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Generalized Chain Exponential Product in Regression Estimator for estimating the Mean in Nutritional and Agricultural Sciences

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Abstract

The ancillary information is broadly employed in sample surveys to estimate the mean in Nutritional Science. Numerous research works for estimating the population mean using one or more than one ancillary variables have been completed. The recent research paper proposes generalized chain exponential product-in-regression estimator for population mean using the information on the ancillary and the additional ancillary variables. The bias and mean square error expressions for the generalized chain exponential product-in-regression estimator, have been derived in case of large sample approximation. An efficiency comparison of the proposed estimators has also been made. Further by using real data sets, numerical study is also given to verify the theoretical results.

Keywords

Ancillary variable, additional ancillary variable, bias, double sampling, mean square error, nutritional science.

INTRODUCTION

In nutritional Science such as dietry intake and body mass index, the precision of the estimators for mean of the study variable can be increased by using one ancillary variable. The information on ancillary variable will be either known or unknown. In cases when the population mean of the ancillary variable is unknown, many authors such as Neyman (1938), Cochran (1940, 77), Sukhatme (1962) and Singh and Vishawakarma (2007) suggested various estimators for population mean in the double phase sampling scheme. Further by using more than one ancillary variable, some authors such as Chand (1975), Kiregyera (1980, 84), Srivastava et al. (1990), Upadhyaya et. al.(1990), Singh and Singh(1991), Singh and Upadhyaya (1995), Upadhyaya and Singh (2001), Khare et al. (2013)

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and Singh and Majhi (2014) suggested the chain type estimators for population mean which are found to be more efficient in comparision to the estimators suggested by using one or more ancillary variable.

In the recent paper, we have suggested generalized chain exponential product-in-regression estimator for the population mean using the information on the ancillary and the additional ancillary variables. This paper's main objective is to develop generalized chain exponential product-in-regression estimator that can achieves lower mean square error in comparision to the estimators developed by Sukhatme (1962), Cochran (1977), Singh and Vishawakarma (2007), Chand (1975), Kiregyera (1984) and Singh and Majhi (2014).

1 THE EXITING ESTIMATORS IN TWO PHASE SAMPLING

Suppose a finite population $U = U_1, U_2, ..., U_N$ of size *N*. Let (y, x, z) stand for the study variable, ancillary variable and additional ancillary variable and $(\bar{Y}, \bar{X}, \bar{Z})$ stand for the population means of (y, x, z) having the values (Y_l, X_l, Z_l), where *l* varies from 1 to *N*.

Let $\bar{x}'$ denotes the mean of the first-phase sample that can be acquired after drawing a large sample of size n' from the population of size N using the simple random sampling without replacement (SRSWOR) method. Again, let $(\bar{y}, \bar{x})$ denote the means of the second-phase sample that can be acquired after drawing a second-phase sample of size n from the first-phase sample of size n'. If $\bar{X}$ is not available, then $\bar{x}'$ can be used in place of $\bar{X}$. In this case, Sukhatme (1962), Cochran (1977) and Singh and Vishawakarma (2007) suggested the following ratio, regression and exponential ratio type estimators:

$$\hat{\bar{Y}}_1 = \frac{\bar{y}}{\bar{x}} \bar{x}' \tag{1}$$

$$\hat{\bar{Y}}_2 = \bar{y} + c_{yx}(\bar{x}' - \bar{x}) \tag{2}$$

and

$$\hat{\bar{Y}}_3 = \bar{y} \exp\left(\frac{\bar{x}' - \bar{x}}{\bar{x}' + \bar{x}}\right),$$

(3)

where $c_{yx} = \hat{S}_{yx} / \hat{S}_x^2$ $(\hat{S}_{yx}, \hat{S}_x^2)$ are defined based on n units and they are used to estimate (S_{yx}, S_x^2) which are defined based on N units.

