

Rao, Hartley, and Cochran's Sampling Scheme: Application

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Abstract

This paper takes a look at the Rao, Hartley, and Cochran's sampling scheme, when it is required to select sample of sizes 4, 6, 12, and 18 with probability proportional to size without replacement sampling (unequal probability sampling without replacement). This is done by using the data from the 2008 Nigeria Demographic and Health Survey (NDHS).

We studied the distribution of women age 15 – 49 years employed in the 12 months preceding the survey by type of employer. Here, we considered self-employed women alone. It is shown how sample of sizes 4, 6, 12, and 18 could be randomly selected from the population of size 36. Population total and variance were computed with confidence interval constructed for the population total.

For the randomly selected states in this paper, we realized that as the sample size increases, the variance and standard error decreases.

Keywords: Rao, Hartley, and Cochran's sampling scheme, probability proportional to size without replacement, sample size four, six, twelve, eighteen.

1. Introduction

We shall be dealing with probability proportional to size without replacement sampling. Horvitz and Thompson (1952) were the first to give theoretical frame work of unequal probability sampling without replacement (Alodat, 2009). The estimator given by Horvitz and Thompson (1952) has a very high chance of giving negative variance. Apart from the difficulty of getting over sometimes negative estimator of the variance, there is also difficulty, when the sample size is greater than two, in computation of probabilities of inclusion of population units in singles or in pairs (Tikkiwal, 1965). These two problems have attracted a lot of survey statisticians. Some of them are: Yates and Grundy (1953), Sen (1953), Durbin (1953), Rao, Hartley, and Cochran (1962), and so on.

Rao, Hartley, and Cochran (1962) suggested a slightly modified estimator, based on different sampling scheme. The variance estimate under Rao, Hartley, and Cochran (RHC) sampling scheme is always positive unlike Horvitz and Thompson estimator. Also sample size selected could be more than 2, unlike Horvitz and Thompson estimator. Rueda et al (2009) stressed that Rao, Hartley, and Cochran's scheme (1962) has very good reputation and image among the survey statisticians from the last four – five decades, and nobody could challenge it by now because of its simplicity and practicability in real surveys.

Here, we shall be dealing with the distribution of self – employed women age 15 – 49 years employed in the 12 months preceding the survey. The auxiliary variable to be used is the number of local governments in each of those states in Nigeria.

The 2008 NDHS collected information relating to women's employment. In measuring women's employment, it is important to take extra care because some of the activities that women do are often not perceived by women themselves as employment and hence are not reported as such. These activities include work on family farms, in family businesses and other aspects of the informal sector. To avoid underestimation of women's employment, the 2008 NDHS asked female respondents several questions to ascertain their employment status. First they were asked, "Aside from your own housework, are you currently working?" Women who answered "no" to this question were then asked, "As you know, some women take up jobs for which they are paid in cash or kind. Others sell things, have a small business, or work on the family farm or in the family business. Are you currently doing any of these things or any other work? Do you have any job or business from which you were on leave, illness, vacation, maternity leave, or any other such reason? Have you done any work in the last 12 months? What is your occupation, that is, what kind of work do you mainly do?"

2.0 Rao, Hartley, and Cochran Sampling Scheme

The procedure for probability proportional to size without replacement sampling scheme for selecting a sample of size n as explained by Okafor (2002) goes thus:

- Divide a population of N units into n groups at random with group g containing N_g units ($g = 1, 2, \dots, n$ such that $N_1 + N_2 + \dots + N_n = N$).
- Select one unit independently from each group. This gives a total of n units selected in the sample with

probability proportional to size without replacement.

The probability of selecting U_i in the sample in g^{th} group is

$$P_i^* = \frac{x_i}{X_g} = \frac{x_i/X}{X_g/X} = \frac{P_i}{\sum_{i=1}^{N_g} P_i} = \frac{P_i}{P_g} \quad (1)$$

Where

$$X_g = \sum_{i=1}^{N_g} X_i, \quad (2)$$

X_i 's are the auxiliary variables, and P_g is the sum of the initial probabilities in g^{th} group.

Units are selected using the table of random numbers.

