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Precision Ranking of Double Sampling and Sampling on Successive Occasions in Specific Distributions

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***Abstract* – The accuracy of estimates depends largely on the appropriateness of sampling methods adopted for the study. Precision of closely related sampling methods may be at variance with minimum cost of survey. The focus of samplers is to adopt a sampling method which can guarantee optimum precision at minimum cost. The central idea of this study is to examine the precision of two closely related sampling techniques with little dissimilarities in the procedures for a case where the data exhibits known distribution. Double sampling with attention on ratio as well as regression estimators and sampling on successive occasions were used for a normally distributed population and Skewed (Gamma) population. The second stage sample was considered to be the matched pairs in sampling on successive occasions which was varied from 10% to 90% to know the effect of sample size on the precision of the methods. The result revealed that sampling on successive occasion is better than both the ratio and regression estimators of double sampling in terms of precision across the three correlation coefficients for Skewed distribution while ratio estimator for double sampling has the least precision. The regression estimator for double sampling performs better than its ratio counterpart for double sampling and sampling on successive occasion under a normally distributed data case across three correlation coefficients while its ratio counterpart has the least.**

***Keywords* – Sampling, Optimum, Population, Gamma distribution, Correlation Coefficient.**

I. Introduction

Sampling plays a key role in virtually all areas of human endeavours as it serves as the realistic alternative when census is either not possible or required. In most real life situations the units in the population may not be accessible or available for enumeration due to reasons beyond the control of the sampler thereby resulting to selection from the available units. Sampling has thus become a very important and versatile aspect of human life that is concerned with the estimation of certain statistic from the sample with the use of appropriate estimators while inferences about the population parameter will then be drawn using the value of the sample statistic, since the main idea of sample survey is to take a random sample from a population and then use the information from the sample to draw inference(s) about some population characteristics such as the mean, the standard deviation or the proportion of unit in the population that have a certain characteristic(s) or feature(s). Sampling is capable of furnishing the investigators adequate, reliable and accurate information that can serve as the basis of generalization on the given population which depends on planning and appropriateness of the sampling design employ for the task. Assessment of appropriateness rests on the precision based on performance indices such as the variance (Oshungade, Ajayi &Masopa, 2014).

There are many sampling methods with varying usages and feasibilities where some of the methods may be similar in terms of the procedure for selection but with different estimators. In situations where there are closely related sampling methods, the sampler will no doubt settle for the methods that can guarantee optimum precision. Samplers or investigators need to have adequate knowledge about population coverage, the stages of sampling as well as the methods of sampling. Also, factors such as the population structure, the distribution of variable (s) under consideration, the relative accuracy and precision of the sampling method (s) must be considered before the adoption of any method. Raj and Chandhok (1998) opined that sampling designs which satisfy the guiding principle of giving the highest precision for a given cost or a minimum cost for a specified level of precision is preferable. Over the years, samplers do prefer sampling methods involving the use of auxiliary variable. This could be due to the fact that a good auxiliary variable will furnish some information about the actual variable of interest since it is expected to be correlated with the variable of interest and thereby improving the precision of estimators of population parameter both at the selection and estimation stages. Raj (1968) pointed out the use of auxiliary variable to improve the precision of sampling method is one of the edges sampling theory enjoys over other areas of areas such as statistical theory. Double sampling and sampling on successive occasions are typical examples of sampling methods that rely on auxiliary information but the latter gives room for estimation of parameters on different occasions. The methods have a wide range of application (Okafor F.C. & Lee H., 2000; Anieting & Ezugwu, 2013).

