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SIMULATION STUDY TO ASSESS THE PRECISION OF THE TWO-STAGE CLUSTER SURVEY FOR INJECTION SAFETY

Stacy Woodard, Stanley Lemeshow, Meng Chen[1]

ABSTRACT

A simulation study was conducted to assess the sampling scheme designed for the World Health Organization (WHO) Injection Safety Assessment Survey. The objective of this assessment is to determine whether facilities in which injections are given meet the necessary safety requirements for injection administration, equipment, supplies, and waste disposal. The main parameter of interest is the proportion of health care facilities in a country that have safe injection practices. The objective of this simulation study was to assess the accuracy and precision of the proposed sampling design. To this end, two artificial populations were created based on the two African countries of Niger and Burkina Faso, in which the assessment was pilot tested. To create a wide variety of hypothetical populations, the assignment of whether a health care facility was safe or not was based on the different combinations of the population proportion of safe health care facilities in the country, the homogeneity of the districts in the country with respect to injection safety, and whether the health care facility is located in an urban or rural district. The original sampling design specified that 8 districts (clusters) would be selected with probability proportionate to the size (PPS) of the population, and within each of the selected clusters, 10 health care facilities would be randomly selected. In addition to evaluating the original sampling design, it was of interest to determine how some modifications of the design (such as stratification, PPS sampling with respect to the number of HFs, sample size reduction) would effect the precision and accuracy of the estimates. Using the results of the simulation, a multi-factor analysis of variance was used to determine which factors affect the outcome measures of absolute bias, standard error, and mean-squared error. From this simulation can conclude that the original sampling design did not quite meet the desired precision of plus/minus 10 percentage points, stratification on the urban and rural clusters would be beneficial, and that sampling the clusters with probability proportionate to the number of HFs in the district would not negatively effect the results.

1. INTRODUCTION

Assuring injection safety in developing countries is a high priority for the international public health establishment. To this end the World Health Organization (WHO) Department of Vaccines and Biologicals and SIGN (Safe Injection Global Network) developed a survey tool to assess injection safety.[1] This survey instrument was designed to assess the risks to three groups: (1) the patient, (2) the health care provider, and (3) the community. Risks to the patient include items such as the use of non-sterilized syringes or the use of vaccines that have not been stored properly. Risks to the health care provider include items such as the absence of puncture-proof sharps containers and absence of two-handed recapping. Risks to the community include items such as presence of sharps around the health facility and improper disposal of sharps containers.

For this survey, the Health Facility (HF) is the primary sampling unit. Based on the information gathered in the survey, each of the HFs will be categorized as ‘Safe’ or ‘Unsafe’ with respect to their injection practices. The overall goal of this survey is to estimate the proportion of ‘Safe’ health facilities in a country. These surveys can be carried out in subsequent years to measure change in safety practices over time.

Once the survey instrument was developed, the sampling design (i.e., the method for sampling the health facilities) needed to be created. In creating this design, some limitations had to be considered. First of all, a general design that can be applied to any country was desired. Secondly, the design needed to be simple to implement. Third, the limitations on the amount of time it can take to conduct the survey (within 2 weeks) and number of personnel involved (at most two survey teams) had to be considered. The proposed design is a two-stage cluster sample such

[1] Center for Biostatistics, The Ohio State University

that, for each country, 8 clusters (i.e., districts) are selected with probability proportional to the size of the population of the cluster (i.e., the more populated clusters have a greater chance of being selected), and within each of the selected clusters, 10 health facilities are randomly selected. This design was chosen to minimize travel time and expense, and to obtain an estimate with acceptable precision. Due to the complexity of the sample size calculations for a two-stage cluster sample (i.e., two equations - one fixing the number of clusters and the other fixing the sample size per cluster; assumptions concerning the within and between cluster variability; and the estimated costs associated with sampling additional clusters or units per cluster), there is no straightforward way to determine the precision of the estimates obtained from this sampling design.[2] For this reason, a simulation study was proposed to answer the following research questions:

1. How precise is the estimated proportion of safe HFs in a country?

The precision is a measure of the variability of the estimate. It can also be thought of as the margin of error. It is desired to produces estimates within ± 10 percentage points of the true population value, with at least 95% confidence.