2.1 The Rao, Hartley, and Cochran estimator of the population total and variance

The RHC estimator of the total is

$$\hat{Y}_{RHC} = \sum_{g=1}^n \frac{y_{gi}}{P_i^*} = \sum_{g=1}^n P_g \frac{y_{gi}}{P_i} = \sum_{g=1}^n \hat{Y}_g \quad (3)$$

where y_{gi} is the value of the study variate for the i^{th} unit in g^{th} group, and

$$P_i^* = \frac{P_i}{P_g}. \quad (4)$$

The RHC estimator of the variance is given as

$$\hat{V}(\hat{Y}_{RHC}) = \frac{N-n}{N(n-1)} \left[\sum_{g=1}^n P_g \frac{y_{gi}^2}{P_i^2} - \hat{Y}_{RHC}^2 \right] \quad (5)$$

3. Analysis

The correlation coefficient r between the auxiliary variable x_i (number of local governments in each state) and the variable of interest y_i (number of women under consideration who are employed during the past 12 months) is 0.65.

The results of the analysis are summarized in Tables 3 – 48.

4. Discussion / Summary of Results

Here, we used the Rao, Hartley, and Cochran's sampling scheme to select samples of sizes four, six, twelve, and eighteen randomly from a population of size thirty - six.

Table 48 clearly shows that the interval within which the true population total lies. The interval is widest when the sample size is four, followed by six, then twelve, and smallest when the sample size is eighteen. Also, Table 47 shows that the highest value of the variance and standard error were recorded when the sample size is four, followed by six, then twelve, and the lowest recorded when the sample size is eighteen.

5. Conclusion

This shows that the Rao, Hartley, and Cochran's sampling scheme can be used to estimate the population total and variance selecting any sample size, unlike the Horvitz and Thompson estimator that can conveniently estimate sample size of two.

The confidence interval constructed shows that small samples bring wide interval, while large sample size brings a small interval. We also realized that as the sample size increases the variances and the standard errors decrease. Based on these, it may be better to go for higher sample size, all other things being equal.

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Table 1: Percentage distribution of self – employed women age 15 – 49 years employed in the 12 months preceding the survey

S/N	States	Percentage of the self – employed women under consideration	Number of women under consideration, who are employed during the past 12 months (y_i)
1	Benue	57.8	846
2	Kogi	68.8	564
3	Kwara	75.6	399
4	Nassarawa	54.7	305
5	Niger	82.8	492
6	Plateau	22.6	318
7	Adamawa	67.0	535
8	Bauchi	92.4	595
9	Borno	69.5	586
10	Gombe	65.2	211
11	Taraba	67.0	414
12	Yobe	90.4	267
13	Jigawa	63.9	480
14	Kaduna	72.8	531
15	Kano	76.1	1264
16	Katsina	92.3	736
17	Kebbi	81.2	432
18	Sokoto	93.7	500
19	Zamfara	86.6	324
20	Abia	64.3	467
21	Anambra	67.2	649
22	Ebonyi	70.3	414
23	Enugu	53.4	414
24	Imo	60.4	501
25	Akwa Ibom	73.4	618
26	Bayelsa	86.1	264
27	Cross River	70.5	530
28	Delta	80.3	659
29	Edo	63.9	522
30	Rivers	67.6	1036
31	Ekiti	62.0	370
32	Lagos	66.2	1649
33	Ogun	88.8	682
34	Ondo	78.3	511
35	Osun	70.3	634
36	Oyo	82.3	995
		Total	20714

Source: Nigeria Demographic and Health Survey, 2008.