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Further, numerous authors have tried to find out more efficient estimators than the estimators suggested by Sukhatme (1962), Cochran (1977) and Singh and Vishawakarma (2007). In this context, Chand (1975), Kiregyera (1984) and Singh and Majhi (2014) have suggested chain ratio, chain regression and chain exponential ratio type estimators for the population mean in the case when the population mean $(\bar{X})$ of ancillary variable x is not known but population mean $(\bar{Z})$ of an additional ancillary variable z is known, where z is probably cheaper and may be less correlated with the study variable y compared to the anciliary variable x (i.e. $\rho_{yx} > \rho_{yz}$).

$$\hat{\bar{Y}}_4 = \bar{y}\frac{\bar{x}'}{\bar{x}}\frac{\bar{Z}}{\bar{z}'}, \tag{4}$$

$$\hat{\bar{Y}}_5 = \bar{y} + c_{yx}\left\{\bar{x}'\frac{\bar{Z}}{\bar{z}'} - \bar{x}\right\} \tag{5}$$

and

$$\hat{\bar{Y}}_6 = \bar{y} + c_{yx}\left\{\bar{x}'\exp\left(\frac{\bar{Z}-\bar{z}'}{\bar{Z}+\bar{z}'}\right) - \bar{x}\right\}, \tag{6}$$

where $\bar{z}'$ is the first phase sample mean of the additional ancillary variable z based on n' units.

2 NEW SUGGESTED ESTIMATORS

Now, we suggest the following generalized chain exponential product in regression estimator for the population mean under the case of the unknown population mean $\bar{X}$ of an ancillary variable and the known population mean $\bar{Z}$ of an additional ancillary variable.

$$\hat{\bar{Y}}_{gk} = \bar{y} + c_{yx}\left[\bar{x}'\exp\left\{\alpha\left(\frac{\bar{z}'-\bar{Z}}{\bar{z}'+\bar{Z}}\right)\right\} - \bar{x}\right],$$

(7)

where α is unknown constent (to be determined later).

For $\alpha = 0$, $\hat{\bar{Y}}_{gk}$ reduces $\hat{\bar{Y}}_2 = \bar{y} + c_{yx}(\bar{x}' - \bar{x})$. (8)

For $\alpha = -1$, $\hat{\bar{Y}}_{gk}$ reduces $\hat{\bar{Y}}_6 = \bar{y} + c_{yx}\left\{\bar{x}'\exp\left(\frac{\bar{Z}-\bar{z}'}{\bar{Z}+\bar{z}'}\right) - \bar{x}\right\}$ (9)

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For $\alpha = 1$, $\hat{\hat{Y}}_{gk}$ reduces $\hat{\hat{Y}}_7 = \bar{y} + c_{yx}\left\{\bar{x}'\exp\left(\frac{\bar{z}'-\bar{Z}}{\bar{z}'+\bar{Z}}\right) - \bar{x}\right\}$ (10)

2.1 The bias and mean square error

In order to derive the expressions for the estimators' biases and MSEs in the case of the large sample approximation, let

$$\bar{y} = \bar{Y}(1+\varepsilon_0),\ \bar{x} = \bar{X}(1+\varepsilon_1),\ \bar{x}' = \bar{X}(1+\varepsilon_2),\ \bar{z}' = \bar{Z}(1+\varepsilon_3),\ \hat{S}_{yx} = S_{yx}(1+\varepsilon_4),\ \hat{S}_x^2 = S_x^2(1+\varepsilon_5)$$

such that $E(\varepsilon_i) = 0\ \forall\, i = 0, 1, 2, 3, 4, 5$. By utilizing the SRSWOR sampling technique, we obtain

$$E(\varepsilon_0^2) = \left(\frac{1}{n}-\frac{1}{N}\right)\frac{S_y^2}{\bar{Y}^2},\ E(\varepsilon_1^2) = \left(\frac{1}{n}-\frac{1}{N}\right)\frac{S_x^2}{\bar{X}^2},\ E(\varepsilon_2^2) = \left(\frac{1}{n'}-\frac{1}{N}\right)\frac{S_x^2}{\bar{X}^2},\ E(\varepsilon_3^2) = \left(\frac{1}{n'}-\frac{1}{N}\right)\frac{S_z^2}{\bar{Z}^2},$$

