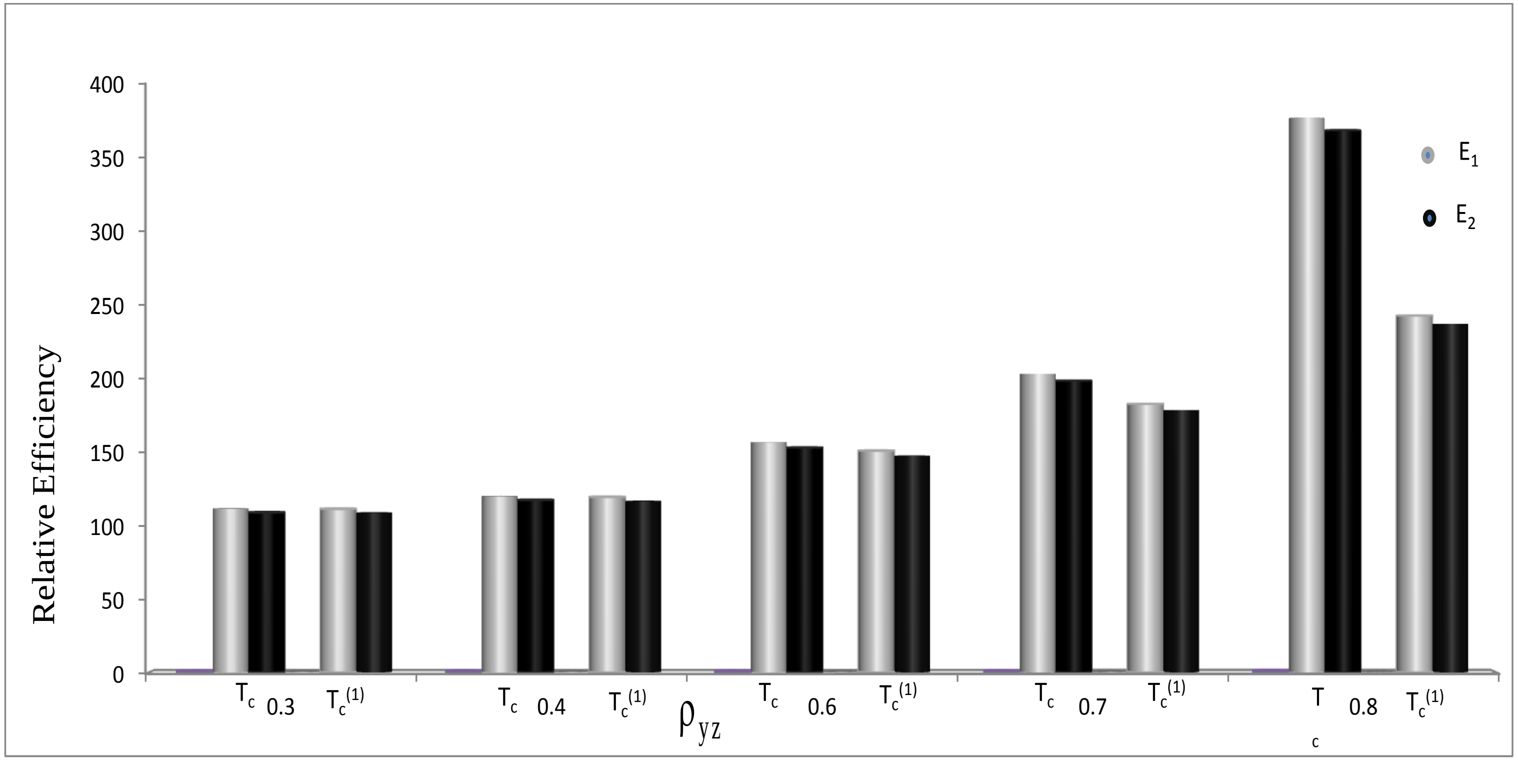
$$E_1(T_c^{(1)}) = \frac{V\bar{y}_n}{V(T_c^{(1)})_{opt}|_{\mu_0}} \times 100 \quad and E_2(T_c^{(1)}) = \frac{V_{opt}\bar{y}_{CD}}{V(T_c^{(1)})_{opt}|_{\mu_0}} \times 100 \tag{4.3}$$

Findings are shown in Table 4.1. A pictorial representation of $E_i(T_c)$ and $E_i(T_c^{(1)}), i = 1,2$ is given in figure 4.1.