Table 2: Local government in Nigeria

S/N	States	Number of local government in each state (X_i)
1	Benue	23
2	Kogi	21
3	Kwara	16
4	Nassarawa	13
5	Niger	26
6	Plateau	17
7	Adamawa	21
8	Bauchi	20
9	Borno	27
10	Gombe	11
11	Taraba	16
12	Yobe	17
13	Jigawa	27
14	Kaduna	23
15	Kano	45
16	Katsina	34
17	Kebbi	20
18	Sokoto	23
19	Zamfara	14
20	Abia	18
21	Anambra	21
22	Ebonyi	12
23	Enugu	16
24	Imo	27
25	Akwa Ibom	31
26	Bayelsa	8
27	Cross River	18
28	Delta	25
29	Edo	18
30	Rivers	23
31	Ekiti	16
32	Lagos	20
33	Ogun	20
34	Ondo	18
35	Osun	30
36	Oyo	33
	Total	768

Source: National Bureau of Statistics, Nigeria

A. To select a sample of size four, the following tables are formed randomly

Table 3: First Random Group

States	Number of local government in each state (X_i)	Cummulative frequency of X_i	Range
Ondo	18	18	1 – 18
Yobe	17	35	19 – 35
Kano	45	80	36 – 80
Adamawa	21	101	81 – 101
Kaduna	23	124	102 – 124
Anambra	21	145	125 – 145
Borno	27	172	146 – 172
*Ogun	20	192	173 – 192
Sokoto	23	215	193 – 215

Source: Researchers' analysis

* state selected

Table 4: Second Random Group

States	Number of local government in each state (X_i)	Cummulative frequency of X_i	Range
Cross River	18	18	1 – 18
Niger	26	44	19 – 44
Gombe	11	55	45 – 55
Osun	30	85	56 – 85
Imo	27	112	86 – 112
Delta	25	137	113 – 137
*Ebonyi	12	149	138 – 149
Plateau	17	166	150 – 166
Bayelsa	8	174	167 – 174

Source: Researchers' analysis

Table 5: Third Random Group

States	Number of local government in each state (X_i)	Cummulative frequency of X_i	Range
Benue	23	23	1 – 23
Kwara	16	39	24 – 39
Edo	18	57	40 – 57
Oyo	33	90	58 – 90
*Kebbi	20	110	91 – 110
Jigawa	27	137	111 – 137
Rivers	23	160	138 – 160
Enugu	16	176	161 – 176
Lagos	20	196	177 – 196

Source: Researchers' analysis

Table 6: Fourth Random Group

States	Number of local government in each state (X_i)	Cummulative frequency of X_i	Range
*Zamfara	14	14	1 – 14
Akwa Ibom	31	45	15 – 45
Taraba	16	61	46 – 61
Abia	18	79	62 – 79
Kogi	21	100	80 – 100
Bauchi	20	120	101 – 120
Ekiti	16	136	121 – 136
Nassarawa	13	149	137 – 149
Katsina	34	183	150 – 183

Source: Researchers' analysis

Table 7: The four randomly selected states with the probability of selecting unit in the sample in g^{th} group (P_i^*), the probability of selecting unit from the overall sample (P_i), the sum of the initial probabilities in g^{th} group (P_g), and the variable of interest (y_i)

Randomly Selected States	P_i^*	P_i	P_g	Number of self – employed women under consideration (y_i)
Ogun	20/215	20/768	215/768	606
Ebonyi	12/174	12/768	174/768	291
Kebbi	20/196	20/768	196/768	351
Zamfara	14/183	14/768	183/768	281

Source: Researchers' analysis

B. To select a sample of size six, the following tables are formed randomly

Table 8: First Random Group

States	Number of local government in each state (X_i)	Cummulative frequency of X_i	Range
*Borno	27	27	1 – 27
Anambra	21	48	28 – 48
Akwa Ibom	31	79	49 – 79
Bauchi	20	99	80 – 99
Niger	25	124	100 – 124
Nassarawa	13	137	125 – 137

Source: Researchers' analysis

Table 9: Second Random Group

States	Number of local government in each state (X_i)	Cummulative frequency of X_i	Range
Ebonyi	12	12	1 – 12
Kebbi	20	32	13 – 32
Yobe	17	49	33 – 49
*Benue	23	72	50 – 72
Lagos	20	92	73 – 92
Katsina	34	126	93 – 126

Source: Researchers' analysis

Table 10: Third Random Group

States	Number of local government in each state (X_i)	Cummulative frequency of X_i	Range
Cross River	18	18	1 – 18
Rivers	23	41	19 – 41
*Edo	18	59	42 – 59
Abia	18	77	60 – 77
Kaduna	23	100	78 – 100
Oyo	33	133	101 – 133