2. What is the bias associated with the estimate?

By definition, the estimated proportion from a two-stage PPS cluster sample is *unbiased*. This means that upon repeated sampling, the average of the sample estimates will equal the true population value. It is of interest to verify the accuracy of this measurement.

3. What factors affect the precision and bias of the estimate?

There are factors inherent in the population that may effect the precision and bias of the estimated proportion of safe HFs. Although we can't simulate all of the different possible populations, we did incorporate the following factors into our simulation:

- *the true proportion of safe HFs in the population*,
- *the homogeneity of the clusters* - how similar the clusters are to one another with respect to the safety of immunizations,
- *the homogeneity of the HFs within a cluster* - which is a function of the true proportion of safe HFs (i.e., the countries with a proportion of 0.5 will have the greatest HF to HF variability),
- *stratification on the urban and rural clusters* - it is thought that the rural clusters may be less safe due to problems with access to supplies, limitations of facilities, education, etc.,
- *sampling of the clusters with probability proportionate to the number of HFs in cluster* rather than the size of the population.

2. SIMULATION DESIGN

Populations

In this study, entire simulated populations are created and multiple samples are drawn from these populations to assess the proposed sampling design. The population of interest is all of the health facilities in a country. In general, countries are divided into districts, and each district can be classified as urban or rural based on the population density, and within each district there are a number of health facilities that will either have safe or unsafe immunization practices.

WHO piloted the Immunization Safety Assessment Survey and the proposed sampling design in both Niger and Burkina Faso to test the logistics of the survey. These two populations were used as base populations for this simulation, rather than creating a totally fictional country. Information from pilot studies of these two countries includes the number of districts in the country, the population size in each district, and the number of health facilities (HF) in each district. It was also of interest to designate each district as urban or rural, which was based on population density estimates obtained from ArcData Online. The district was deemed to be urban if the population density was estimated to be more than roughly 50 persons per sq. km; otherwise the district was deemed to be rural. In Niger, there are a total of 40 districts, with 676 health facilities and a total population of 11 million people. For the pilot study, some of the districts were combined so that each cluster contained at least 15 HFs, yielding 25 pseudo-districts (clusters). Six clusters were classified as rural and the remaining 19 were classified as urban, there were an average of 27 HFs per cluster (sd=11), and an average population per cluster of 441,000 persons (sd=189,000). In Burkina Faso, there are a total of 52 districts, with 1043 health facilities and a population of 11.3 million people. For the pilot study, some of the districts were combined so that each cluster contained at least 15 HFs, yielding 46 pseudo-districts (clusters). Twenty-one clusters were classified as rural and the other 25 clusters were classified as urban, there were an average of 20 HFs per cluster (sd=9.6), and an average population per cluster of 218,000 persons (sd=96,000). Both Burkina Faso and Niger were used as base populations in this simulation because of their apparent differences. Niger is a larger country with one group of urban districts, whereas Burkina Faso is a smaller country with many urban areas.

Assignment of Safe Health Facilities

To make our population complete, each health facility needs to be identified as to whether it has safe immunization practices or not. Given that this information is not known for all of the HFs in the pilot study populations (only 80 HFs were sampled), this information was simulated. The assignment of whether a HF is safe or not was based on the factors previously described using the following technique. Each cluster was first assigned a proportion of safe facilities that was generated from a normal distribution with mean equal to the overall desired proportion of safe HFs for the population and standard deviation equal to the desired homogeneity of the clusters (i.e., a smaller standard deviation indicates that the clusters are more homogeneous, or similar, with respect to the proportion of safe HFs, and a larger standard deviation indicates that the proportions of safe HFs from cluster to cluster are highly variable, or heterogeneous). Once the proportion of safe facilities was assigned for a cluster, the assignment of whether each health facility was safe or not was done using a uniform random number generator. The true proportion of safe health facilities was obtained by dividing the number safe health facilities by the total number of health facilities in the population.

Sampling

The proposed sampling design specified that 8 districts (clusters) would be selected with probability proportionate to the size of the population, and that within each of the selected clusters 10 health facilities would be randomly selected. To select the 8 clusters, the cumulative population sum was calculated, 8 random numbers were then generated between 1 and the total cumulative population sum, and finally the random numbers were matched to the cumulative population ranges to obtain the selected clusters. (Note that the same cluster may be selected more than once.) From each of the 8 selected clusters, 10 health facilities were randomly selected by generating 10 unique random numbers between 1 and the total number of HFs existing in the selected cluster.

