Dichotomous Randomized Response Technique for Data Collection of Sensitive Questions

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Abstract
Data are needed to make informed decision in every facet of life. Also, for any government to make remarkable success in terms of national planning and development, there is need for good and reliable data. However, obtaining data on sensitive issues is difficult as many respondents may refuse or give false response when direct method is used. This leads to bias in data collection and to correct this bias,the paper presents Randomized Response Technique (RRT) as a solution to obtaining reliable data in sample survey and censuses. Practical applications show that RRT is more efficient than the traditional/direct method of data collection. Hence, RRT is recommended in place of direct method of data collection especially for sensitive questions.
Keywords: Data, Efficiency, Sensitive Questions, Traditional Method.

1. Introduction

In obtaining sensitive information on socially embarrassing or illegal acts such as induced abortion, illicit drugs usage, drunk driving, illegal possession of arms using direct method of data collection,reliability of data is compromised.However, obtaining valid and reliable information is a prerequisite for any government to make remarkable success in terms of national planning and development.Hence, there is need to ensure confidentiality of respondents which will in-turn lead to more reliable information for better decision making.Warner (1965) developed an interview procedure designed to reduce or eliminate this bias and called it Randomized Response Technique (RRT).A lot of work has been done to improve Warner's design in order to increase efficiency and reduce its bias.Some of these include; Greenberg *et al.* (1969), Mangat and Singh (1990), Hussain-Shabbir (2007), Adebola and Adepetun (2011), Ewemooje (2017), Adebola *et al.* (2017) and Ewemooje *et al.* (2018) among others.

However, there are limited applications of these models, some of these are; Cobo *et al.,* (2016)work which examinedthe use of cannabis among Spanish University students using RRT and compared the result with Direct Method (DM), their results revealed that RRT increases response rate for cannabis use;Ewemooje *et al.,* (2017) also used Improved Randomized Response Technique for two sensitive attributes in estimating prevalence of induced abortion and multiple sexual partners to show that RRToutperforms DM. Furthermore, Ewemooje *et al.,* (2019) used RRT and DM to measure substance use disorder prevalence; their findings revealed that RRT estimated the disorder better with lower error than the DM. Therefore, this paperset to modify Ewemooje *et al.,*(2018) model by considering dichotomous randomized response design in the presence of unrelated questions and also, to verify more-is-better assumption, the proposed method and DM were applied to collect data on same subpopulation.

2. Alternative Unbiased Estimator in Dichotomous Randomized Response Model (ADRRT)

In ADRRT, respondentwas asked sensitive question directly if he/she responds "yes" then he/she is not allowed to use the randomized device while if "no", respondentis required to use the randomized device. Two randomized devices were used andeach consisting of two questions with different selection probabilities. A simple random sample with replacement sampling was adopted in their sample selection with α and β as any two positive real numbers such that $q = \frac{\alpha}{\alpha+\beta}$ is the probability of using the first randomized device and $1- q = \frac{\beta}{\alpha+\beta}$ is the probability of using the second randomized device.

Supposed all respond truthfully, their population proportion of "yes" answers were given by:

$$P(yes) = \theta_1 = \pi + \frac{\alpha}{\alpha+\beta}(1-P_1)(1-\pi) + \frac{\alpha}{\alpha+\beta}(1-P_2)(1-\pi) \quad (1)$$

where P_1 is the probability of the sensitive attribute in randomized device R_1 and P_2 is the probability of the sensitive attribute in randomized device R_2.

This yielded an unbiased estimate of the population proportion as:

$$\hat{\pi} = \frac{\hat{\theta}_1(\alpha+\beta) - P_2\alpha - P_1\beta}{P_1\alpha + P_2\beta} \quad (2)$$

The variance of their estimate was given as

$$V(\hat{\pi}) = \frac{\pi(1-\pi)}{n} + \frac{(1-\pi)(P_2\alpha + P_1\beta)}{n(P_1\alpha + P_2\beta)^2} \quad (3)$$

3. Proposed Model

In a finite population, sample size, n, of respondents who respond to sensitive questions was selected throughsimple random sample with replacement. Sensitive question was asked directly from the respondent, if "yes" answer is obtained, he/she does not need to use the randomized device but if he/she answers "no", then he/she uses the randomized devices,R_1 and R_2, consists of two unrelated questions (the sensitive question A in which the interviewer is interested in with probability, P, and non-sensitive attribute question U that is unrelated to the sensitive question A with probability, 1-P) each. Say:

Sensitive question: "*do you belong to a sensitive attribute, A?*"

Non-sensitive question: "*do you eat rice,* U?"