Source: Researchers' analysis

Table 11: Fourth Random Group

States	Number of local government in each state (X_i)	Cummulative frequency of X_i	Range
Zamfara	15	15	1 – 15
Adamawa	21	36	16 – 36
*Taraba	16	52	37 – 52
Bayelsa	8	60	53 – 60
Osun	30	90	61 – 90
Gombe	11	101	91 – 101

Source: Researchers' analysis

Table 12: Fifth Random Group

States	Number of local government in each state (X_i)	Cummulative frequency of X_i	Range
*Delta	25	25	1 – 25
Ekiti	16	41	26 – 41
Sokoto	23	64	42 – 64
Plateau	17	81	65 – 81
Enugu	16	97	82 – 97
Kwara	16	113	98 – 113

Source: Researchers' analysis

Table 13: Sixth Random Group

States	Number of local government in each state (X_i)	Cummulative frequency of X_i	Range
Imo	27	27	1 – 27
Jigawa	27	54	28 – 54
Ondo	18	72	55 – 72
Kogi	21	93	73 – 93
Kano	45	138	94 – 138
*Ogun	20	158	139 – 158

Source: Researchers' analysis

Table 14: The six randomly selected states with the probability of selecting unit in the sample in g^{th} group (P_i^*), the probability of selecting unit from the overall sample (P_i), the sum of the initial probabilities in g^{th} group (P_g), and the variable of interest (y_i)

Randomly Selected States	P_i^*	P_i	P_g	Number of self – employed women under consideration (y_i)
Borno	27/137	27/768	137/768	407
Benue	23/126	23/768	126/768	489
Edo	18/133	18/768	133/768	334
Taraba	16/101	16/768	101/768	277
Delta	25/113	25/768	113/768	529
Ogun	20/158	20/768	158/768	606

Source: Researchers' analysis

C. To select a sample of size twelve, the following tables are formed randomly

Table 15: First Random Group

States	Number of local government in each state (X_i)	Cummulative frequency of X_i	Range
Zamfara	14	14	1 – 14
*Adamawa	21	35	15 – 35
Bauchi	20	55	36 – 55

Source: Researchers' analysis

Table 16: Second Random Group

States	Number of local government in each state (X_i)	Cummulative frequency of X_i	Range
Ebonyi	12	12	1 – 12
*Kaduna	23	35	13 – 35
Kogi	21	56	36 – 56

Source: Researchers' analysis

Table 17: Third Random Group

States	Number of local government in each state (X_i)	Cummulative frequency of X_i	Range
*Anambra	21	21	1 – 21
Sokoto	23	44	22 – 44
Borno	27	71	45 – 71

Source: Researchers' analysis

Table 18: Fourth Random Group

States	Number of local government in each state (X_i)	Cummulative frequency of X_i	Range
Rivers	23	23	1 – 23
* Osun	30	53	24 – 53
Edo	18	71	54 – 71

Source: Researchers' analysis

Table 19: Fifth Random Group

States	Number of local government in each state (X_i)	Cummulative frequency of X_i	Range
Delta	25	25	1 – 25
Nassarawa	13	38	26 – 38
*Imo	27	65	39 – 65

Source: Researchers' analysis

Table 20: Sixth Random Group

States	Number of local government in each state (X_i)	Cummulative frequency of X_i	Range
Plateau	17	17	1 – 17
Katsina	34	51	18 – 51
*Bayelsa	8	59	52 – 59

Source: Researchers' analysis

Table 21: Seventh Random Group

States	Number of local government in each state (X_i)	Cummulative frequency of X_i	Range
Kebbi	20	20	1 – 20
*Niger	26	46	21 – 46
Yobe	17	63	47 – 63

Source: Researchers' analysis

Table 22: Eighth Random Group

States	Number of local government in each state (X_i)	Cummulative frequency of X_i	Range
Cross River	18	18	1 – 18
*Ogun	20	38	19 – 38
Kwara	16	54	39 – 54

Source: Researchers' analysis

Table 23: Ninth Random Group

States	Number of local government in each state (X_i)	Cummulative frequency of X_i	Range
*Jigawa	27	27	1 – 27
Abia	18	45	28 – 45
Ekiti	16	61	46 – 61