$$E(\varepsilon_0\varepsilon_1) = \left(\frac{1}{n}-\frac{1}{N}\right)\frac{S_{yx}}{\bar{Y}\bar{X}},\quad E(\varepsilon_0\varepsilon_2) = \left(\frac{1}{n'}-\frac{1}{N}\right)\frac{S_{yx}}{\bar{Y}\bar{X}},\quad E(\varepsilon_0\varepsilon_3) = \left(\frac{1}{n'}-\frac{1}{N}\right)\frac{S_{yz}}{\bar{Y}\bar{Z}},\quad E(\varepsilon_1\varepsilon_2) =$$

$$\left(\frac{1}{n'}-\frac{1}{N}\right)\frac{S_x^2}{\bar{X}^2},\quad E(\varepsilon_1\varepsilon_3) = \left(\frac{1}{n'}-\frac{1}{N}\right)\frac{S_{xz}}{\bar{X}\bar{Z}},\quad E(\varepsilon_2\varepsilon_3) = \left(\frac{1}{n'}-\frac{1}{N}\right)\frac{S_{xz}}{\bar{X}\bar{Z}},\quad E(\varepsilon_1\varepsilon_4) = \frac{Cov(\bar{x},\hat{S}_{yx})}{\bar{X}\ S_{yx}} = \mu_{14},$$

$$E(\varepsilon_1\varepsilon_5) = \frac{Cov(\bar{x},\hat{S}_x^2)}{\bar{X}\ S_x^2} = \mu_{15},\quad E(\varepsilon_2\varepsilon_4) = \frac{Cov(\bar{x}',\hat{S}_{yx})}{\bar{X}\ S_{yx}} = \mu_{24},\quad E(\varepsilon_2\varepsilon_5) = \frac{Cov(\bar{x}',\hat{S}_x^2)}{\bar{X}\ S_x^2} = \mu_{25},$$

$$E(\varepsilon_3\varepsilon_4) = \frac{Cov(\bar{z}',\hat{S}_{yx})}{\bar{Z}\ S_{yx}} = \mu_{34},\quad E(\varepsilon_3\varepsilon_5) = \frac{Cov(\bar{z}',\hat{S}_x^2)}{\bar{Z}\ S_x^2} = \mu_{35}.$$

We have obtained the following mathematical expressions for the estimators' bias and MSE up to the $O(n^{-1})$.

$$B(\hat{\hat{Y}}_{gk}) = \beta\left[-\mu_{14}+\mu_{15}+\mu_{24}-\mu_{25}+\frac{\alpha}{2}\mu_{34}-\frac{\alpha}{2}\mu_{35}+\theta_2\left\{\frac{\alpha(\alpha-2)}{8}C_z^2+\frac{\alpha}{2}C_{xz}\right\}\right] \quad (11)$$

and

$$MSE\,(\hat{\hat{Y}}_{gk}) = \bar{Y}^2C_y^2\left[\theta_1-\theta_3\rho_{yx}^2+\theta_2\left(\alpha^2\frac{\rho_{yx}^2}{4}\frac{C_z^2}{C_x^2}+\alpha\,\rho_{yx}\rho_{yz}\frac{C_z}{C_x}\right)\right]. \quad (12)$$

The optimum values of α which minimize $MSE(\hat{\hat{Y}}_{gk})$ is obtained as:

$$\alpha_{opt} = -2\frac{\rho_{yz}}{\rho_{yx}}\frac{C_x}{C_z}. \quad (13)$$

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The minimum mean square error of the estimator $\hat{\hat{Y}}_{gk}$ is obtained as:

$$MSE\,(\hat{\hat{Y}}_{gk})_{\min} = \bar{Y}^2 C_y^2 \left[\theta_1 - \theta_3 \rho_{yx}^2 - \theta_2 \rho_{yz}^2\right]. \tag{14}$$