Dichotomous responses were considered for each of the two unrelated questions: "yes" and "no", where α and β are positive real numbers such that $q = \frac{\alpha}{\alpha+\beta}, \alpha \neq \beta$ is the probability of using R_1 and $1 - q = \frac{\beta}{\alpha+\beta}, \alpha \neq \beta$ is the probability of using R_2 with preset probabilities P_1 and P_2 respectively, for each of the devices.

Let $\pi_A$be the true proportion of people that belongs to the sensitive attribute andπ_u, the proportion of people that belongs to the unrelated non-sensitive attribute. If all respond truthfully as the devices provide protection for respondents, the population proportion of "yes" answer is given by:

$$P(yes) = \theta = \pi_A + \frac{\alpha}{\alpha+\beta}[P_1\pi_A + (1-P_1)\pi_U] + \frac{\beta}{\alpha+\beta}[P_2\pi_A + (1-P_2)\pi_U] \quad (4)$$

Solving equation (4) further yield the population proportion of the sensitive attribute

$$\pi_A = \frac{\theta(\alpha+\beta) - \pi_U((\alpha+\beta) - \alpha P_1 - \beta P_2)}{(\alpha+\beta + \alpha P_1 + \beta P_2)} \quad (5)$$

The test for unbiasedness shows that $E(\hat{\pi}_A) = \pi_A$. Hence, the unbiased estimate of $\pi_A$is given as:

$$\hat{\pi}_A = \frac{\hat{\theta}(\alpha+\beta) - \pi_U((\alpha+\beta) - \alpha P_1 - \beta P_2)}{(\alpha+\beta + \alpha P_1 + \beta P_2)} \quad (6)$$

where $\hat{\theta} = {n_0}/{n}$, n_0 is number of respondents that answered "yes" to sensitive question while n is the sample size.

3.1 Variance Estimation

The variance of the proposed unbiased estimator is given as:

$$v(\hat{\pi}_A) = \frac{\pi_A\{(\alpha+\beta) - \pi_A(\alpha+\beta + \alpha P_1 + \beta P_2)\}}{n(\alpha+\beta + \alpha P_1 + \beta P_2)} + \frac{\pi_U(\alpha+\beta - \alpha P_1 - \beta P_2)(\alpha+\beta - 2\pi_A(\alpha+\beta + \alpha P_1 + \beta P_2))}{n(\alpha+\beta + \alpha P_1 + \beta P_2)^2} \quad (7)$$

Therefore, the estimate of the variance of the proposed unbiased estimator is:

$$\hat{v}(\hat{\pi}_A) = \frac{\hat{\pi}_A\{(\alpha+\beta) - \hat{\pi}_A(\alpha+\beta + \alpha P_1 + \beta P_2)\}}{(n-1)(\alpha+\beta + \alpha P_1 + \beta P_2)} + \frac{\pi_U(\alpha+\beta - \alpha P_1 - \beta P_2)(\alpha+\beta - 2\hat{\pi}_A(\alpha+\beta + \alpha P_1 + \beta P_2))}{(n-1)(\alpha+\beta + \alpha P_1 + \beta P_2)^2} \quad (8)$$

3.2 Relative Efficiency Comparison

The proposed model will be more efficient than theADRRTmodel if the condition for the relative efficiency holds:

$$RE = \frac{\text{variance of ADRRT model}}{\text{variance of proposed model}} > 1$$

The Relative efficiency of the proposed model over the ADRRT model was gotten for varying sample sizes (n), varying probabilities P_1 and $P_2$of using the randomized devices at different values of π_A and π_U.