Source: Researchers' analysis

Table 24: Tenth Random Group

States	Number of local government in each state (X_i)	Cummulative frequency of X_i	Range
Kano	45	45	1 – 45
* Ondo	18	63	46 – 63
Akwa Ibom	31	94	64 – 94

Source: Researchers' analysis

Table 25: Eleventh Random Group

States	Number of local government in each state (X_i)	Cummulative frequency of X_i	Range
Benue	23	23	1 – 23
Taraba	16	39	24 – 39
* Oyo	33	72	40 – 72

Source: Researchers' analysis

Table 26: Twelfth Random Group

States	Number of local government in each state (X_i)	Cummulative frequency of X_i	Range
Lagos	20	20	1 – 20
*Enugu	16	36	21 – 36
Gombe	11	47	37 – 47

Source: Researchers' analysis

Table 27: The twelve randomly selected states with the probability of selecting unit in the sample in g^{th} group (P_i^*), the probability of selecting unit from the overall sample (P_i), the sum of the initial probabilities in g^{th} group (P_g), and the variable of interest (y_i)

Randomly Selected States	P_i^*	P_i	P_g	Number of self – employed women under consideration (y_i)
Adamawa	21/55	21/768	55/768	358
Kaduna	23/56	23/768	56/768	387
Anambra	21/71	21/768	71/768	436
Osun	30/71	30/768	71/768	446
Imo	27/65	27/768	65/768	303
Bayelsa	8/59	8/768	59/768	227
Niger	26/63	26/768	63/768	407
Ogun	20/54	20/768	54/768	606
Jigawa	27/61	27/768	61/768	307
Ondo	18/94	18/768	94/768	400
Oyo	33/72	33/768	72/768	819
Enugu	16/47	16/768	47/768	221

Source: Researchers' analysis

D. To select a sample of size eighteen, the following tables are formed randomly

Table 28: First Random Group

States	Number of local government in each state (X_i)	Cummulative frequency of X_i	Range
Jigawa	27	27	1 – 27
*Niger	26	53	28 – 53

Source: Researchers' analysis

Table 29: Second Random Group

States	Number of local government in each state (X_i)	Cummulative frequency of X_i	Range
Borno	27	27	1 – 27
*Kwara	16	43	28 – 43

Source: Researchers' analysis

Table 30: Third Random Group

States	Number of local government in each state (X_i)	Cummulative frequency of X_i	Range
Zamfara	14	14	1 – 14
*Lagos	20	34	15 – 34

Source: Researchers' analysis

Table 31: Fourth Random Group

States	Number of local government in each state (X_i)	Cummulative frequency of X_i	Range
*Osun	30	30	1 – 30
Kaduna	23	53	31 – 53

Source: Researchers' analysis

Table 32: Fifth Random Group

States	Number of local government in each state (X_i)	Cummulative frequency of X_i	Range
Taraba	16	16	1 – 16
*Akwa Ibom	31	47	17 – 47

Source: Researchers' analysis

Table 33: Sixth Random Group

States	Number of local government in each state (X_i)	Cummulative frequency of X_i	Range
*Gombe	11	11	1 – 11
Ondo	18	29	12 – 29

Source: Researchers' analysis

Table 34: Seventh Random Group

States	Number of local government in each state (X_i)	Cummulative frequency of X_i	Range
Rivers	23	23	1 – 23
*Ekiti	16	39	24 – 39

Source: Researchers' analysis

Table 35: Eighth Random Group

States	Number of local government in each state (X_i)	Cummulative frequency of X_i	Range
*Benue	23	23	1 – 23
Oyo	33	56	24 – 56

Source: Researchers' analysis

Table 36: Ninth Random Group

States	X_i	Cummulative frequency of X_i	Range
*Yobe	17	17	1 – 17
Kogi	21	38	18 – 38

Source: Researchers' analysis

Table 37: Tenth Random Group

States	Number of local government in each state (X_i)	Cummulative frequency of X_i	Range
Cross River	18	18	1 – 18
*Kano	45	63	19 – 63