Mean square errors of the other exiting estimators up to $O(n^{-1})$ are derived as:

$$MSE\,(\bar{y}) = \bar{Y}^2 \theta_1 C_y^2\,, \tag{15}$$

$$MSE\,(\hat{\hat{Y}}_1) = \bar{Y}^2 \left[\theta_1 C_y^2 + \theta_3 \left(C_x^2 - 2\rho_{yx} C_y C_x\right)\right], \tag{16}$$

$$MSE\,(\hat{\hat{Y}}_2) = \bar{Y}^2 C_y^2 \left[\theta_1 - \theta_3 \rho_{yx}^2\right], \tag{17}$$

$$MSE\,(\hat{\hat{Y}}_3) = \bar{Y}^2 \left[\theta_1 C_y^2 + \theta_3 \left(\frac{C_x^2}{4} - \rho_{yx} C_y C_x\right)\right], \tag{18}$$

$$MSE\,(\hat{\hat{Y}}_4) = \bar{Y}^2 \left[\theta_1 C_y^2 + \theta_3 \left(C_x^2 - 2\rho_{yx} C_y C_x\right) + \theta_2 \left(C_z^2 - 2\rho_{yz} C_y C_z\right)\right], \tag{19}$$

$$MSE\,(\hat{\hat{Y}}_5) = \bar{Y}^2 C_y^2 \left[\theta_1 - \theta_3 \rho_{yx}^2 + \theta_2 \left(\rho_{yx}^2 \frac{C_z^2}{C_x^2} - 2\rho_{yx}\rho_{yz} \frac{C_z}{C_x}\right)\right], \tag{20}$$

$$MSE\,(\hat{\hat{Y}}_6) = \bar{Y}^2 C_y^2 \left[\theta_1 - \theta_3 \rho_{yx}^2 + \theta_2 \left(\frac{\rho_{yx}^2}{4} \frac{C_z^2}{C_x^2} - \rho_{yx}\rho_{yz} \frac{C_z}{C_x}\right)\right], \tag{21}$$

where $\theta_1 = \left(\frac{1}{n} - \frac{1}{N}\right)$, $\theta_2 = \left(\frac{1}{n'} - \frac{1}{N}\right)$, $\theta_3 = \left(\frac{1}{n} - \frac{1}{n'}\right)$, $\beta = \bar{X}\frac{S_{yx}}{S_x^2}$, $C_y = \frac{S_y}{\bar{Y}}$, $C_x = \frac{S_x}{\bar{X}}$,

$C_z = \frac{S_z}{\bar{Z}}$, $S_y^2 = \frac{1}{N-1}\sum_{l=1}^{N}(Y_l - \bar{Y})^2$, $S_x^2 = \frac{1}{N-1}\sum_{l=1}^{N}(X_l - \bar{X})^2$, $S_z^2 = \frac{1}{N-1}\sum_{l=1}^{N}(Z_l - \bar{Z})^2$

and ρ_{yx} denotes the correlation coefficient between y and x and ρ_{yz} denotes the correlation coefficient between y and z respectively.

2.2 Efficiency comparision

In this section, we have obtained mathematical conditions under which the suggested estimators have lower MSEs than the other existing estimators.

Comparing the estimator $\hat{\hat{Y}}_{gk}$ with $(\bar{y}, \hat{\hat{Y}}_1, \hat{\hat{Y}}_2, \hat{\hat{Y}}_3, \hat{\hat{Y}}_4, \hat{\hat{Y}}_5, \hat{\hat{Y}}_6)$, we get

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$$MSE(\hat{\hat{Y}}_{gk}) < MSE(\bar{y}) \text{ If } \frac{-B_1-\sqrt{B_1^2-4A_1C_1}}{2A_1} < \alpha < \frac{-B_1+\sqrt{B_1^2-4A_1C_1}}{2A_1} \quad (22)$$

$$MSE(\hat{\hat{Y}}_{gk}) < MSE(\hat{\hat{Y}}_1) \text{ If } \frac{-B_2-\sqrt{B_2^2-4A_2C_2}}{2A_2} < \alpha < \frac{-B_2+\sqrt{B_2^2-4A_2C_2}}{2A_2} \quad (23)$$