The comparison between the proposed estimator and ADRRT estimator at different sample sizes in Table 1 shows that the proposed estimator is approximately ten (10) times more efficient than ADRRT. Also, as the sample size increases from 50 to 500, the variances due to ADRRT estimator reduces from 0.0053 to 0.0005 while the proposed estimator reduces from 0.0005 to 0.0001. Therefore, as the sample sizes increases the variability reduces which implies consistency of the two models.

n	$\boldsymbol{\pi_A}$	$\boldsymbol{\pi_U}$	$\mathbf{P_1}$	$\mathbf{P_2}$	**α**	**β**	$\mathbf{v(\hat{\pi})}$	$\mathbf{v(\hat{\pi}_A)}$	**RE**
50	0.5	0.5	0.5	0.5	25	35	0.005333	0.000537	9.931034
100	0.5	0.5	0.5	0.5	25	35	0.002667	0.000269	9.931034
150	0.5	0.5	0.5	0.5	25	35	0.001778	0.000179	9.931034
200	0.5	0.5	0.5	0.5	25	35	0.001333	0.000134	9.931034
250	0.5	0.5	0.5	0.5	25	35	0.001067	0.000107	9.931034
300	0.5	0.5	0.5	0.5	25	35	0.000889	0.0000895	9.931034
350	0.5	0.5	0.5	0.5	25	35	0.000762	0.0000767	9.931034
400	0.5	0.5	0.5	0.5	25	35	0.000667	0.0000671	9.931034
450	0.5	0.5	0.5	0.5	25	35	0.000593	0.0000597	9.931034
500	0.5	0.5	0.5	0.5	25	35	0.000533	0.0000537	9.931034

Table 1: Relative efficiency comparison between proposed model and ADRRT modelwhen π_A = 0.5; π_U= 0.5; P_1= 0.5; P_2= 0.5; α= 25; β= 35 for varying sample sizes (n).

Allowing for a constant sample size at varying probabilities of selecting the randomized device, the relative efficiency reduces from 7.089 to 6.227 as shown in Table 2.

n	π_A	π_U	P_1	P_2	α	β	$v(\hat{\pi})$	$v(\hat{\pi}_A)$	RE
200	0.5	0.5	0.1	0.9	25	35	0.001306	0.000184	7.089034
200	0.5	0.5	0.2	0.8	25	35	0.001312	0.000188	6.966797
200	0.5	0.5	0.3	0.7	25	35	0.001318	0.000193	6.848074
200	0.5	0.5	0.4	0.6	25	35	0.001325	0.000197	6.733115
200	0.5	0.5	0.5	0.5	25	35	0.001333	0.000201	6.622212
200	0.5	0.5	0.6	0.4	25	35	0.001342	0.000206	6.515705
200	0.5	0.5	0.7	0.3	25	35	0.001352	0.000211	6.413994
200	0.5	0.5	0.8	0.2	25	35	0.001363	0.000216	6.317551
200	0.5	0.5	0.9	0.1	25	35	0.001376	0.000221	6.226937

Table 2: Relative efficiency comparison between proposed model and ADRRT model when $\pi_A = 0.5$; $\pi_U = 0.5$; $\alpha = 25$; $\beta = 35$; n=200 for varying P_1 and P_2

Table 3 shows that for varying π_A and π_U, $P_1 = 0.3$; $P_2 = 0.7$, the variance of the ADRRTmodel increases at all values of $\pi_A$while the variance of the proposed model increases as π_U increases when $0.1 \leq \pi_A \leq 0.3$ and decreases as π_U increases when $0.35 \leq \pi_A \leq 0.45$. The relative efficiency of the proposed model over ADRRT reduces as π_U increases when $0.1 \leq \pi_A \leq 0.3$and increases as π_U increases when $0.35 \leq \pi_A \leq 0.45$. However, as the sensitive character, π_A increases, the relative efficiency increases with the values ranging from 1.0135 to 21.4409,this shows that the proposed model is more efficient than the ADRRTmodel as the proportion of people belonging to the sensitive attribute increases.

