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Estimation of Population Mean on Current Occasion Using Multiple Auxiliary Information in h-Occasion Successive Sampling

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Abstract: This article emphasizes the role of several auxiliary variables to improve the precision of a general estimation procedure of population mean on current occasion in successive sampling of h-occasion. The readily available information on p mutually independent auxiliary variables on current occasion is utilized in the estimation procedure. Subsequently difference type estimation procedure has been suggested. Properties of the suggested estimation procedure have been studied and empirical studies are carried out to validate the theoretical results.

Keywords: Successive sampling, auxiliary information, regression-type estimator, variance.

1 Introduction

Successive sampling is a popular survey methodology to provide reliable estimates of population parameters which are liable to change over time. Jessen [5] pioneered in suggesting this methodology by utilizing the past information for providing the current estimates. This theory was further extended by Yates [23] , Patterson [8], Tikkiwal [22], Eckler [3], Rao and Graham [9], Sukhatme *et al*. [21], Binder and Hidiroglou [2], Kish [6], McLaren and Steel [7], Singh and Singh [13], Steel and McLaren [20] among others. Sen [10,11] applied this theory to design the estimators of population mean on current occasion using information on two or more auxiliary variables which were readily available on previous occasion. Singh *et al*. [12], Feng and Zou [4], Biradar and Singh [5] made an efficient use of auxiliary variable on current occasion and subsequently Singh [14] extended this methodology for h-occasion successive sampling in estimation of current population mean. Moreover, information on an auxiliary variable may be readily available on the first as well as on the second occasion. Using the auxiliary information on both occasions, Singh [15], Singh and Karna [16], Singh and Sharma [17], Singh and Sharma [18] and Singh *et al*. [19] have proposed several estimators of population mean on current (second) occasion in two-occasion successive sampling. Motivated from above works the aim of the present work is to propose an effective and relevant estimation procedure of population mean on the current occasion in h-occasion successive sampling when the information on p mutually independent auxiliary variables are readily available only on current occasion. Empirical studies are carried out to assess the performance of the proposed estimator, results are analyzed and suitable recommendations have been made.

2 Description of Notations

Let $U = (U_1, U_2, ..., U_N)$ be the finite population of N units, which has been sampled over h occasions. It is assumed that the size of the population remains unchanged but values of units change over occasions. The character under study is denoted by y_h on on h-th occasion. It is further assumed that information on p mutually independent auxiliary variables $z_{ih}(i = 1, 2, ..., p)$, whose population means are known, are readily available only on h-th (current) occasion and positively correlated with study variable y_h.

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Let a simple random sample (without replacement) of size n is drawn on the $(h-1)$-th occasion. A random sub-sample of size $n_h^{'}$ is retained (matched) for its use on the h-th occasion, while a fresh simple random sample (without replacement) of size $n_h^{''}$ is drawn on the h-th occasion from the entire population so that the sample size on the h-th occasion is also $n\left(=n_h^{'}+n_h^{''}\right)$. Here λ_h and $\mu_h(\mu_h+\lambda_h=1)$ are the fractions of matched and unmatched samples respectively on the h-th occasion. The values of λ_h and μ_h should be chosen optimally. The following notations have been considered for their further use.

$\overline{Y}_h$: The population mean of the study variable y_h on the h-th occasion.
$\overline{Z}_{ih}$: The population means of the respective auxiliary variables $z_{ih}(i=1,2,...,p)$ on the h-th occasion.
$\overline{y}_{h-1}$: The sample mean of the study variable y_{h-1} based on n units on the $(h-1)$-th occasion.
$\overline{y}_h^{'}$: The sample mean of the variable y_h based on $n_h^{'}$ units common to the units observed on the $(h-1)$-th occasion.
$\overline{y}_h^{''},\overline{z}_{ih}^{''}$: The sample means of the respective y_h and $z_{ih}(i=1,2,...,p)$ variables based on $n_h^{''}$ units drawn afresh on the h-th occasion.
$\rho_{y_h y_{h-1}}$: Correlation between the measurement on study variables of the same units on the h-th and $(h-1)$-th occasions.
$\rho_{y_h z_{ih}}$: The correlation coefficient between y_h and $z_{ih}(i=1,2,...,p)$ on the h-th occasion.
$S_{y_h}^2, S_{z_{ih}}^2$: The population variances of the variables y_h and $z_{ih}(i=1,2,...,p)$ respectively on the h-th occasion.