Double sampling and successive sampling is used repeatedly to survey a population over time. The selection procedure in the two methods involves taking initial sample (on the first occasion) and a second sample (on the second occasion). The method provides an opportunity for the researcher to make use of the information obtained in the first sample in order to improve on the precision of future estimates. However, estimates of means and total depend on both occasions. In double sampling, the information on auxiliary variable is collected from a preliminary large sample using simple random sampling without replacement (SRSWOR) while information on the variable of interest say, y is collected from a second sample whose size is smaller than the preliminary sample size using SRSWOR. In contrast to the above, for sampling on successive occasions the sample may be used on each occasion and a new sample may be taken on each occasion. A part of the sample may be retained while the remainder of the sample may be drawn afresh. It also requires the selection of additional units (unmatched units) for estimating the means. In addition , Eze, Amahia, Olayiwola and Adewara (2011) said that high positive correlation always exist between observations made on the same unit at two occasions that are successive.

The principal concern of this study is to examine the precision of the estimators of these closely related methods where the sampler has a reasonable idea of specific distributions exhibited by the variable of interest. Oshungade, Ajayi and Masopa (2014) examined the rating of the sampling methods without any attention on the distribution of the variable whereas variables are bound to exhibit a particular distribution which can affect the precision of sampling estimators. Generally, variables such as income and height of individuals are known to be skewed in distribution while scores of students could be normally distributed. In this study, normally distributed and skewed data with specific attention to the gamma case are considered. Raj (1968) compared regression and ratio estimators of double sampling developed by Neyman (1938) with various conditions under which each of the methods is better than the other were established. Rao (1973) studied double sampling in context of stratification. Cochran (1977) proposed a variety of both direct and indirect estimation techniques which use a double sampling with regression procedure to minimize bias and presented the basic result of two-phase sampling, including the simplest regression estimators for this class of sampling design. Okafor (1987), Okafor and Lee (2000), Sodipo and Obisesan (2007), and Kumar, Singh, Boughal and Gupta (2011) were among many authors who have assessed double sampling method to ascertain the efficiency of ratio and regression estimators. The problem of sampling on two successive occasions was first introduced by Jessen (1942). Utilizing the entire information collected in the previous occasions with an idea on estimation of two estimates that is, the sample mean based on new sample units only and the other was a regression estimate based on the sample units observed on both occasions and an overall sample mean obtained on the first occasion (Sen, 1971; Sen, 1972; Sen, 1973; Singh & Singh, 2001). Closely related to this idea were studies of Rao and Graham (1964), Gupta (1979), Das (1982) and Chaturvedi and Tripathi (1983). A scheme involving more than two occasions (h>2) where the procedure is confined to unit stage simple random sampling is also a possibility (Yate, 1949). This leads to a generalization case (Patterson, 1950; Tikkiwal, 1967). There has been review of the method over time (Sen, 1971; Singh & Shukla, 1991; Biradar &Singh, 2001). Eckler (1955) showed different level rotation sampling where it was established that for one level rotation sampling, only sampled values that have been drawn from the population of current time can be added to the sample pattern and in this situation, higher levels, both the earlier sample values and current values can be added. Raj (1965) pioneered the use of varying probability with replacement for sampling over two successive occasions by using proportional to size with replacement (PPSWR) and simple random sampling without replacement (SRSWOR). He based his estimation for the population total on the second occasion on a linear combination of two independent estimates of the population total from the matched and unmatched samples. Pathak and Rao (1966) proposed a modification of the estimators of Raj (1965) while Rodriguez and Luengo (2001) presented a sampling strategy for estimating, by a linear estimate, the population ratio of two characters under two-stage sampling over two occasions (or sampling with partial replacement of units). A related study was carried out by Reuda, Arcos, Martinez-Miranda and Roman. (2004) considered the problem of estimation of a finite population mean and for the current occasion based on sample selected over two occasions for the case when, several auxiliary variables are correlated with the main variable. They presented a double sampling multivariate product estimate from the matched portion, after which expressions for optimum estimator and its error were derived. The gain in efficiency of the combined estimate over the direct estimate using no information gathered on the first occasion was computed. Artes, Reuda and Arcos (2005) considered the case when the auxiliary variables are negatively correlated using a product estimate. The double sampling product estimate from the matched portion of the sample was presented and the expression for optimum estimator and its variance were derived. By extension Singh, Pandey, Singh and Suman (2019) combined cases of positively and negatively correlated auxiliary variables with exponential-type estimators and some improved estimators and generalized estimation were proposed (Singh, Pandey, & Singh, 2019; Singh, Pandey, & Sharma, 2020). Housila, Ritech, Sarjinder and Jong-Min (2007) studied how to estimate a finite population quantile in successive sampling on two occasions. The theory developed was aimed at providing the optimum estimates by combining three double sampling estimators viz: ratio-type, product-type and regression-type from the matched portion of the sample and a simple quantile based on a random sample from the unmatched portion of the sample on the second occasion. It was discovered from their study that the performance of regression-type estimator is the best among all the estimators discussed. Housila, Ritech, Sarjinder and Jong-Min (2010) examined the estimation of population variance in successive sampling and proposed a class of estimators of finite population variance in successive sampling on two occasions and analyzed its properties. This class of estimators can be used when considering the problem of estimation of finite population variance in survey sampling.