Simulation Parameters

The specific factors and levels that were included in the simulated populations and samples are as follows:

Factor	***Levels***
Urban/Rural Proportions of Safe HFs	0.1/0.1, 0.5/0.1, 0.5/0.5, 0.9/0.5, 0.9/0.9
Homogeneity (i.e. standard deviation)	0.01, 0.15
Country	Burkina Faso, Niger
PPS with respect to	Population, HF
Stratification on Urban and Rural Clusters	Yes, No
Number of Clusters	8, 6, 4
Number of HFs	10, 7, 5

These factors yield a total of 720 combinations (5 urban/rural levels * 2 standard deviation levels * 2 PPS levels * 2 stratification levels * 3 cluster levels * 3 HF levels*2 countries = 720), which were each replicated 1000 times. The outcome measures in the analyses are obtained from the average of the 1000 replications. The simulation was programmed in C++.[3]

Outcome Measures

One-thousand samples were selected from each of the simulated populations using each of the sampling schemes. For each of the samples, estimates of the proportion of safe HFs, absolute bias, standard error of the estimate, an indicator of whether the 95% confidence interval contained the true population proportion, and an indictor of whether the estimate was within 10 percentage points of the true proportion of safe HFs were obtained. The outcome measurements are the values of these estimates averaged over the 1000 replications, as well as the mean squared error of the estimated proportion (MSE).

3. STATISTICAL METHODS

Descriptive statistics were calculated for each of the factors in the simulation (i.e., population proportion of safe health care facilities, homogeneity of the clusters, stratification, number of clusters and HFs selected, and country) for the outcome variables of absolute bias, standard error, MSE, proportion of 95% confidence intervals that contain the true proportion, and the proportion of estimates that fall within ± 10 percentage points of the true proportion of safe health care facilities. For the factor of the urban and rural proportions of safe health care facilities, one-way analysis of variance was used to test for overall differences in the outcome variables, and multiple comparisons with a Bonferroni Correction were used to determine where the differences lie. T-tests were used to determine significant differences in the factors of the homogeneity of the clusters and the different countries. Multi-factor analysis of variance was used to investigate the simultaneous effect of the factors on the outcome variables, and to test all of the possible two-way and three-way interactions between the factors. The analysis of the simulation results was conducted using Stata Version 7.[4]

4. RESULTS

An example of the results obtained from the simulation is presented in Table 1. This table provides the average values for the outcome measures over the 1000 replications for each of the presented simulated populations, where the population is defined by the proportion of urban and rural proportions, the homogeneity of the clusters, and the base country. The results will be organized in terms of the answers to the research questions.

1. How precise is the estimated proportion of safe HFs in a country?

For the proposed sampling design, the average precision was 13.6 percentage points (n=20, SD=0.05, range=0.06, 0.20), averaging over the two countries, the different proportions of safe HFs, and the homogeneity of the clusters. The best precision occurred in the populations where the clusters were homogeneous and where the true proportion of safe HFs was either very low (p=0.1) or very high (p=0.9) in both the urban and rural clusters [n=4 (of the 20 simulated populations), average precision=0.067, range=0.063, 0.071]. The worst precision occurred in the populations where the clusters were heterogeneous and where the true proportions of safe HFs were different between the urban and rural clusters [n=4 (of the 20 simulated populations), average precision=0.188, range=0.171, 0.200]. The majority of the populations had greater than 95% of the confidence intervals containing the true proportion of safe HFs.

2. What is the bias of the estimated proportion of safe HFs in a country?
For the proposed sampling design the average bias was –0.010 [n=20 (from all of the simulated population), SD=0.02, range=-0.06, 0.02], the average absolute bias was 0.053 [n=20 (from all of the simulated population), SD=0.02, range=0.02, 0.09], and the average absolute relative bias was 0.156 [n=20 (from all of the simulated population), SD=0.09, range=0.03, 0.30], averaging over the two countries, the different proportions of safe HFs, and the homogeneity of the clusters. The average proportion of estimates within ± 10 percentage points of the true proportion of safe HFs was 0.853 [n=20 (from all of the simulated population), SD=0.12, range=0.63, 1.00] indicating that the average precision will be greater than ± 10 percentage points.