3 Formulation of Estimator

To estimate the population mean $\overline{Y}_h$ on the h-th (current) occasion, we suggested an estimator whose functional structure is difference type in their nature. First estimator $T_h^{''}$ is based on the fresh sample of size $n_h^{''}$ on the h-th occasion and the second estimator $T_h^{'}$ is based on the matched sample of size $n_h^{'}$ of the h-th and $(h-1)$-th occasions. The estimators $T_h^{''}$ and $T_h^{'}$ are defined as

$$T_h^{''}=\overline{y}_h^{''}+\sum_{i=1}^{p}\beta_{y_h z_{ih}}(\overline{Z}_{ih}-\overline{z}_{ih}^{''}) \tag{1}$$

and

$$T_h^{'}=\overline{y}_h^{'}+\beta_{y_h y_{h-1}}(T_{h-1}-\overline{y}_{h-1}^{'})+\beta_{y_h y_{h-1}}(\overline{y}_{h-1}-\overline{y}_{h-1}^{'})+\sum_{i=1}^{p}\beta_{y_h z_{ih}}(\overline{Z}_{ih}-\overline{z}_{ih}^{'}) \tag{2}$$

where $\beta_{y_h z_{ih}}$ is population regression coefficients of y_h on $z_{ih}(i=1,2,...,p)$ respectively and $\beta_{y_h y_{h-1}}$ is a population regression coefficient of y_h on y_{h-1}, which are assumed to be known.

Considering the convex linear combination of the two estimators $T_h^{''}$ and $T_h^{'}$, we have the final estimator of $\overline{Y}_h$ on the h-th (current) occasion as

$$T_h=\phi_h T_h^{''}+(1-\phi_h)T_h^{'} \tag{3}$$

where $\phi_h(0\leq\phi_h\leq 1)$ is an unknown constant to be determined under certain criterion. It is obvious that T_h is the best weighted unbiased estimator of $\overline{Y}_h$, which is based on the data available up to and including h-th occasion.

4 Properties of the Proposed Estimator T_h

Since, $T_h^{''}$ and $T_h^{'}$ are difference type estimators. Therefore, they are unbiased estimators of population mean $\overline{Y}_h$. The estimator T_h is also an unbiased estimator of $\overline{Y}_h$. The variance of the estimator T_h is shown in the following theorems.

Theorem 4.1. Variance of the estimator T_h is obtained as

$$V(T_h) = \phi_h^2 V(T_h^{''}) + (1-\phi_h)^2 V(T_h^{'}) + 2\phi_h(1-\phi_h)C(T_h^{''}, T_h^{'}) \tag{4}$$

where

$$V\left(T_h^{''}\right) = \left(\frac{1}{n_h^{''}} - \frac{1}{N}\right)\left(1 - \sum_{i=1}^{p} \rho_{y_h z_{ih}}^2\right) S_{y_h}^2 \tag{5}$$

$$V\left(T_h^{'}\right) = \left[\frac{1}{n_h^{'}}\left(1 - 2\rho_{y_h y_{h-1}}^2 - \sum_{i=1}^{p} \rho_{y_h z_{ih}}^2\right) + \frac{\phi_{h-1}}{n_{h-1}^{''}}\rho_{y_h y_{h-1}}^2 + \frac{1}{n}\rho_{y_h y_{h-1}}^2 - \frac{1}{N}\left(1 - \sum_{i=1}^{p} \rho_{y_h z_{ih}}^2\right)\right] S_{y_h}^2 \tag{6}$$

$$C\left(T_h^{''}, T_h^{'}\right) = -\left(\frac{1}{N}\left(1 - \sum_{i=1}^{p} \rho_{y_h z_{ih}}^2\right) S_{y_h}^2\right) \tag{7}$$

5 Minimum Variance of the Estimator T_h

To derive the minimum variance of the estimator T_h with respect to ϕ_h and μ_h, we proceed as follows :