π_A	π_U	$v(\hat{\pi})$	$v(\hat{\pi}_A)$	RE	π_A	π_U	$v(\hat{\pi})$	$v(\hat{\pi}_A)$	RE
	0.1	0.000573	0.000345	1.662303		0.1	0.001146	0.000536	2.137366
	0.2	0.000573	0.000413	1.387377		0.2	0.001146	0.000543	2.108094
	0.3	0.000573	0.000481	1.191302		0.3	0.001146	0.000551	2.080862
	0.4	0.000573	0.000549	1.044416		0.4	0.001146	0.000557	2.055543
0.1	0.5	0.000573	0.000616	0.930275	0.3	0.5	0.001146	0.000564	2.032025
	0.6	0.000573	0.000683	0.839031		0.6	0.001146	0.00057	2.010205
	0.7	0.000573	0.00075	0.764424		0.7	0.001146	0.000576	1.989992
	0.8	0.000573	0.000816	0.702286		0.8	0.001146	0.000581	1.971302
	0.9	0.000573	0.000882	0.649735		0.9	0.001146	0.000586	1.954063
	1	0.000573	0.000948	0.604711		1	0.001146	0.000591	1.938206
	0.1	0.000754	0.00043	1.752585		0.1	0.001226	0.000521	2.352242
	0.2	0.000754	0.000483	1.559987		0.2	0.001226	0.000514	2.387847
	0.3	0.000754	0.000536	1.406395		0.3	0.001226	0.000505	2.426134
	0.4	0.000754	0.000588	1.281057		0.4	0.001226	0.000497	2.46731
0.15	0.5	0.000754	0.00064	1.176839	0.35	0.5	0.001226	0.000488	2.511608
	0.6	0.000754	0.000692	1.088822		0.6	0.001226	0.000479	2.559291
	0.7	0.000754	0.000744	1.013506		0.7	0.001226	0.00047	2.610657
	0.8	0.000754	0.000795	0.948329		0.8	0.001226	0.00046	2.666043
	0.9	0.000754	0.000846	0.891377		0.9	0.001226	0.00045	2.725833
	1	0.000754	0.000896	0.841189		1	0.001226	0.000439	2.790465
	0.1	0.000909	0.00049	1.854419		0.1	0.001282	0.000482	2.661543
	0.2	0.000909	0.000528	1.721451		0.2	0.001282	0.000459	2.79495
	0.3	0.000909	0.000566	1.607214		0.3	0.001282	0.000435	2.944671
	0.4	0.000909	0.000603	1.508023		0.4	0.001282	0.000412	3.113841
0.2	0.5	0.000909	0.00064	1.421098	0.4	0.5	0.001282	0.000388	3.306451
	0.6	0.000909	0.000676	1.344305		0.6	0.001282	0.000363	3.52767
	0.7	0.000909	0.000713	1.275977		0.7	0.001282	0.000339	3.784304
	0.8	0.000909	0.000749	1.214796		0.8	0.001282	0.000314	4.085509
	0.9	0.000909	0.000784	1.159703		0.9	0.001282	0.000288	4.443899
	1	0.000909	0.000819	1.109838		1	0.001282	0.000263	4.877343

	0.1	0.00104	0.000526	1.978355		0.1	0.001313	0.000417	3.147851
	0.2	0.00104	0.000548	1.896602		0.2	0.001313	0.000379	3.465365
	0.3	0.00104	0.000571	1.822394		0.3	0.001313	0.00034	3.857866
	0.4	0.00104	0.000593	1.754752		0.4	0.001313	0.000301	4.355411
0.25	0.5	0.00104	0.000614	1.692864	0.45	0.5	0.001313	0.000262	5.006603
	0.6	0.00104	0.000636	1.636043		0.6	0.001313	0.000223	5.895497
	0.7	0.00104	0.000657	1.583709		0.7	0.001313	0.000183	7.181136
	0.8	0.00104	0.000677	1.53537		0.8	0.001313	0.000143	9.205181
	0.9	0.00104	0.000698	1.490601		0.9	0.001313	0.000102	12.85955
	1	0.00104	0.000718	1.449035		1	0.001313	0.0000612	21.44086

Table 3: Relative efficiency comparison between proposed model and ADRRT model when P_1= 0.3; P_2= 0.7; α= 25; β= 35; n=200 for varying π_A and π_U.