$$MSE(\hat{\hat{Y}}_{gk}) < MSE(\hat{\hat{Y}}_2) \text{ If } -\frac{B_1}{A_1} < \alpha < 0 \quad (24)$$

$$MSE(\hat{\hat{Y}}_{gk}) < MSE(\hat{\hat{Y}}_3) \text{ If } \frac{-B_2-\sqrt{B_2^2-4A_2C_3}}{2A_2} < \alpha < \frac{-B_2+\sqrt{B_2^2-4A_2C_3}}{2A_2} \quad (25)$$

$$MSE(\hat{\hat{Y}}_{gk}) < MSE(\hat{\hat{Y}}_4) \text{ If } \frac{-B_2-\sqrt{B_2^2-4A_2C_4}}{2A_2} < \alpha < \frac{-B_2+\sqrt{B_2^2-4A_2C_4}}{2A_2} \quad (26)$$

$$MSE(\hat{\hat{Y}}_{gk}) < MSE(\hat{\hat{Y}}_5) \text{ If } \frac{-B_1-\sqrt{B_1^2-4A_1C_5}}{2A_1} < \alpha < \frac{-B_1+\sqrt{B_1^2-4A_1C_5}}{2A_1}$$

(27)

$$MSE(\hat{\hat{Y}}_{gk}) < MSE(\hat{\hat{Y}}_6) \text{ If } \frac{-B_1-\sqrt{B_1^2-4A_1C_6}}{2A_1} < \alpha < \frac{-B_1+\sqrt{B_1^2-4A_1C_6}}{2A_1} \quad (28)$$

where $A_1=\theta_2\dfrac{\rho_{yx}^2C_z^2}{4C_x^2}$, $B_1=\theta_2\,\rho_{yx}\rho_{yz}\dfrac{C_z}{C_x}$, $C_1=-\theta_3\,\rho_{yx}^2$, $A_2=\theta_2\dfrac{\rho_{yx}^2C_y^2C_z^2}{4C_x^2}$,

$B_2=\theta_2\,\rho_{yx}\rho_{yz}C_y^2\dfrac{C_z}{C_x}$, $C_2=-\theta_3(\rho_{yx}C_y-C_x)^2$, $C_3=-\theta_3\left(\rho_{yx}C_y-\dfrac{C_x}{2}\right)^2$, $C_4=-\theta_3\left(\rho_{yx}C_y-C_x\right)^2$

$-\theta_2\left(C_z^2-2\rho_{yz}C_yC_z\right)$, $C_5=-\theta_2\left(\rho_{yx}^2\dfrac{C_z^2}{C_x^2}-2\rho_{yx}\rho_{yz}\dfrac{C_z}{C_x}\right)$, $C_6=-\theta_2\left(\rho_{yx}^2\dfrac{C_z^2}{4C_x^2}-\rho_{yx}\rho_{yz}\dfrac{C_z}{C_x}\right)$

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3 NUMERICAL STUDY

To validate the efficiency of the proposed generalized exponential chain product in regression estimator, we have used the following data set:

Population Data-I: Ahmed (1997)

y :Total number of literate persons.

x: Total number of cultivators.

z: Total population size.

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$\bar{Y}$ =316.6, $\bar{X}$ = 141.1, $\bar{Z}$ = 1075.3, C_y = 0.77, C_x = 0.84, C_z = 0.77, ρ_{yx} = 0.91, ρ_{yz} = 0.90, ρ_{xz} = 0.86.

Population Data-II: Abu-Dayyeh et al. (2003)

y : Total number of cultivators.

x : Area of the village (in acres).

z : Total number of households in a village.

$\bar{Y}$ = 1093.1, $\bar{X}$ =181.5, $\bar{Z}$ = 143.3, C_y = 0.76 , C_x = 0.77, C_z = 0.76, ρ_{yx} = 0.97, ρ_{yz} = 0.86, ρ_{xz} = 0.84.