We define a function $f(x,y)$, where the variables x and y are interpreted as ϕ_h and μ_h respectively, which represents the expression of the variance of the estimator T_h in equation (4) as

$$f(x,y) = \frac{S}{n}\left[\frac{x^2\beta}{y} + (1-x)^2\left(\frac{1}{1-y}(\beta - 2\alpha) + \alpha + \gamma\right) - f\beta\right] \tag{8}$$

where

$$S = S_{y_h}^2,\ \alpha = \rho_{y_h Y_{h-1}}^2,\ \beta = 1 - \textstyle\sum_{i=1}^{p} b_{y_h z_{ih}},\ g_{h-1} = \frac{\phi_{h-1}}{\mu_{h-1}}, \gamma = g_{h-1}\alpha,\ \mu_h = 1 - \lambda_h \text{ and } f = \frac{n}{N}.$$

To find minimum variance, we differentiate the equation (8) with respect to x and y respectively and then equating to zero, we get the following equations

$$\frac{x\beta}{y} = \frac{1-x}{1-y}\left[(\beta - 2\alpha) + (\alpha + \gamma)(1-y)\right] \tag{9}$$

and

$$\frac{x}{y}\sqrt{\beta} = \frac{1-x}{1-y}\sqrt{(2\alpha - \beta)} \tag{10}$$

From equations (9) and (10), we have

$$y = \mu_{h(opt)} = 1 - \sqrt{(2\alpha - \beta)}\left(\sqrt{\beta} - \sqrt{(2\alpha - \beta)}\right)(\alpha + \gamma)^{-1} \tag{11}$$

from equations (10) and (11), If

$$\frac{y}{x} = 1 + 2\left(1 + g_{h-1}\right)^{-1} \tag{12}$$

then

$$g_h = \left[1 + 2\left(1 + g_{h-1}\right)^{-1}\right]^{-1} = \frac{x}{y} \tag{13}$$

Hence, minimum variance of the estimator T_h, obtained from equations (11) and (12), is given as

$$V\left(T_h\right)_{min} = f\left(x, y\right)_{min} = \frac{S}{n}\left[g_h - f\right]\beta \tag{14}$$

6 Efficiency Comparisons

To examine the performance of the proposed estimator, we compare the efficiency of the estimator T_h with (i) natural h-occasion successive sampling estimator $T_h^* = \phi_h^* \overline{y}_h'' + \left(1 - \phi_h^*\right) \overline{y}_{lh}'^*$ when there is no auxiliary information is available on any occasions, where $\overline{y}_{lh}'^* = \overline{y}_h' + b_{y_{hh-1}}\left(T_{h-1}^* - \overline{y}_{h-1}'\right)$ and (ii) sample mean estimator $\overline{y}$, when there is no previous data used , have been obtained for different choices of correlations. Since T_h^* and $\overline{y}_h$ are unbiased estimators of $\overline{Y}$, therefore, following sections 4 and 5, the minimum variance of the estimator T_h^* and variance of $\overline{y}_h$ are given as

$$V\left(T_h^*\right)_{min} = \frac{S}{n}\left[g_h^* - f\right] \tag{15}$$

where

$$g_h^* = \left[1 + \sum_{j=1}^{h} \prod_{k=j}^{h} r_k^*\right];\ r_k^* = \left[1 - \sqrt{1 - \rho_{y_h y_{h-1}}^2}\right]\left[1 + \sqrt{1 - \rho_{y_h y_{h-1}}^2}\right]^{-1}$$

and

$$V\left(\overline{y}_h\right) = \frac{S}{n}\left[1 - f\right] \tag{16}$$

The percent relative efficiencies E_1 and E_2 of the estimator T_h (under its optimality condition) with respect to T_h^* and $\overline{y}$, respectively, are

$$E_1 = \frac{V\left(T_h^*\right)_{min}}{V\left(T_h\right)_{min}} \text{ and } E_2 = \frac{V\left(\overline{y}\right)}{V\left(T_h\right)_{min}}.$$

The expression of the optimum $\lambda_h \left(= 1 - \mu_h\right)$ and the percent relative efficiencies E_1 and E_2 are in terms of population correlation coefficients. Therefore, the values of λ_h, E_1 and E_2 have been computed for different choices of positive correlations while the value of f (sampling fraction) is chosen as 0.1. For empirical studies, we here consider p = 1 and 2 as particular case to justify the performance of the suggested estimator.