Despite the closeness and adaptability of double sampling and sampling on successive occasions, comparative analysis on precision of the sampling methods has so far received little or no attention. This paper intends to uncover the precision preference between the two sampling methods and thereby recommend the best and most efficient to be adopted for a given survey where the pattern of distribution for the variable is known. Oshungade, et al. (2014) established that double sampling for regression performed better than its ratio counterpart without given attention to the distribution of the variable.

II. Materials and Methods

The data for this study was generated by simulation with reference to two probable cases, that is normally distributed data and positively skewed (gamma) distributed data. It has been observed that a number of variables in survey practices, such as income, size of land holding, employment and output of industrial establishment are likely to follow a skewed distribution. Since this study is centred on the assessment of performance with respect to precision between two methods of sampling, attention is focused on the unbiased estimator of the variances of the sampling methods to determine the precision hierarchy of the estimators under consideration such that the lower the variance the higher the precision and vice versa.

III. Selection Procedure and Estimators for the Variances

The selection procedure in double sampling involves taking an initial sample of size $n' = 40$ d by simple random sampling without replacement, then a subsample of size $n(20 \le n \le 36)$ was taken from the initial sample. The subsample was varied from 50% to 90% of the initial sample where the upper limit of the subsample was restricted to 90% to avoid a case of complete matching while the lower limit ensures that at least 50% matching was observed. However, lower percentages of the lower bound could be of interest in further studies. In the case of sampling on two occasions, the n subsample is referred to as the matched or retained units "m". This implies that $n = m$. However for estimation of means and total, sampling on two occasions requires taking $n' - m$ new units independent of the initial sample. The $n' - m$ units are referred to as the unmatched units on the second occasion.

Let λ and θ be the percentage matched (subsample) and unmatched (new units) respectively. Then $\lambda_m = m/n'$ and $\theta = (1 - m/n')$ such that $\lambda + \theta = 1$ holds

Considering the modified variance estimators for the variance estimators of these sampling methods with common elements (Oshungade et al., 2014). The variances of the estimators for double sampling for regression and ratio are given in eq.1 & eq.2 respectively while eq. 3 is the estimator for the variance of sampling on successive occasions. This study is an extension focusing on the practical situations where the variable of interest is known or assumed to exhibit a specific distribution pattern.

$$V(y'lr) = \left(\frac{N-m}{Nm}\right)S_{my}^2 + \left(\frac{n'-m}{n'm}\right)S_{my}^2(1-\rho_m^2) \tag{1}$$

$$V(\bar{y}'_R) = \left[\left(\frac{N-m}{Nm}\right)S_{my}^2 + \left(\frac{n'-m}{n'm}\right)\left[R_m^2 S_{mx}^2 - 2R_m S_{mxy}\right]\right] \tag{2}$$

$$V(\mu) = \frac{\left(1-\rho_m^2\theta\right)}{\left(1-\rho_m^2\theta^2\right)}\frac{S_m}{m} \tag{3}$$