3. What factors affect the precision and bias of the estimated proportion of safe HFs?

The impact of the factors on the outcome measurements were first investigated univariately, with results being presented in Tables 2 and 3, for Burkina Faso and Niger, respectively. The majority of the results were similar for the two countries. The proportion of safe HFs was significantly related to all of the outcome measurements. Absolute bias, standard error, MSE are all significantly smaller when the true proportion of safe HFs are small (p=0.10) or large (p=0.90), for both the urban and rural clusters. The proportion of CI's containing the true proportion of safe HFs, is greatest when the urban and rural proportions are equal. The proportion of estimates within ± 10 percentage points of the true proportion of safe HFs is greatest when the urban and rural proportions are both equal to 0.10 or 0.90. The homogeneity of the clusters was significantly related to all of the outcome measures such that the populations with homogeneous clusters (i.e., σ=0.01) had significantly lower absolute bias, standard error, and MSE, as well as significantly greater proportions of estimates within ± 10 percentage points of the true proportion of safe HFs and proportions of CI's containing the true population value. Absolute bias and MSE were significantly smaller when the sample was stratified; and the proportion of CI's containing the true p and the proportion of estimates within ± 10 percentage points of the true p were significantly greater when the sample was stratified. For Niger, the standard error is significantly greater for the stratified samples, but for Burkina Faso, stratification on the urban and rural clusters had no effect on the standard error. There were no significant differences in the outcome variables with respect to whether the clusters were selected with probability proportionate to the size of the population in the cluster or the number of HFs, except in the Niger population where the PPS on the population size produced a significantly greater proportion of CI's containing the true proportion of safe HFs. The outcomes of absolute bias, standard error, and MSE all significantly increased as the number of clusters or number of HFs decreased; the proportion of estimates within ± 10 percentage points of the true proportion of safe HFs significantly decreased as the number of clusters or HFs decreased; and there are no significant differences in absolute relative bias between 6 and 8 clusters, and between 7 and 10 HFs. For the proportion of CI's containing the true proportion of safe HFs, in Burkina Faso there are no significant differences between the number of clusters/HFs, but in Niger there was a significant difference between 4 clusters versus 6 or 8 clusters.

As univariable analyses are considered to be crude because they do not adjust for the other factors or for the possible interactions between the factors, multi-factor models were investigated for the outcome measures of the standard error of the estimate, MSE, and the proportion of estimates within ± 10 percentage points of the true p. The full models contained the main effects of the urban and rural proportions of safe health facilities, the homogeneity of the clusters, stratification on the urban and rural clusters and the different countries, as well as all the possible 2- and 3-way interactions between these variables. The country effect was not significant in any of the models (p=0.231, 0.056, and 0.075 for the standard error, MSE, and proportion of estimates within ± 10 percentage points of the true p, respectively). For the standard error models, the 3-way interaction was not significant, but all the of 2-way interactions were, indicating (1) the standard error of the estimates greater when the clusters are more heterogeneous but less so when the urban and rural proportions are 0.9 and 0.5, respectively; (2) the non-stratified samples have smaller standard errors, except when the urban and rural proportions are not equal; and (3) the stratified samples have greater standard errors when the clusters are more variable. For MSE, the only significant interactions were between the urban and rural proportion and both sigma and the stratification indicator, and the interpretations are similar to those of the standard error outcome. For the model of the proportion of estimates within ± 10 percentage points of the true population value, the 3-way interaction between the urban/rural proportion, sigma, and stratification was highly significant ($p < 0.001$). This interaction is illustrated in Figure 1, an indicates that the stratification doesn't make a difference when the urban and rural proportions are equal and that stratification makes more of difference when the clusters are homogeneous.

5. DISCUSSION

The goal of this simulation study was to assess the proposed sampling design used to estimate the proportion of HFs in a country that have safe immunization practices. We investigated the sampling design over a variety of populations with different proportions of safe health facilities, differences in the homogeneity of the proportion of safe health facilities between the clusters, and two different country make-ups. It was found that some of the populations yield better results than others. For example, the results are more favorable when the clusters are homogeneous (i.e., similar) with respect to the proportion of HFs with safe immunization practices, and/or when the proportions of HFs with safe immunization practices are very high or very low. These findings, however, are not surprising because by definition, the results will be less variable, and more precise, when the clusters are similar, and the within cluster variability is smallest when the proportion of safe HFs is very high or very low (i.e., the largest variability occurs when the proportion of safe HFs is 0.5). Since we can't control the population and since this sampling scheme was designed to be used on a variety of populations, it was of interest to obtain the average outcomes over these possible populations.

