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A GENERALIZED CLASS OF PREDICTIVE ESTIMATORS OF FINITE POPULATION MEAN IN SAMPLE SURVEYS

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ABSTRACT

In this paper a generalized class of Srivastava's (1971) estimators and a generalized class of predictive estimators using auxiliary information are compared as regards their efficiencies to estimate the finite population mean in sample surveys. Some special cases are considered to derive conditions under which the predictive estimators are more efficient than their non-predictive counter parts.

AMS CLASSIFICATION
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KEYWORDS
Auxiliary variable, Ratio method of estimation, Predictive estimators.

1. INTRODUCTION

In large scale sample surveys it is a usual practice to search for auxiliary information to help improving the efficiency of estimates based on only study variable. The use of auxiliary information in sample surveys dates back to Cochran (1940) who used it for estimation of yields of agricultural crops in course of his research in agricultural sciences. Ratio method of estimation is one of the most popular methods to make use of auxiliary information to estimate the population mean or total of the study variable. It is well known that ratio estimator is a biased estimator whose bias decreases with increase in sample size and further under certain conditions it is more efficient than the sample mean per unit estimator using study variable in simple random sampling. During last century a large volume of research work on variants of ratio method of estimation has been developed. Srivastava (1971) suggested a class of estimators which includes ratio estimator as a special case. Basu (1971) proposed a model free approach of prediction, where the unobserved part in the sample is predicted with the help of auxiliary information to compute the estimate of the population mean. A number of modifications of the ratio estimators have been reviewed by Swain (2013) which is more efficient than the classical one under certain conditions.

Let there be N units in a finite population indexed by $U_1, U_2, \ldots\ldots U_N$. Each unit of the population is associated with a pair of real numbers (y_i, x_i) corresponding to the study variable *y* and the auxiliary variable *x*. A simple random sample without replacement of size n is selected out of the finite population under consideration.

With usual notations define $\overline{Y}$ and $\overline{X}$ as the population means of *y* and *x* respectively; S_y^2 and S_x^2 as the finite population variances of *y* and *x* respectively; ρ as the correlation coefficient between *y* and *x*; C_y and C_x as the coefficients of variation of *y* and *x* respectively.

Further define $\overline{y}$ and $\overline{x}$ as the sample means and s_y^2 and s_x^2 as the sample variances of *y* and *x* respectively. The classical ratio estimator of the population mean $\overline{Y}$ is given by,

$$\hat{\overline{Y}}_R = \frac{\overline{y}}{\overline{x}}\overline{X}$$

which is more efficient than the sample mean $\overline{y}$, when $\rho\dfrac{C_y}{C_x} > \frac{1}{2}$.

Although $\hat{\overline{Y}}_R$ is a biased estimator, whose large sample variance (i.e. bias up to $0\left(\frac{1}{n}\right)$) is given by

$$\text{Bias}(\hat{\overline{Y}}_R) = \overline{Y}\left(\frac{1-f}{n}\right)\left(C_x^2 - \rho C_y C_x\right).$$

However the bias decreases with increase in sample size.

Following the footsteps of Basu (1971), Agarwal and Sthapit (1997) considered a predictive ratio estimator given by,

$$\hat{\overline{Y}}_{RP} = f\,\overline{y} + (1-f)\overline{y}\left(\frac{\overline{X}}{\overline{x}}\right).$$

Whose first order bias is always less than that of $\hat{\overline{Y}}_R$. Further, $\hat{\overline{Y}}_{RP}$ is more efficient than $\hat{\overline{Y}}_R$ if

$$K < \frac{1}{2}(1+\lambda),$$

Where $K = \rho\dfrac{C_y}{C_x}$ and $\lambda = 1 - f$

Srivastava (1971) suggested a class of estimators

$$t_g = \overline{y}H\left(\frac{\overline{x}}{\overline{X}}\right),$$

which includes the classical ratio estimator as a special case and H(.) is a function satisfying certain regularity conditions.

In the following section we compare the Srivastava's (1971) generalized class of estimators with that of the generalized class of predictive estimators using Basu's approach and obtain certain general conditions under which generalized class of the predictive estimators as more efficient than the generalized class of estimators for some special cases.