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Incorporating the expressions for λ_m and ρ_m eqn. 1, eqn. 2 & eqn. 3 thus becomes eqn 4, eqn. 5 and eqn. 6 respectively on the condition that the finite population correction factor is negligible.

$$V(y'lr) = \frac{S_{my}^2}{m}\left\{1+(1-\lambda)\ (1-\rho_m^2)\right\} \tag{4}$$

$$V(\bar{y}_R') = \frac{1}{m}\left[S_{my}^2 + (1-\lambda)\ \left[R_m^2 S_{mx}^2 - 2R_m\rho_m S_{mx}S_{my}\right]\right] \tag{5}$$

$$V(\mu) = \left\{\frac{1-\rho_m^2(1-\lambda)}{1-\rho_m^2(1-\lambda^2)}\right\}\frac{S_{mx}^2 + S_{my}^2}{2m} \tag{6}$$

The estimators stated above clearly revealed the closeness of the sampling methods common constituents such as λ_m and ρ_m, which play key roles in estimating measures of precision. For the purpose of this study ρ_m is fixed at 0.25, 0.5 and 0.75 to represent cases where the correlation is low, moderate and high respectively.

IV. Data Analysis

This section presents the results of computations carried out by using the variance estimators of the sampling methods derived in the previous section to obtain the standard error of estimates. Having generated the data by simulation, samples are drawn at various values of λ. The sample size depends on the value of λ. Table I shows a the standard error of estimate at various λs $(0.50 \le \lambda \le 0.090)$ with 0.05 interval between successive λs for the case of normally distributed data while Table II shows the standard error of estimate for a skewed data of the gamma distribution pattern. Also, three fixed correlations $\rho = 0.25, 0.50, 0.75$ are chosen. This is to observe the behaviours of the sampling methods for the cases of distributions considered as the values of λ and ρ change. Regression and ratio estimators were considered for double sampling. The three correlation coefficients were chosen to represent the various possibilities of low $(\rho = 0.25)$, intermediate $(\rho = 0.50)$ and high $(\rho = 0.75)$ correlations. More so, it has been established that ratio and regression estimators will be better than a simple random sampling (SRS) when $\rho \ge 0.5$ (Cochcran, 1977). In successive sampling with partial matching, the efficiency will depend on the correlation between the matched units. As stated earlier, the value of λ indicates the percentage of matched sample "m". For example, $\lambda = 0.5$ means half of the initial sample were retained or subsample. That is, if $n^I = 40$ and $\lambda = 0.5$ such that 20 units of the initial sample n' were retained on the second occasion.

V. Discussion of Results

Generally, precision increases as the values of λ and ρ increases for normally distributed data case as shown in table I but for $\lambda = 0.90$ at all values of the correlation coefficients considered, the precision tends to decrease. This could be observed from the increase in the standard error of estimate when compared with the immediate preceding result that is, when $\lambda = 0.85$. There exist precision preferences for the sampling methods in relation to the distribution pattern exhibited by the variable of interest. From the table, it can be deduced that for a normally distributed variable, double sampling for regression has the highest precision at all correlation coefficients and all values of $\lambda's$ considered. Furthermore the contest for the second position in the rating is prerogative with respect to the values of λ and ρ.

Table I. Calculated standard error of estimate at various λs and fixed values of ρs for normal distributed data.

% Matched Sample	Sample Size n	ρ_m	Double Sampling		Sampling on Successive Occasion
			Regression	Ratio	
50	20	0.25	153.8568	244.1737	186.3850
		0.50	146.2170	218.6299	202.9332
		0.75	132.5204	187.7888	186.3703
55	22	0.25	142.6911	216.5267	171.0968
		0.50	136.3565	194.4195	166.7663
		0.75	125.0880	169.5409	158.3324
60	24	0.25	132.4803	207.2054	169.7448
		0.50	167.2829	187.8148	165.6141
		0.75	118.1136	165.1769	157.8490
65	26	0.25	130.7945	196.9045	167.7284
		0.50	126.3360	179.5781	163.9233
		0.75	118.5179	160.3906	156.9123
70	28	0.25	122.8869	177.3591	157.4218
		0.50	119.3126	162.8935	154.1552
		0.75	113.5049	147.0114	149.5429
75	30	0.25	116.9485	162.1147	127.1532
		0.50	113.9348	150.1321	148.0868
		0.75	109.0842	137.1062	145.2006
80	32	0.25	118.4738	152.2165	147.0536
		0.50	116.3006	142.3632	144.7797
		0.75	112.4000	131.7752	140.8281
85	34	0.25	113.6493	132.5977	139.9849