A potential modification to the sampling design is stratification on the urban and rural clusters. The results for the simulation indicate that when (and only when) there is a difference in the proportion of safe HFs between the urban and rural clusters, it is beneficial to stratify the sample. Stratification appears to be more effective when the clusters are homogenous. This makes sense because when the clusters are homogeneous, the urban and rural proportions will be more different. When the clusters are heterogeneous, the urban and rural cluster have a greater chance of overlapping with respect to the proportion of safe HFs, thus stratification is not as effective. One important finding is that, when the clusters are homogeneous, stratification yields relatively the same MSE and proportion of samples within 10 percentage points of the true proportion, regardless of the difference in the urban and rural proportions.

This simulation has determined that for the proposed sampling design, with 95% confidence, the proportion of safe HFs can be estimated to within an average of 13.6 percentage points, which is less precise than was originally desired, but is not bad given the relatively small sample size of 80 health facilities. However, for the populations with very high or very low proportions of safe HFs (i.e., small within cluster variability) and low between cluster variability, the precision may be a good as ± 6.7 percentage points. Overall, this sampling design for the injection safety assessment tool appears to be a reasonable design for the estimation of the proportion of safe health facilities in a country.

6. LIMITATIONS

In this study, there are some factors that may be related to the precision of the estimated proportion of safe HFs that we did not incorporate into the simulation. The first factor is the size of the health facility. The larger health facilities may administer more immunizations and may therefore have better safety procedures. This simulation was based on the binary outcome of whether the HF was safe or not, we did not consider a relative amount of safety for the health facility. Even though in the simulation we allowed for different proportions of safe HFs in the urban and rural districts and for different levels of variability in all of the districts, we did not incorporate the possibility that the urban and rural districts could have different levels of homogeneity.

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Table 1: Example Output from Simulation, Averaging over 1000 replications

Rural P	Urban P	SD	Stratify	Cluster	HF	PPS POP	True P	Avg Est	Avg SE	Abs Bias	MSE	PCI	PABS
0.1	0.1	0.01	1	8	10	1	0.096	0.093	0.040	0.026	0.001	0.974	0.998
0.1	0.1	0.01	1	8	7	1	0.096	0.094	0.049	0.033	0.002	0.978	0.985
0.1	0.1	0.01	1	8	5	1	0.096	0.092	0.057	0.037	0.002	0.973	0.983
0.1	0.1	0.01	1	6	10	1	0.096	0.093	0.050	0.030	0.001	0.986	0.990
0.1	0.1	0.01	1	6	7	1	0.096	0.093	0.059	0.035	0.002	0.984	0.983
0.1	0.1	0.01	1	6	5	1	0.096	0.094	0.071	0.042	0.003	0.967	0.958
0.1	0.1	0.01	1	4	10	1	0.096	0.092	0.071	0.037	0.002	0.978	0.977
0.1	0.1	0.01	1	4	7	1	0.096	0.094	0.090	0.045	0.003	0.977	0.952
0.1	0.1	0.01	1	4	5	1	0.096	0.095	0.102	0.051	0.004	0.975	0.915
0.1	0.1	0.15	1	8	10	1	0.125	0.124	0.057	0.037	0.002	0.974	0.969
0.1	0.1	0.15	1	8	7	1	0.125	0.122	0.062	0.041	0.003	0.969	0.958
0.1	0.1	0.15	1	8	5	1	0.125	0.123	0.073	0.045	0.003	0.979	0.924
0.1	0.1	0.15	1	6	10	1	0.125	0.123	0.070	0.043	0.003	0.984	0.949
0.1	0.1	0.15	1	6	7	1	0.125	0.123	0.078	0.046	0.003	0.976	0.926
0.1	0.1	0.15	1	6	5	1	0.125	0.125	0.090	0.055	0.005	0.979	0.896
0.1	0.1	0.15	1	4	10	1	0.125	0.126	0.103	0.052	0.004	0.971	0.878
0.1	0.1	0.15	1	4	7	1	0.125	0.125	0.116	0.058	0.005	0.980	0.867
0.1	0.1	0.15	1	4	5	1	0.125	0.126	0.128	0.067	0.007	0.977	0.790

