Potential Impact on Bias and Variance

Due to Frame-to-Population Linkages In Telephone Surveys

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Key Words

Sampling; telephone surveys; BRFSS; nonsampling error

Abstract

Nonsampling error in telephone surveys is a result of errors or shortcomings in the process of data collection. A proportion of nonsampling error is a result of measurement error or nonresponse, either among selected members of the sample and/or item nonresponse. A final cause of nonresponse is related to frame problems. In telephone surveys, samples of phone numbers are used to select households, from which individuals are selected to include in the sample. Recent research on sampling error in telephone surveys is focused on bias resulting from the increased saturation of cell phones and the resultant noncoverage bias (Lee et al, 2010; Link et al, 2007; Brick et al, 2007; Keeter et al, 2007;). However, increases in the number of telephone numbers by which individuals may be interviewed is another potential source of bias which has been under-investigated by current research. Individuals may have multiple phone numbers which might be included in the sample and/or multiple individuals may be using a single phone number, resulting in potential for errors association with frames using telephone numbers (Lessler and Kalsbeek, 1992). Such frame issues are often categorized as frame-to-population linkage errors. This research will investigate the potential of frame-to-population linkage bias in the Behavioral Risk Factor Surveillance System (BRFSS), a large state-based survey conducted by each of the fifty states and coordinated by the Centers for Disease Control and Prevention, and discuss how the move to cell phones may alleviate such error.

1. Background

There is substantial and long standing research on the causes of error in surveys (Alwin, 1977; Groves, 1989; deHeer, de Leeuw and van der Zouwen, 1999). Scholars have identified survey error as a function of sample undercoverage, unit and item nonresponse, measurement error and processing error. Standards for sampling methods are well established to minimize error and subsequent bias. In most sampling methodologies, targeted populations are linked to sources of enumeration (Sirken, 1972a). In some instances the linkage of the population to the enumeration units are direct one-to-one connections. When the linkage is not one-to-one, adjustments must be made to the sample, usually in the form of stratifying or clustering sampling units (Sirken, 1972a; Sirken 1972b).

The production of a sample in telephone survey research typically involves the use of lists of telephone numbers, from which groups of numbers are randomly selected. Random Digit Dialing (RDD) procedures have been accepted as appropriate methods for selection of households using telephone numbers as proxies for individuals who will be included in the sample (Lavrakas, 1993). Since many households have more than one resident who may be eligible for inclusion in the sample, random selection of survey participants may be undertaken to reduce bias in selection among eligible units of analyses within households (Kish, 1995, Lavrakas, 1993). This process is similar to using the household as a cluster (Levy and Lemeshow, 2008), from which a single eligible respondent is selected. Since households may also have more than one telephone, four potential states exist between the number of eligible participants and the number of landline telephone lines within a single household. They are:

1. One phone and one eligible respondent households
2. One phone and multiple eligible respondent households
3. Multiple phones and one eligible respondent households
4. Multiple phones and multiple eligible respondent households.

Using established methods, no within household sampling would be undertaken when there is only one eligible person within a household (conditions 1 and 3 above). If an interviewer reaches a household where there are multiple eligible persons (conditions 2 and 4 above), most standard procedures would have a protocol for selection. Such selection methods might include next/last birthday methods or random selection conducted by the interviewer at the point of contact with the household (Levy and Lemeshow, 2008; Lavrakas, 1993; Kish, 1965;). This adds another stage of sampling to the protocols used to select respondents in these households (Lessler and Kalsbeek, 1992) and represents a potential for bias in the linkage in most landline telephone surveys between the targeted population (individuals) and the sample itself (phone numbers). Lessler and Kalsbeek (1992) identify potential bias an error which might be introduced by each of these conditions:

- One phone and one eligible respondent households do not present opportunities for the introduction of additional error and/or bias. In this instance, the selection probability of the telephone number is equal to the selection probability of the household eligible respondent.
- In households with many phones and one eligible respondent, there is potential for a single member of the population to appear in the sample multiple times.

These instances would not necessarily produce bias in response (after weighting), but might have an effect on variance related to the overcoverage of the respondents in these households. Lessler and Kalsbeek (1992) anticipate overcoverage to produce an impact on variance.

- One phone and multiple eligible respondent households offer the potential for increases in survey error. Although sampling within the household is usually conducted, it can be assumed that persons within a single household are more homogeneous than the population, therefore this frame-to-sample linkage is not ideal. In the second stage of sampling (when a specific respondent is identified from among eligible adults within the household), a single respondent is chosen from a group/cluster of potential respondents. In addition the number of persons within these household varies, with only one respondent selecting in a household of two, or in a household of eight eligible persons. Because of this second selection process, bias in estimation might be a result of this form of frame-to-population linkage.
- In households with multiple phones and multiple eligible respondents, a complex multiplicity problem exists. It is possible for more than one phone within the household to be included in the sample and it is possible to introduce bias due to sampling within a group/cluster of homogeneous eligible respondents. Lessler and Kalsbeek (1992) anticipate that these relationships may produce bias in estimates as well as variance increases.

The Behavioral Risk Factor Surveillance System (BRFSS) is an RDD telephone survey conducted in each of the 50 states, the District of Columbia, Puerto Rico, the US Virgin Islands and Guam and coordinated by the Centers for Disease Control and Prevention (CDC). The BRFSS includes a standardized core of questions collected by all states and optional modules (http://www.cdc.gov/brfss/). In its current form, the BRFSS produces a large data set covering a number of health risk behaviors. The CDC provides the infrastructure for data collection including generation of samples, weighting to account for demographic and geographic variables and programming to support report writing. Traditionally the BRFSS was based exclusively on landline Random Digit Dialing (RDD) samples of households, until cell phone frames were introduced in 2008. Random selection within households of multiple adults is conducted for all landline interviews, but is not conducted for cell phone interviews. Therefore the BRFSS landline sample includes household which meet the requirements of all four conditions of single and multiple eligible respondents and telephone numbers. Whether the frame-to-population linkage among landline respondents has an effect on estimates of prevalence of health risk behaviors and the variance of the prevalence estimates is the focus of this research.