% Matched Sample	Sample Size n	ρ_m	Double Sampling		Sampling on Successive Occasion
			Regression	Ratio	
		0.50	112.0244	127.4537	138.2800
		0.75	109.2625	122.0931	135.3226
		0.25	116.6472	132.5977	140.3981
90	36	0.50	115.5415	127.4537	139.1996
		0.75	113.6748	122.0931	137.1822

It could be observed that for $\lambda = 0.50$ to 0.65, sampling on two occasions has a better precision than double sampling for ratio at all values of ρ. This extends for $\lambda = 0.70, 0.75$ and $\rho = 0.25, 0.50$. But for these same values of λ at $\rho = 0.75$, double sampling for ratio has higher precision than sampling on two occasions. Also, table II shows the result of analysis for a positively skewed distribution, it could be deduced that the precision rating is independent of the values of λ and ρ. Sampling on two occasions takes the lead over double sampling both for regression and ratio estimators across all values of λ and ρ, followed by double sampling for regression while double sampling for ratio has the least precision.

Table II. Standard error of estimate at various λs and fixed values of ρs for skewed distributed data.

% Matched Sample	Sample Size n	ρ_m	Double Sampling		Sampling on Successive Occasion
			Regression	Ratio	
		0.25	19.2148	21.6832	16.2985
50	20	0.50	18.2615	19.4163	15.8723
		0.75	16.5509	16.8471	15.0252
		0.25	20.5163	22.9600	17.4287
55	22	0.50	19.6628	20.7687	16.9848
		0.75	18.0379	18.3172	16.1279
		0.25	20.5137	22.6342	17.3558
60	24	0.50	19.7089	20.6854	16.9332
		0.75	18.2890	18.5328	16.1393
		0.25	20.2315	21.3617	17.1118
65	26	0.50	19.5512	20.0108	16.2125
		0.75	17.2021	18.3685	15.6182

% Matched Sample	Sample Size *n*	ρ_m	Double Sampling		Sampling on Successive Occasion
			Regression	Ratio	
70	28	0.25	18.3839	19.8165	15.5191
		0.50	17.8492	18.4981	15.1973
		0.75	16.9206	17.0782	14.6184
75	30	0.25	17.5006	18.6407	14.7606
		0.50	17.0789	17.5911	14.4903
		0.75	16.3518	16.4748	14.0131
80	32	0.25	16.6387	17.5086	14.0237
		0.50	16.3198	16.7074	13.8068
		0.75	15.7738	15.8658	13.4299
85	34	0.25	15.7479	16.3671	13.2655
		0.50	15.5228	15.7964	13.1035
		0.75	15.1401	15.2042	12.8559
90	36	0.25	15.5802	15.9898	13.1183
		0.50	15.4325	15.6119	13.0081
		0.75	15.1831	15.2228	12.8161

VI. Conclusions

It can be observed that generally precision of the estimators increase as the number of subsample units on second occasion increases and there exist a limit at which the idea of taking sample makes reasonable effect. In this case, the limit is when the subsample does not exceed 85% of the initial sample. Also, for reasons of computational difficulty, sampler should not employ double sampling for ratio estimators for analytical purposes since it appears to be the least on the precision rating for the three cases of distributions considered. More so, if the sampler knows that the variable of interest is normally distributed, then double sampling for regression should be used while for a positively skewed (Gamma) distribution cases, the sampler should settle for sampling on two occasions. This could be applicable to similar skewed distributions.

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