Rural P is the designated proportion of safe HFs in the rural districts, Urban P is the designated proportion of safe HFs in the urban districts, SD is the between cluster variability in the proportion of safe HFs (i.e., the homogeneity of the clusters), Stratify is an indicator of whether the sample was stratified on the urban and rural clusters; Cluster is the number of clusters selected in the sample; HF is the number of health facilities selected in each cluster; True P is the true population proportion of safe HFs, Avg Est is the average estimated proportion of safe HFs, Avg SE is the average standard error of the estimate, Abs Bias is the average absolute bias of the estimate, MSE is the mean squared error, PCI is the proportion of 95% confidence intervals that contain the true population value, and PABS is the proportion of estimates that fall within ± 10 percentage points of the true population proportion.

Table 2: Univariate Results for Burkina Faso - Mean (SD)

Factor	Levels	Abs Bias	Avg. SE	MSE	Prop. CI's contain p	Prop. of Est within ±10
Urban/rural	.1/.1	.044 (.01)[a]	.069 (.02)[e]	.003 (.001)[f]	.967 (.01)[g]	.933 (.05)[a]
Proportions	.1/.5	.076 (.02)	.120 (.03)	.010 (.005)	.977 (.009)	.711 (.13)
	.5/.5	.072 (.01)	.117 (.03)	.008 (.003)	.977 (.01)	.738 (.09)
	.5/.9	.070 (.02)	.110 (.03)	.008 (.004)	.977 (.008)	.752 (.13)
	.9/.9	.050 (.02)	.079 (.03)	.004 (.002)	.969 (.02)	.881 (.10)
Sigma	0.01	.056 (.02)[b]	.088 (.04)[b]	.006 (.004)[b]	.976 (.01)[b]	.841 (.14)[b]
(Homogeneity)	0.15	.069 (.02)	.109 (.03)	.008 (.004)	.971 (.01)	.765 (.12)
Stratified	Yes	.056 (.02)[b]	.100 (.04)[ns]	.005 (.003)[b]	.981 (.01)[b]	.841 (.11)[b]
	No	.068 (.02)	.098 (.04)	.008 (.005)	.965 (.01)	.765 (.15)
# Clusters	8	.052 (.02)[b]	.076 (.02)[b]	.005 (.003)[b]	.973 (.01)[ns]	.865 (.10)[b]
	6	.060 (.02)	.093 (.03)	.006 (.003)	.974 (.01)	.814 (.12)
	4	.074 (.02)	.129 (.04)	.009 (.005)	.972 (.02)	.730 (.15)
# HFs	10	.055 (.02)[b]	.088 (.03)[b]	.005 (.004)[b]	.973 (.01)[ns]	.845 (.13)[b]
	7	.062 (.02)	.098 (.03)	.007 (.004)	.973 (.01)	.807 (.13)
	5	.070 (.02)	.111 (.04)	.008 (.005)	.973 (.01)	.756 (.13)
PPS	Popn	.062 (.02)[ns]	.099 (.04)[ns]	.007 (.004)[ns]	.973 (.01)[ns]	.802 (.14)[ns]
	HF	.063 (.02)	.099 (.04)	.007 (.004)	.973 (.01)	.804 (.14)

[a] The urban/rural proportion combinations of .1/.5 and .5/.9 are not significantly different from the urban/rural proportion combination of .5/.5.
[b] All comparisons are significantly different.
[c] No significant difference between 6 and 8 clusters.
[d] No significant differences between 7 to 10 HFs.
[e] No significant difference between the urban/rural proportion combinations of .1/.5, .5/.5, and .5/.9.
[f] No significant difference between the urban/rural proportion combinations of .1/.1 and .9/.9, no significant differences between the urban/rural proportion combinations of .1/.5 and .5/.5.
[g] The urban/rural proportion combinations of .1/.1 and .9/.9 are significantly different from the urban/rural proportion combinations of .1/.5, .5/.5, and .5/.9.
[ns] None of the comparisons are significantly different.