π_A	π_U	$v(\hat{\pi})$	$v(\hat{\pi}_A)$	RE	π_A	π_U	$v(\hat{\pi})$	$v(\hat{\pi}_A)$	RE
	0.1	0.000634	0.000378	1.67503		0.1	0.001193	0.000587	2.030752
	0.2	0.000634	0.000465	1.361891		0.2	0.001193	0.000602	1.982633
	0.3	0.000634	0.000552	1.148251		0.3	0.001193	0.000615	1.938042
	0.4	0.000634	0.000638	0.993193		0.4	0.001193	0.000629	1.896659
0.1	0.5	0.000634	0.000724	0.875529	0.3	0.5	0.001193	0.000642	1.8582
	0.6	0.000634	0.000809	0.783192		0.6	0.001193	0.000655	1.822421
	0.7	0.000634	0.000894	0.7088		0.7	0.001193	0.000667	1.789101
	0.8	0.000634	0.000979	0.647589		0.8	0.001193	0.000679	1.758048
	0.9	0.000634	0.001063	0.596341		0.9	0.001193	0.00069	1.729089
	1	0.000634	0.001146	0.552808		1	0.001193	0.000701	1.702072
	0.1	0.000811	0.000468	1.73255		0.1	0.00127	0.000577	2.200659
	0.2	0.000811	0.000537	1.510522		0.2	0.00127	0.000573	2.215729
	0.3	0.000811	0.000605	1.33985		0.3	0.00127	0.000569	2.232628
	0.4	0.000811	0.000673	1.20457		0.4	0.00127	0.000564	2.251434
0.15	0.5	0.000811	0.000741	1.094713	0.35	0.5	0.00127	0.000559	2.272238
	0.6	0.000811	0.000808	1.003731		0.6	0.00127	0.000553	2.295143
	0.7	0.000811	0.000875	0.927151		0.7	0.00127	0.000547	2.320265
	0.8	0.000811	0.000941	0.861805		0.8	0.00127	0.000541	2.347734
	0.9	0.000811	0.001007	0.805395		0.9	0.00127	0.000534	2.377699
	1	0.000811	0.001072	0.756207		1	0.00127	0.000527	2.410328

0.2	0.1	0.000963	0.000533	1.807757	0.4	0.1	0.001322	0.000542	2.440203
	0.2	0.000963	0.000583	1.650922		0.2	0.001322	0.00052	2.54398
	0.3	0.000963	0.000634	1.520119		0.3	0.001322	0.000497	2.659183
	0.4	0.000963	0.000683	1.409372		0.4	0.001322	0.000474	2.787741
	0.5	0.000963	0.000733	1.314408		0.5	0.001322	0.000451	2.932044
	0.6	0.000963	0.000782	1.232084		0.6	0.001322	0.000427	3.095093
	0.7	0.000963	0.00083	1.160041		0.7	0.001322	0.000403	3.280704
	0.8	0.000963	0.000879	1.096473		0.8	0.001322	0.000379	3.493806
	0.9	0.000963	0.000926	1.039974		0.9	0.001322	0.000354	3.740884
	1	0.000963	0.000974	0.989432		1	0.001322	0.000328	4.030638
0.25	0.1	0.001091	0.000573	1.904498	0.45	0.1	0.00135	0.000482	2.801958
	0.2	0.001091	0.000605	1.802396		0.2	0.00135	0.000441	3.057695
	0.3	0.001091	0.000637	1.711794		0.3	0.00135	0.000401	3.368273
	0.4	0.001091	0.000669	1.630872		0.4	0.00135	0.00036	3.753384
	0.5	0.001091	0.0007	1.558175		0.5	0.00135	0.000318	4.243433
	0.6	0.001091	0.000731	1.492525		0.6	0.00135	0.000276	4.887965
	0.7	0.001091	0.000761	1.432962		0.7	0.00135	0.000234	5.773544
	0.8	0.001091	0.000791	1.37869		0.8	0.00135	0.000191	7.066269
	0.9	0.001091	0.000821	1.329049		0.9	0.00135	0.000148	9.13035
	1	0.001091	0.00085	1.283481		1	0.00135	0.000104	12.94899

Table 4: Relative efficiency comparison between proposed model and ADRRT model when P_1= 0.7; P_2= 0.3; α= 25; β= 35; n=200 for varying π_A and π_U.