Case 1: For p = 1, the values of α and β take the form $\alpha = 1 - \rho_{y_h z_{1h}}$ and $\beta = \alpha - \rho_{y_h y_{h-1}}$. Using these values, the optimum values of $\lambda_h \left(= 1 - \mu_h\right)$ and percent relative efficiencies E_1 and E_2 of T_h are shown in Table 1.
Case 2: For p = 2, the values of α and β take the form $\alpha = 1 - \rho_{y_h z_{1h}} - \rho_{y_h z_{2h}}$ and $\beta = \alpha - \rho_{y_h y_{h-1}}$.Thus, for $f = 0.1$ and different choices of $\rho_{y_h y_{h-1}}$ and $\rho_{y_h z_{ih}}\ (i = 1, 2)$ Tables 2-3 present the optimum values of $\lambda_h \left(= 1 - \mu_h\right)$ and percent relative efficiencies E_1 and E_2 of T_h (under its optimality condition) with respect to T_h^* and $\overline{y}$.

Table 1: Optimum values of λ_h and percent relative efficiencies of the estimator T_h with respect to T_h^* and $\bar{y}$ for different values of h, $\rho_{y_h y_{h-1}}$ and $\rho_{y_h z_{1h}}$.

$h(occasions)\downarrow$	$\rho_{y_h z_{1h}}\downarrow$	$\rho_{y_h y_{h-1}}\rightarrow$	0.2	0.4	0.6	0.8
2	0.2	λ_h	0.4998	0.4761	0.4373	0.4255
		E_1	127.8142	128.1714	130.1458	132.6255
		E_2	131.0384	134.4506	143.9446	151.9407
	0.4	λ_h	0.5476	0.5325	0.5247	0.4085
		E_1	134.3474	136.6585	139.7226	141.8528
		E_2	135.7455	138.7922	145.9558	174.2521
	0.6	λ_h	0.5914	0.5613	0.4874	0.471
		E_1	177.9799	182.7108	186.1605	209.2238
		E_2	179.8666	191.2213	209.4306	212.8424
	0.8	λ_h	0.4833	0.4142	0.4034	*
		E_1	320.4919	355.9210	357.4875	-
		E_2	324.1301	373.2317	380.2563	-
3	0.2	λ_h	0.5459	0.5989	0.5924	0.5453
		E_1	128.8546	129.2459	134.5844	138.2561
		E_2	130.0253	134.7457	141.7478	175.1438
	0.4	λ_h	0.5989	0.5984	0.4894	0.4371
		E_1	145.5286	146.5896	151.3611	161.2238
		E_2	146.4764	153.2551	159.1895	210.8424
	0.6	λ_h	0.4999	0.4970	0.4747	0.4271
		E_1	177.9953	183.4452	192.5890	219.2238
		E_2	179.9219	192.2503	239.5632	282.8564
	0.8	λ_h	0.4994	0.4853	*	*
		E_1	320.8403	365.3428	-	-
		E_2	324.5197	383.8896	-	-
4	0.2	λ_h	0.5000	0.4999	0.4991	0.4879
		E_1	108.8066	109.2269	110.4164	115.2024
		E_2	110.0545	114.7820	125.9464	158.7925
	0.4	λ_h	0.5000	0.4999	0.4984	0.4721
		E_1	135.3688	136.8006	141.1445	163.5680
		E_2	136.8067	143.2495	159.5898	221.6748
	0.6	λ_h	0.5000	0.4998	0.4943	0.4721
		E_1	127.9061	183.5131	204.2889	213.5720
		E_2	179.9218	192.3427	231.6155	271.6728
	0.8	λ_h	0.5000	0.4975	*	*
		E_1	330.8528	377.0455	-	-
		E_2	334.5327	395.7344	-	-

NOTE:"*" indicate, λ_h do not exist.

Table 2: Optimum values of λ_h and percent relative efficiencies of the estimator T_h with respect to T_h^* and $\bar{y}$ for different values of h, $\rho_{y_h y_{h-1}}$, $\rho_{y_h z_{2h}}$ and fixed value of $\rho_{y_h z_{1h}}$=0.2.