The percent relative efficiencies (PRE) of the estimators $(\hat{\bar{Y}}_1, \hat{\bar{Y}}_2, \hat{\bar{Y}}_3, \hat{\bar{Y}}_4, \hat{\bar{Y}}_5, \hat{\bar{Y}}_6, \hat{\bar{Y}}_{gk})$ with respect to $\bar{y}$, are obtained by

$$\text{PRE}=\frac{MSE\ (\bar{y})}{MSE\ (T_i)} \text{ X } 100\,;\, i=1,2,3,4,5,6,7,$$

where $T_1=\hat{\bar{Y}}_1,\ T_2=\hat{\bar{Y}}_2,\ T_3=\hat{\bar{Y}}_3,\ T_4=\hat{\bar{Y}}_4,\ T_5=\hat{\bar{Y}}_5,\ T_6=\hat{\bar{Y}}_6,\ T_7=\hat{\bar{Y}}_{gk}$.

Table 1 Percent Relative efficiency (PRE) and MSE of the estimators with respect to $\bar{y}$ Population Data-I $(\alpha_{opt}=-2.16)$

Estimators	$N=376,\ n'=80,\ n=20$		$N=376,\ n'=90,\ n=25$	
	PRE	**MSE**	**PRE**	**MSE**
$\bar{y}$	100.00	2813.43	100.00	2219.13
$\hat{\bar{Y}}_1$	270.30	1040.85	259.98	853.59
$\hat{\bar{Y}}_2$	290.67	967.912	278.29	797.39
$\hat{\bar{Y}}_3$	222.57	1264.08	216.38	1025.56
$\hat{\bar{Y}}_4$	490.99	572.99	491.21	451.77
$\hat{\bar{Y}}_5$	566.37	496.75	565.04	392.74
$\hat{\bar{Y}}_6$	446.15	630.59	437.10	507.69
$\hat{\bar{Y}}_{gk}$	569.27	494.21	568.19	390.56

Table 2 Percent Relative efficiency (PRE) and MSE of the estimators with respect to $\bar{y}$

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Population Data-II ($\alpha_{opt} = -1.80$)

Estimators	$N = 332,\ n' = 70,\ n = 20$		$N = 332,\ n' = 80,\ n = 25$	
	PRE	MSE	PRE	MSE
$\bar{y}$	100.00	32428.99	100.00	25527.44
$\hat{\bar{Y}}_1$	349.33	9283.21	331.30	7705.19
$\hat{\bar{Y}}_2$	351.06	9237.30	332.83	7669.84
$\hat{\bar{Y}}_3$	223.17	14530.77	217.33	11745.81
$\hat{\bar{Y}}_4$	880.94	3681.19	853.61	2990.51
$\hat{\bar{Y}}_5$	911.79	3556.60	883.63	2888.94
$\hat{\bar{Y}}_6$	702.84	4613.99	675.53	3778.85
$\hat{\bar{Y}}_{gk}$	931.12	3482.78	903.04	2826.82

DISCUSSION AND CONCLUSION

From tables 1, 2, it has been perceived that for the data-I, II, the proposed generalized chain exponential product in regression estimator $(\hat{\bar{Y}}_{gk})$ has less mean square error and more percent relative efficiency in comparison to the estimators $\bar{y}$ and $(\hat{\bar{Y}}_1, \hat{\bar{Y}}_2, \hat{\bar{Y}}_3)$, which were suggested by Sukhatme (1962), Cochran (1977) and Singh and Vishawakarma (2007). Further it has also been observed that in cases of different sample sizes, the proposed estimator has less mean square error and more percent relative efficiency in comparision to the estimators $(\hat{\bar{Y}}_4, \hat{\bar{Y}}_5, \hat{\bar{Y}}_6)$, which were suggested by Chand (1975), Kiregyera (1984) and Singh and Majhi (2014) From both the data sets, it has been found that the values of mean square error of all estimators decrese when the values of sample sizes increase.

We may therefore conclude that the suggested estimator do better than the other existing estimators in the setup where the population mean of the ancillary variable is not known, but the population mean of additional ancially variable is known. So we suggest this estimator for estimating the mean in Nutritional Science.

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