Source: Researchers' analysis

Table 38: Eleventh Random Group

States	Number of local government in each state (X_i)	Cummulative frequency of X_i	Range
Ebonyi	12	12	1 – 12
*Abia	18	30	13 – 30

Source: Researchers' analysis

Table 39: Twelfth Random Group

States	Number of local government in each state (X_i)	Cummulative frequency of X_i	Range
Ogun	20	20	1 – 20
*Bauchi	20	40	21 – 40

Source: Researchers' analysis

Table 40: Thirteenth Random Group

States	Number of local government in each state (X_i)	Cummulative frequency of X_i	Range
*Kebbi	20	20	1 – 20
Adamawa	21	41	21 – 41

Source: Researchers' analysis

Table 41: Fourteenth Random Group

States	Number of local government in each state (X_i)	Cummulative frequency of X_i	Range
*Imo	27	27	1 – 27
Enugu	16	43	28 – 43

Source: Researchers' analysis

Table 42: Fifteenth Random Group

States	Number of local government in each state (X_i)	Cummulative frequency of X_i	Range
Anambra	21	21	1 – 21
*Delta	25	46	22 – 46

Source: Researchers' analysis

Table 43: Sixteenth Random Group

States	Number of local government in each state (X_i)	Cummulative frequency of X_i	Range
Edo	18	18	1 – 18
*Nassarawa	13	31	19 – 31

Source: Researchers' analysis

Table 44: Seventeenth Random Group

States	Number of local government in each state (X_i)	Cummulative frequency of X_i	Range
Plateau	17	17	1 – 17
*Sokoto	23	40	18 – 40

Source: Researchers' analysis

Table 45: Eighteenth Random Group

States	Number of local government in each state (X_i)	Cummulative frequency of X_i	Range
*Katsina	34	34	1 – 34
Bayelsa	8	42	35 – 42

Source: Researchers' analysis

Table 46: The eighteen randomly selected states with the probability of selecting unit in the sample in g^{th} group (P_i^*), the probability of selecting unit from the overall sample (P_i), the sum of the initial probabilities in g^{th} group (P_g), and the variable of interest (y_i)

Randomly Selected States	P_i^*	P_i	P_g	Number of self – employed women under consideration (y_i)
Niger	26/53	26/768	53/768	407
Kwara	16/43	16/768	43/768	302
Zamfara	20/34	20/768	34/768	281
Osun	30/53	30/768	53/768	446
Akwa Ibom	31/47	31/768	47/768	454
Gombe	11/29	11/768	29/768	138
Ekiti	16/39	16/768	39/768	229
Benue	23/56	23/768	56/768	489
Yobe	17/38	17/768	38/768	241
Kano	45/63	45/768	63/768	962
Abia	18/30	18/768	30/768	300
Bauchi	20/40	20/768	40/768	550
Kebbi	20/41	20/768	41/768	351
Imo	27/43	27/768	43/768	303
Delta	25/46	25/768	46/768	529
Nassarawa	13/31	13/768	31/768	167
Sokoto	23/40	23/768	40/768	469
Katsina	34/42	34/768	42/768	679

Source: Researchers' analysis

Table 47: Summary of the various values of the population totals, variances and standard errors, varying the sample size.

Sample size (n)	\hat{Y}_{RHC}	$\hat{V}(\hat{Y}_{RHC})$	S.E (\hat{Y}_{RHC})
4	14380.31	4341064.204	2083.52
6	16138.95	2643935.62	1626.02
12	14684.05	1249738.53	1117.92
18	13421.47	277336.28	526.63

Source: Researchers' analysis

Table 48: Table showing the confidence interval for the population total, Y_{RHC}

Confidence Coefficient	Sample size 4	Sample size 6	Sample size 12	Sample size 18
0.90	(14419.48, 21274.26)	(13464.15, 18813.75)	(12815.07, 16493.03)	(12555.16, 14287.78)
0.95	(13763.17, 21930.56)	(12951.99, 19325.91)	(12462.93, 16845.17)	(12389.28, 14453.66)
0.99	(12475.56, 23218.18)	(11947.07, 20330.83)	(11772.05, 17536.05)	(12063.82, 14779.12)

Source: Researchers' analysis

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