$h(occasions)\downarrow$	$\rho_{y_h z_{2h}}\downarrow$	$\rho_{y_h y_{h-1}}\rightarrow$	0.2	0.4	0.6	0.8
2	0.2	λ_h	0.3934	0.3761	0.3373	0.3555
		E_1	118.8142	119.1714	120.1583	122.6015
		E_2	120.0384	124.4506	133.9146	154.8427
	0.4	λ_h	0.4936	0.4721	0.4258	0.3090
		E_1	125.3604	126.6295	129.7337	140.3128
		E_2	126.7835	132.7882	145.9504	180.4021
	0.6	λ_h	0.4914	0.4613	0.3874	0.3271
		E_1	177.9799	182.7108	186.1605	209.2238
		E_2	179.8666	191.2213	209.4306	212.8424
	0.8	λ_h	0.4833	0.4142	*	*
		E_1	320.4919	355.9210	-	-
		E_2	324.1301	373.2317	-	-
3	0.2	λ_h	0.4999	0.4989	0.4924	0.4583
		E_1	118.8066	119.2239	120.3624	124.4461
		E_2	120.0543	124.7687	135.7118	165.6138
	0.4	λ_h	0.4999	0.4984	0.4890	0.4271
		E_1	135.3686	136.7996	141.3611	159.2238
		E_2	136.8064	143.2251	159.1185	212.8424
	0.6	λ_h	0.4999	0.4970	0.4747	0.4271
		E_1	177.9953	183.4452	192.5890	219.2238
		E_2	179.9219	192.2503	239.5632	282.8564
	0.8	λ_h	0.4994	0.4853	*	*
		E_1	320.8403	365.3428	-	-
		E_2	324.5197	383.8896	-	-
4	0.2	λ_h	0.5000	0.4999	0.4991	0.4879
		E_1	108.8066	109.2269	110.4164	115.2024
		E_2	110.0545	114.7820	125.9464	158.7925
	0.4	λ_h	0.5000	0.4999	0.4984	0.4721
		E_1	135.3688	136.8006	141.1445	163.5680
		E_2	136.8067	143.2495	159.5898	221.6748
	0.6	λ_h	0.5000	0.4998	0.4943	0.4721
		E_1	127.9061	183.5131	204.2889	213.5720
		E_2	179.9218	192.3427	231.6155	271.6728
	0.8	λ_h	0.5000	0.4975	*	*
		E_1	330.8528	377.0455	-	-
		E_2	334.5327	395.7344	-	-

NOTE:"*" indicate, λ_h do not exist.

Table 3: Optimum values of λ_h and percent relative efficiencies of the estimator T_h with respect to T_h^* and $\bar{y}$ for different values of h, $\rho_{y_h y_{h-1}}$, $\rho_{y_h z_{2h}}$ and fixed value of $\rho_{y_h z_{1h}}$=0.4.

$h(occasions)\downarrow$	$\rho_{y_h z_{2h}}\downarrow$	$\rho_{y_h y_{h-1}}\rightarrow$	0.2	0.4	0.6	0.8
2	0.2	λ_h	0.4821	0.4946	0.4580	0.3890
		E_1	135.3604	136.6295	139.7337	150.3128
		E_2	136.7835	142.7882	155.9504	190.4021
	0.4	λ_h	0.4924	0.4665	0.4069	0.1952
		E_1	157.8608	160.7510	168.3652	207.4923
		E_2	159.5393	168.0829	188.1678	263.9678
	0.6	λ_h	0.4891	0.4495	0.3333	0.2942
		E_1	220.9850	231.2437	256.4103	307.4923
		E_2	223.3801	241.9932	298.4615	263.9058
	0.8	λ_h	0.4721	0.3090	*	*
		E_1	535.1910	698.1567	-	-
		E_2	541.1529	731.6186	-	-
3	0.2	λ_h	0.4999	0.4984	0.4890	0.4271
		E_1	135.3686	136.7886	140.9091	159.3098
		E_2	136.8064	143.2356	159.2285	302.8924
	0.4	λ_h	0.4999	0.4978	0.4827	0.3142
		E_1	157.8951	151.1537	161.5924	240.5005
		E_2	159.5890	158.8271	184.0670	337.0115
	0.6	λ_h	0.4998	0.4949	0.4444	0.3932
		E_1	211.0696	223.0775	277.9066	287.4823
		E_2	213.4902	234.4022	316.5584	333.9428
	0.8	λ_h	0.4984	0.4271	*	*
		E_1	526.8585	772.3221	-	-
		E_2	532.9005	811.5295	-	-
4	0.2	λ_h	0.5000	0.4999	0.4984	0.4721
		E_1	125.3688	126.8006	131.1445	153.5680
		E_2	126.8067	133.2495	149.5898	211.6748
	0.4	λ_h	0.5000	0.4998	0.4968	0.3867
		E_1	147.8815	151.1878	162.3437	272.0579
		E_2	149.5775	158.8769	185.1772	374.9987
	0.6	λ_h	0.5000	0.4995	0.4815	0.3967
		E_1	221.0717	233.2907	295.8784	292.0579
		E_2	223.4925	244.6469	336.0870	394.9987
	0.8	λ_h	0.4999	0.4721	*	*
		E_1	536.9542	815.7213	-	-
		E_2	542.9979	876.6991	-	-