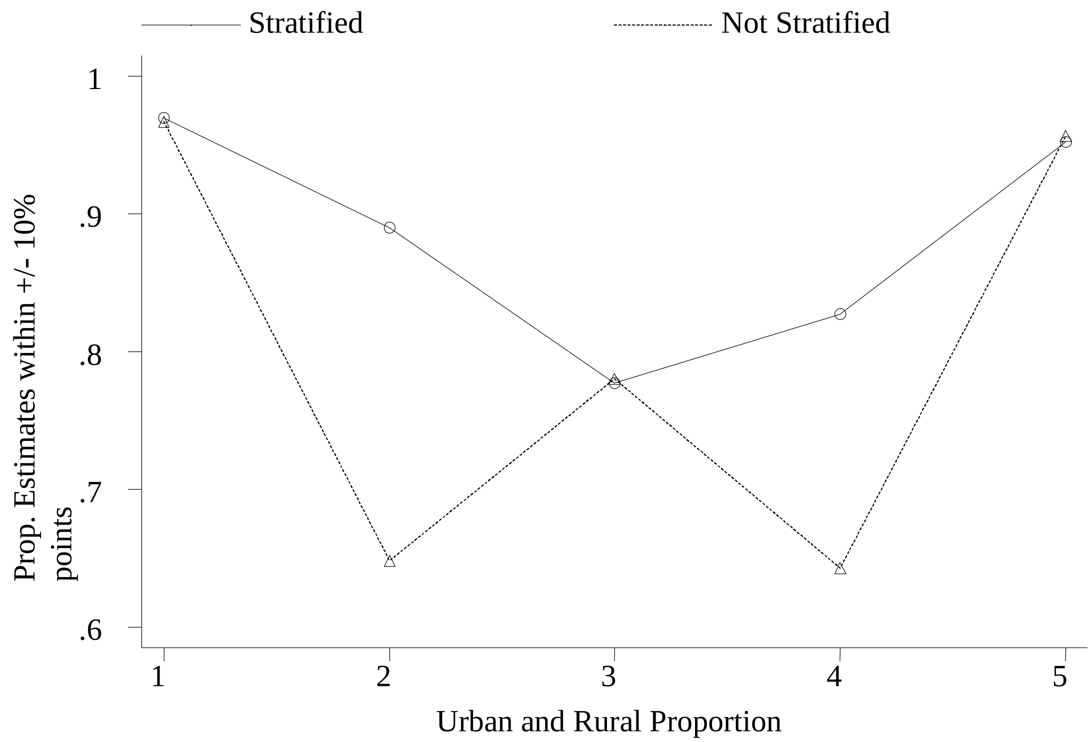
Table 3: Univariate Results for Niger - Mean (SD)

Factor	Levels	Abs Bias	Avg. SE	MSE	Prop. CI's contain p	Prop. of Est within ±10
Urban/rural	.1/.1	.048 (.02)[a]	.077 (.03)[f]	.004 (.003)[a]	.970 (.02)[g]	.896 (.09)[a]
Proportions	.1/.5	.073 (.02)	.115 (.03)	.009 (.004)	.961 (.03)	.727 (.13)
	.5/.5	.072 (.02)	.116 (.04)	.008 (.004)	.975 (.009)	.737 (.11)
	.5/.9	.082 (.02)	.126 (.04)	.011 (.005)	.967 (.01)	.680 (.12)
	.9/.9	.045 (.01)	.074 (.03)	.003 (.002)	.974 (.01)	.913 (.07)
Sigma	0.01	.055 (.02)[b]	.088 (.04)[b]	.006 (.004)[b]	.969 (.02)[ns]	.841 (.14)[b]
(Homogeneity)	0.15	.073 (.02)	.115 (.04)	.009 (.005)	.971 (.01)	.740 (.13)
Stratified	Yes	.060 (.02)[b]	.108 (.04)[b]	.006 (.004)[b]	.979 (.01)[b]	.818 (.13)[b]
	No	.068 (.02)	.096 (.04)	.008 (.005)	.960 (.02)	.763 (.15)
# Clusters	8	.053 (.02)[b]	.079 (.02)[b]	.005 (.003)[b]	.971 (.02)[d]	.857 (.11)[b]
	6	.061 (.02)	.093 (.03)	.006 (.004)	.973 (.02)	.806 (.13)
	4	.078 (.02)	.133 (.04)	.010 (.006)	.965 (.02)	.708 (.15)
# HFs	10	.057 (.02)[b]	.090 (.04)[b]	.006 (.004)[b]	.970 (.02)[ns]	.832 (.14)[b]
	7	.064 (.02)	.101 (.04)	.007 (.005)	.970 (.02)	.793 (.14)
	5	.072 (.02)	.114 (.04)	.009 (.005)	.969 (.02)	.747 (.14)
PPS	Popn	.065 (.02)[ns]	.102 (.04)[ns]	.007 (.005)[ns]	.966 (.02)[b]	.784 (.15)[ns]
	HF	.063 (.02)	.102 (.04)	.007 (.005)	.973 (.01)	.797 (.14)