Table 4 shows that for varying π_A and π_U, P_1= 0.7; P_2= 0.3, the variance of the ADRRTmodel increases at all values of $\pi_A$from 0.00043 to 0.00135 while the variance of the proposed model also increases as π_U increases when $0.1 \leq \pi_A \leq 0.3$ and decreases as π_U increases when $0.35 \leq \pi_A \leq 0.45$. The relative efficiency of the proposed model over ADRRT shows that as the sensitive character increases, the relative efficiency increases with the values ranging from 1.0037 to 12.9490.

4. Proposed Model Application

Information on examination malpractices prevalence among students at a Nigerian university was collected using both the proposed and direct methods. Two hundred (200) questionnaires were administered using two decks of cards consisting of the sensitive question *"have you ever been involved in examination malpractices?"* and unrelated question "*do you eat rice*?" as the randomized devices.The respondents were given proper education on how to use the randomized devices with appropriate demonstration. The interviewer ensured confidentiality by making sure responses given cannot be traced to respondents; hence, respondents willingly participated in the survey.

The sensitive question *"have you ever been involved in examination malpractices?"* was asked directly (DM) from the respondents, if "yes" answer is obtained from a particular respondent, he/she is not allowed to use the randomized device but if he/she answers "no", then he/she is instructed to choose one of the two decks of cards at random and then respond accordingly without revealing question answered to the interviewer. The two randomized devices R_1 and R_2 consist of two unrelated questions (the sensitive question with probability, $P_1 = 0.7$, and unrelated question with probability, $1\text{-}P_1 = 0.3$ for R_1 while $P_1 = 0.3$ and $P_2 = 0.7$ for R_2).

The results show that age distribution of the sampled respondents ranges between 16 and 29 years with age group 20–24 years having the higher percentage of 58.0% and about three-quarters of them are male (74.0%). The estimate of examination malpractices prevalence and their associated coefficient of variation (CV) are presented in table 5. The DM estimated prevalence of examination malpractices as 19.0% compared to 23.0% for the proposed method. The standard error associated with DM is 2.8% (CV = 14.6%) while proposed model is 2.6% (CV = 11.5%).

However, contrary to what was stated by Jann et al., (2012) where Crosswise Model (CM) produced higher estimate with higher standard error, the proposed method produced higher estimate with lower standard error as against the DM. Hence, the proposed model performs better than the DM in line with earlier works of Jann *et al.* (2012), Ewemooje *et al.,* (2017), Cobo *et al.,* (2016) and Ewemooje *et al.,* (2019).

Method	π_A	$V(\hat{\pi}_A)$	$S.E(\hat{\pi}_A)$	$C.V(\hat{\pi}_A)$
Direct Method	0.19	0.00077	0.028	14.6%
Proposed Model	0.23	0.00070	0.026	11.5%

Table 5: Comparative analysis of the Proposed Model verse the direct method

5. Conclusion

The unrelated design has been shown to improve efficiency of a randomized response method and reduces distrust of the respondents; hence, we proposed a new RRT which consists of the unrelated questions in dichotomous randomized response model. The variance of the proposed model decreases as the proportion of the sensitive attribute, π_A, and unrelated attribute, π_U, increases as against the ADRRT model which increases as the proportion of the sensitive attribute increases. Application of the proposed model also revealed its efficiency over the direct method in estimating the prevalence of examination malpractices among university students. Hence, the proposed model is shown to be more efficient than the direct method and ADRRTmodel as the proportion of people belonging to the sensitive attribute increases.

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