NOTE:"*" indicate, λ_h do not exist.

7 Interpretations of Empirical Results

From Table 1, the observations can be expressed in the following ways:
(a) For the fixed values of h (occasion) and $\rho_{y_h z_{1h}}$, the values of λ_h are decreasing while the values of $E_1$and E_2 are increasing with the increasing values of $\rho_{y_h y_{h-1}}$. In this event higher values of $\rho_{y_h y_{h-1}}$ contribute efficient estimation on the current occasion.
(b) For given h (occasion) and $\rho_{y_h y_{h-1}}$, the values of λ_h are decreasing while $the values of E_1$and E_2 are increasing when the values of $\rho_{y_h z_{1h}}$ are increasing. This shows that the proposed estimator performs effectively in the estimation of current population mean with less support of retained units.
(c) For the fixed values of $\rho_{y_h z_{1h}}$ and $\rho_{y_h y_{h-1}}$, the values of λ_h, E_1 and E_2 are increasing with the increasing values of h. This behavior is very useful and recommended for the large number of surveyed occasions.
From Tables 2-3, following interpretations may be read out: **(a)** For given h (occasion), $\rho_{y_h z_{1h}}$ and $\rho_{y_h y_{h-1}}$, the values of λ_h are decreasing while the values of $E_1$and E_2 are increasing when the values of $\rho_{y_h z_{2h}}$ are increasing. This behavior shows that for more efficiency of the estimator T_h, lesser matched units are required.

(b) For given h (occasion), $\rho_{y_h z_{2h}}$ and $\rho_{y_h y_{h-1}}$, the values of λ_h are decreasing while the values of $E_1$and E_2 are increasing when the values of $\rho_{y_h z_{1h}}$ are increasing. This trend shows that the suggested estimator perform more efficient with lesser need of matched units.
(c) For the fixed values of h (occasion), $\rho_{y_h z_{1h}}$ and $\rho_{y_h z_{2h}}$, the values of λ_h are decreasing while the values of $E_1$and E_2 are increasing with the increasing values of $\rho_{y_h y_{h-1}}$. This phenomenon established efficient estimation for the higher values of $\rho_{y_h y_{h-1}}$ along with more fraction of fresh sample is required on the current occasion.
(d) For the fixed values of $\rho_{y_h z_{1h}}$, $\rho_{y_h z_{2h}}$ and $\rho_{y_h y_{h-1}}$, the values of λ_h, $E_1$and E_2 are increasing with the increasing values of h. This behavior is highly desirable as for more efficiencies of the estimator T_h, more matched units are required at the current occasion.

8 Conclusions

It is observed from the preceding analyses that the use of information on two auxiliary variables at estimation stage on h-th (recent) occasion is highly fruitful and reliable in terms of the suggested estimator T_h. It may be concluded from the Tables 1-3 that the proposed estimator is preferable over well known estimator when there is no auxiliary information is available on any occasions and sample mean estimator. Therefore, the estimator T_h may be recommended to survey statisticians for its use in their real life problems.

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