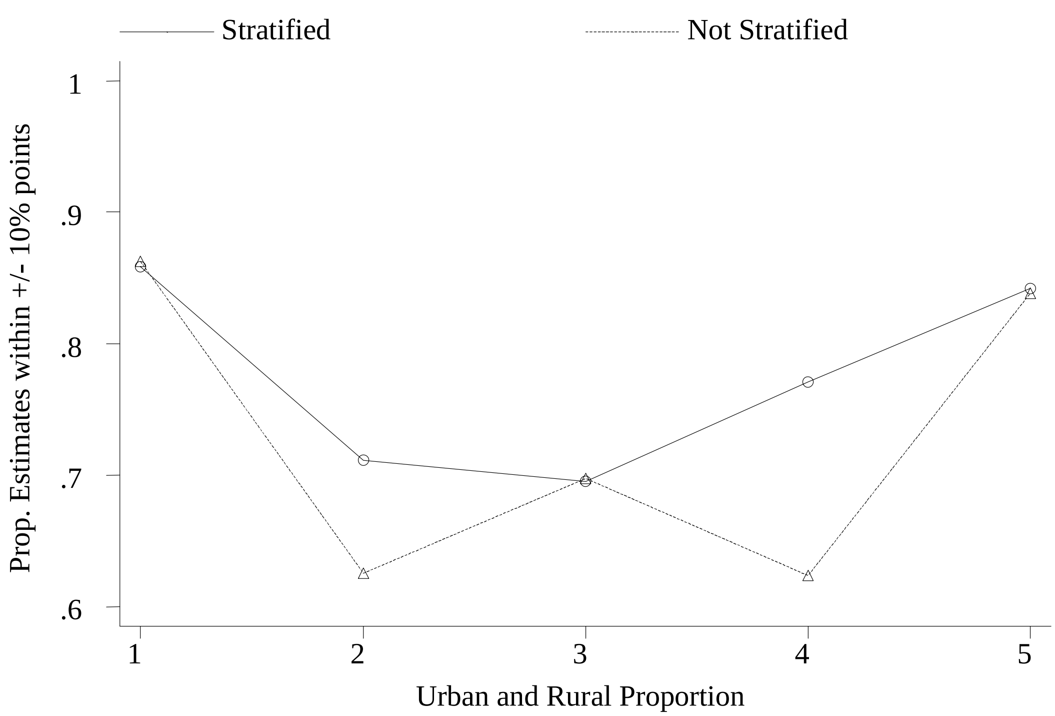
[a] No significant difference between the urban/rural proportion combinations of .1/.1 and .9/.9, no significant differences between the urban/rural proportion combinations of .1/.5 and .5/.5.
[b] All comparisons are significantly different.
[c] No significant differences between the urban/rural proportion combinations of .5/.5 and .5/.9.
[d] No significant difference between 6 and 8 clusters.
[e] 5 and 10 HFs are significantly different.
[f] The urban/rural proportion combinations of .1/.1 and .9/.9 are significantly different from the other urban/rural combinations, but are not significantly different from one another.
[g] The urban/rural proportion combinations of .1/.5 is significantly different from the rest, there is no difference among the combinations with equal rural and urban proportions, and there is no significant difference between the urban/rural proportion combinations of .1/.1 and .5/.9.
[ns] None of the comparisons are significantly different.

Figure 1: 3-way Interaction between Urban and Rural Proportion, Stratification, and Sigma

Sigma = 0.01



Sigma = 0.15



1=0.1U/R, 2=0.5U/0.1R, 3=0.5U/R, 4=0.9U/0.5R, 5=0.9U/R