2. GENERALIZED CLASS OF PREDICTIVE ESTIMATORS

Srivastava (1971) proposed a generalized class of estimators to estimate the population mean $\bar{Y}$ of study variable *y* when information on single auxiliary variable *x* is available with known population mean $\bar{X}$ given by,

$$t_g = \bar{y}H(u) \qquad (2.1)$$

where $u = \frac{\bar{x}}{\bar{X}}$ and *H(.)* is a parametric function satisfying the following regularity conditions.

(a) *H (1) = 1*

(b) The first and second order partial derivatives of *H* with respect to *u* exists and are known constants at the given point *u=1*.

Expanding *H(u)* by Taylor's series about the point *u=1*, we have,

$$H(u) = H(\mathrm{I}) + (\mathrm{u}-1)H'(1) + \frac{(u-1)^2}{2!}H''(1) + \ldots\ldots$$

$$= H(\mathrm{I}) + (u-1)H_1 + (u-1)^2 H_2 + \ldots\ldots\ldots\ldots\ldots\ldots \qquad (2.2)$$

where $H_1 = H'(1)$, $H_2 = \frac{H''(1)}{2!}$, ... so on.

Now substituting, $\frac{\bar{y}}{\bar{Y}} - 1 = \in_0$ and $\frac{\bar{x}}{\bar{X}} - 1 = u - 1 = \in_1$

We write t_g as,

$$t_g = \bar{Y}(1+\in_0)\{1+\in_1 H_1 + \in_1^2 H_2 + \ldots\ldots\}$$

$$= \bar{Y}[1+\in_0 + \in_1 H_1 + \in_1^2 H_2 + \in_0\in_1 H_1 + O(\in)] \qquad (2.3)$$

Taking expected value of t_g up to first order of approximation,

$$E(t_g) = \bar{Y}[1 + \frac{1-f}{n}(H_2 C_x^2 + H_1\rho C_y C_x)]$$

Hence, Bias $(t_g) = \bar{Y}\left(\frac{1-f}{n}\right)[H_2 C_x^2 + H_1\rho C_y C_x]$ (2.4)

And to first order of approximation the mean square error (MSE) is given by,

$$\mathrm{MSE}(t_g) = \bar{Y}^2\left(\frac{1-f}{n}\right)[C_y^2 + H_1^2 C_x^2 + 2H_1\rho C_y C_x] \qquad (2.5)$$

MSE (t_g) is minimum if $H_1 = -\rho\frac{C_y}{C_x}$

Hence , MSE $(t_g)_{min}$ = $\frac{(1-f)}{n}C_y^2(1-\rho^2)$ (2.6)

Basu's (1971) predictive approach starts with writing the population means $\bar{Y}$ of *y* as

$$\bar{Y} = \frac{1}{N}\sum_1^N Y_i = \frac{1}{N}\left(\sum_1^n Y_i + \sum_{n+1}^N Y_i\right)$$

= $\frac{1}{N}$ (sampled part of *y*'s + non-sampled part of *y*'s)

Hence, t_g^* = $\hat{\bar{Y}} = \frac{1}{N}\left(\sum_1^n y_i + \sum_{n+1}^N \hat{Y}_i\right)$,

where $\hat{Y}_i$ stands for the estimate of Y_i (for i = n+1, n+2, n+3, ... N) in the non-sampled part

Thus , t_g^* = $\frac{1}{N}[n\bar{y} + (N-n)\bar{y}H(u)]$

$= f\,\bar{y} + (1-f)\bar{y}H(u)$, where $f = \frac{n}{N}$ (2.7)

The estimator t_g^* belongs to the same class as that of t_g. Expanding t_g^* using Taylor's series expansion of *H(u)*, we have

$t_g^* = \bar{Y}[1+\epsilon_0 + (1-f)\epsilon_1 H_1 + (1-f)^2 \epsilon_1^2 H_2 + (1-f)\epsilon_0\epsilon_1 H_1 + O(\epsilon)]$ (2.8)

$E(t_g^*) = \bar{Y}[1 + \frac{(1-f)}{n}(1-f)(H_2 C_x^2 + H_1\rho C_y C_x)]$ (2.9)