TABLE 1. Relative Efficiencies (%) of T_c and $T_c^{(1)}$ with respect to $\bar{y}_n$ and $\bar{y}_{CD}$

		ρ_{yx}											
		0.3		0.4		0.5		0.6		0.7		0.8	
ρ_{yz}		T_c	$T_c^{(1)}$	T_c	$T_c^{(1)}$	T_c	$T_c^{(1)}$	T_c	$T_c^{(1)}$	T_c	$T_c^{(1)}$	T_c	$T_c^{(1)}$
	μ_0	0.5068	0.5062	0.5154	0.5149	0.5283	0.5279	0.5470	0.5467	0.6152	0.6151	0.6869	0.6869
0.3	E_0	111.39	111.25	113.28	113.17	116.12	116.03	120.22	120.16	135.21	135.18	150.97	150.96
	E_2	108.83	108.69	108.55	108.44	108.34	108.26	108.02	108.14	108.17	108.15	108.39	108.38
	μ_0	0.5035	0.5013	0.5106	0.5089	0.5224	0.5210	0.5400	0.5390	0.6069	0.6065	0.6788	0.6786
0.4	E_1	119.89	119.35	121.58	121.16	124.37	124.05	128.57	128.34	144.50	144.40	161.62	161.57
	E_2	117.30	116.60	116.51	116.10	116.04	115.74	115.72	115.50	115.60	115.52	116.03	116.00
	μ_0	0.5011	0.4829	0.5005	0.4870	0.5061	0.4962	0.5189	0.5118	0.5793	0.5764	0.6507	0.6495
0.6	E_1	156.59	150.92	156.40	152.17	158.17	155.05	162.17	159.93	181.03	118.13	203.35	202.96
	E_2	152.99	147.44	149.87	145.82	147.57	144.66	145.95	143.94	144.83	144.10	146.00	145.72
	μ_0	0.5187	0.4660	0.5040	0.4671	0.5001	0.4741	0.5060	0.4880	0.5574	0.5504	0.6271	0.6240
0.7	E_1	203.32	182.73	197.62	183.19	196.10	185.92	198.41	191.35	218.58	215.83	245.91	244.72
	E_2	198.72	178.52	189.38	175.54	182.96	173.47	178.57	172.22	174.87	172.66	176.55	175.70
	μ_0	0.7526	0.4372	0.5730	0.4345	0.5205	0.4386	0.5016	0.4500	0.5275	0.5092	0.5911	0.5834
0.8	E_1	418.13	242.91	315.37	241.41	288.86	243.64	278.63	250.02	293.02	282.90	328.39	324.10
	E_2	408.50	237.31	302.02	231.33	269.79	227.32	250.78	225.02	234.44	226.32	235.78	232.69

Fig. 4.1 Relative Efficiencies (%) of T_c and $T_c^{(1)}$ with respect to $\bar{y}_n$ and $\bar{y}_{CD}$ when $\rho_{yx} = 0.3$



Remark 4.1 However, if one is able to conduct a well designed simulation study it may throw some more light on the behavior of the suggested estimator in comparison to other existing estimators. Due to authors limitations we have not conducted the simulation study which is one of the criterion to examine the merit of the estimator.

5. Conclusions

The performance of an estimator in successive sampling is generally judged on the basis of relative efficiency and cost of the survey involved in terms of optimum value of for using the considered estimator since same is directly associated to the cost of the survey. It is observed from Table 4.1 that the values of $E_1(T_c), E_2(T_c), E_1(T^{(1)})$ and $E_2(T^{(1)})$ are more than 100. Thus, the chain regression type estimators T_c and $T_c^{(1)}$ are better than usual unbiased estimators $\bar{y}_n$ and the estimator $\bar{y}_{CD}$. The proposed estimator utilizes the information on relationship between auxiliary and study variables more efficiently as compared to Singh and Priyanka (2008) estimator. It is further observed from the Table 4.1 that the proposed estimator results into high gain in efficiency at the cost of increased optimum value of μ as compared to that for Singh and Priyanka (2008) estimator particularly when the relationship between study variables over two occasions is weak and between study and auxiliary variables is strong. The price that we pay for using the proposed estimator, in this case, for increased efficiency, is in terms of high cost of survey since more fresh sampling units are required on the current occasion. However, the difference in cost of using proposed and Singh and Priyanka estimators is marginal when the relationship between study variables is strong. Moreover, the proposed estimator continues to be more efficient than Singh and Priyanka (2008) estimator even if it is used with which is optimum for Singh and Priyanka estimator. In other words, the proposed estimator continues to be superior to Singh and Priyanka estimator even at a fixed cost. The above observations on the performance of the proposed estimator can easily be seen by considering fixed high value of $\rho_{yx} = 0.8$ and low values of $\rho_{yx} = 0.3$. The proposed estimator results in 72% gain in efficiency over Singh and Priyanka (2008) estimator but with increased cost of the survey that is with increased optimum value of μ about 75%. Further, the proposed estimator continues to report high relative efficiency about 56% at a fixed cost that is when the proposed estimator is used at 44% of an optimum value of μ for Singh and Priyanka estimator. One may thus notice that the proposed estimator addresses the problem of weak relationship between study variables on two occasions and compensates for this situation by allowing for more fresh units on the current occasion while continuing to yield high efficiencies by exploiting strong relationship between study and auxiliary variables. Thus a survey statistician can use the proposed estimator over Singh and Priyanka (2008) estimator in case of strong relationship between study variables over two occasions. However, in case of weak relationship between study variables over two occasions, a survey statistician can use the proposed estimator over Singh and Priyanka (2008) estimator for higher gain in efficiency but with increased cost if efficiency is the priority and budget is not a limitation. Even if the budget is limited, statistician can use the proposed estimator at a fixed cost in terms of optimum value of μ for Singh and Priyanka (2008) estimator for better efficiency. Thus, the proposed estimator is justified.

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