So,

$\text{Bias}(t_g^*) = \bar{Y}\left(\frac{1-f}{n}\right)(1-f)\left[H_2 C_x^2 + H_1 \rho C_y C_x\right]$, to first order of approximation (2.10)

$MSE(t_g^*) = \bar{Y}^2\left(\frac{1-f}{n}\right)\left[C_y^2 + (1-f)^2 H_1^2 C_x^2 + 2(1-f)H_1\rho C_y C_x\right]$ (2.11)

$MSE(t_g^*)_{min} = \bar{Y}^2\left(\frac{1-f}{n}\right)C_y^2(1-\rho^2)$, for $H_1 = -\frac{1}{1-f}\rho\frac{C_y}{C_x}$ (2.12)

3. COMPARISON OF t_g^* WITH t_g

MSE (t_g) – MSE (t_g^*)

$= \bar{Y}^2\left(\frac{1-f}{n}\right)\left[H_1^2\{1-(1-f)^2\}C_x^2 + 2H_1\{1-(1-f)\}\rho C_y C_x\right]$ (3.1)

Thus, t_g^* will be more efficient than t_g if,

$$H_1^2\{1-(1-f)^2\}C_x^2 + 2H_1\{1-(1-f)\}\rho C_y C_x > 0$$

$\Rightarrow H_1^2(1+\lambda) + 2H_1 K > 0$, where $\lambda = 1-f$ and $K = \rho\frac{C_y}{C_x}$.

$\Rightarrow H_1\{H_1(1+\lambda) + 2K\} > 0$

$\Rightarrow$ either $H_1<0$ and $\{H_1(1+\lambda)+2K\} < 0$ (3.2)

or

$H_1>0$ and $\{H_1(1+\lambda)+2K\} > 0$ (3.3)

In the following Table-1 we compare certain special cases of t_g and its predictive counterpart t_g^* as regards to their efficiency. It may be mentioned here that t_g^* is always less biased than tg subject to first order approximation.

TABLE-1: SOME SPECIAL CASES OF GENERALIZED CLASS OF ESTIMATORS

Estimator $t_g = \bar{y}H(u)$ With following $H(u)$	H_1	Condition when t_g^* will be more efficient than t_g
$H(u) = \frac{\bar{x}}{\bar{X}} = u$	1	$K > -\frac{1}{2}(1+\lambda)$
$H(u) = \frac{\bar{X}}{\bar{x}} = \frac{1}{u}$	–1	$K < \frac{1}{2}(1+\lambda)$
$H(u) = \left(\frac{\bar{x}}{\bar{X}}\right)^\alpha = u^\alpha$	α	$K > -\frac{\alpha}{2}(1+\lambda)$
$H(u) = \left(\frac{\bar{X}}{\bar{x}}\right)^\alpha = u^{-\alpha}$	$-\alpha$	$K < \frac{1}{2}\alpha(1+\lambda)$
$H(u) = 2 - \left(\frac{\bar{x}}{\bar{X}}\right)^\beta = 2 - u^\beta$	$-\beta$	$K < \frac{1}{2}\beta(1+\lambda)$
$H(u) = 1 - \theta\left(\frac{\bar{x}^\delta - \bar{X}^\delta}{\bar{X}^\delta}\right)^\beta = 1-\theta[u^\delta - 1]$	$-\theta\delta$	$K < \frac{1}{2}\theta\delta(1+\lambda)$
$H(u) = \omega_1 + \omega_2\left(\frac{\bar{X}}{\bar{x}}\right)^q = \omega_1 + \omega_2 u^{-q}$	$-\omega_2 q$	$K < \frac{1}{2}\omega_2 q(1+\lambda)$
$H(u) = \left[\alpha\left(\frac{\bar{X}}{\bar{x}}\right)^g + (1-\alpha)\left(\frac{\bar{x}}{\bar{X}}\right)^h\right]^\delta = [\alpha u^{-g} + (1-\alpha)u^h]^\delta$	$(1-\alpha)h - \alpha g$	$K < \frac{1}{2}\{\alpha g - (1-\alpha)h\}(1+\lambda)$

4. CONCLUSION

The predictive generalized class of estimators should be preferred over the generalized class of estimators when certain moderate conditions are satisfied. More over predictive estimators to first order of approximation are always less biased than their usual non-predictive counter parts.

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