2. <u>Methods</u>

Since the linkage between persons who live alone in households with a single phone line is the most direct connection between sampling frame and targeted population, it is anticipated that data from single person/single phone households will not incur bias which might be present in other frame-to population linkages. It should be made clear that one phone/one adult households are not assumed to be without bias when compared to true measures. The question is whether additional bias is introduced based on the frame-to-population linkages in other households.

BRFSS data from 2009 landline survey interviews are used to assess frame linkage impacts for a number of health status and chronic disease indicators for four types of frame-to-population linkages: one phone/one adult; multiple phones/one adult; one phone/multiple adults, and; multiple adults/multiple phones. Health status indicators include current smoker, binge drinking, obesity, leisure time physical activity, moderate physical activity, high blood pressure, and high cholesterol.

Initially all variables are examined by frame-to-population linkage of the household without weighting. Since all of the variables were coded as dichotomous, logistic regression was used to calculate prevalence estimates and confidence intervals of prevalence estimates for each category of frame-to-population linkage. Demographic characteristics including sex, age, education, marital status, health insurance coverage and race/ethnicity were controlled for in each equation. These variables were chosen because they are often used by researchers as controls in large scale population data analyses. For each set of frame linkage, prevalence and variance are compared to one phone/one adult households. Differences in prevalence between frame linkages are tested as well as increases in variance (Snedecor and Cochran, 1967).

Weighting is then conducted using standard BRFSS protocols (http://www.cdc.gov/brfss/). These procedures already include weighting for household size, and weighting for the number of phones within each household. Final weights are determined by using the following formulae:

Stratum Weight = average number of telephone records available / number of telephone records selected within each geographic strata.

Design Weight =Stratum weight * 1/ number of household phone lines * number of adults within the household

Final Weight = Design Weight * Post-stratification adjustment

The post-stratification adjustment also includes race, age, gender as well as well as region/state.

The equations are then rerun with weighted data to determine whether weighting affected differences noted between types of frame-to-population households. The following research questions are examined:

1. Will differences in prevalence estimation and variance be apparent among categories of frame-to-population linkage?
2. When differences are noted, will they follow the patterns suggested by the literature?
3. When differences in prevalence estimates among categories of frame-to-population linkage household are noted using unweighted data, will weighting remove those differences?
4. When differences in variance among categories of frame-to-population linkage household are noted using unweighted data, will weighting remove those differences?

3. **Findings**

In 2009, the BRFSS included over 420,000 interviews. As Table 1 indicates, the majority of BRFSS respondents live in households with a single landline phone and multiple adults. Table 1 also indicates the anticipated impact, as suggested by Lessler and Kalsbeek (1992) of the difference conditions related to frame-to-population linkages which exists within the BRFSS sample.

Table 1

Distribution of Number of Phones and Adults in BRFSS Landline Households

Landline Phone Conditions/ Number of Adults (Number of frame units/ Number of population units)	Number of Respondents	Percentage	Anticipated Impact of Frame
One phone/one adult	136,579	32.2%	None
Multiple phones/one adult	4,352	1.0%	Variance increases
One phone/multiple adults	265,442	62.5%	Impact on bias of estimates
Multiple phones/multiple adults	18,369	4.3%	Impact on bias of estimates and variance increases
Total	424,742	100%	

In order to assess the impact of frame-to-population linkage, a series of logistic equations of health behaviors and health status was conducted, first with unweighted estimates (Table 2) and then with weighted estimates (Table 3) using the demographic characteristics included in the BRFSS as control variables. These variables include sex, education (in three levels), marital status (in three groups), age (in three groups), race (in four categories), and whether or not they had health insurance. In Tables 2-3 the far left column, depicting estimates for one phone/one adult households, was used as a standard to assess impact of frame-to-population linkages.

Table 2 indicates **unweighted** frequencies of and corresponding confidence intervals for the variables of interest by the type of frame-to-population linkage of the household.

Table 2. Un-weighted prevalence and confidence intervals of health behaviors and chronic conditions by number of adults and number of phone lines in household after adjusting for demographic factors, BRFSS 2009.

	One phone/ one adult	Multiple phones/one adult	One phone line/multiple adults	Multiple phones/multiple adults
Anticipated difference	Baseline (no difference)	Variance difference expected	Estimate difference expected	Variance and estimate differences

				expected
	Unweighted % (95% CI) #	Unweighted % (95% CI) #	Unweighted % (95% CI) #	Unweighted % (95% CI) #
Current smoker				
Yes	18.31 (18.27-18.37)	15.87 (15.64-16.10) *	15.60 (15.56-15.63) *	11.54 (11.45-11.63)*
Range of CI	.10	.46 $^{\delta}$	.07	.18
Binge drinking				
Yes	8.64 (8.60-8.67)	10.78 (10.55-11.02) *	11.81 (11.77-11.84) *	12.01 (11.90-12.13) *
Range of CI	.07	.47 $^{\delta}$	.07	.23 $^{\delta}$
Weight Status				
Overweight/Obese	63.56 (63.52-63.59)	63.23 (63.00-63.46) *	65.55 (65.52-65.58) *	64.10 (63.99-64.22) *
Range of CI	.07	.46 $^{\delta}$	.06	.23 $^{\delta}$
Leisure time PA				
No	32.85 (32.79-32.91)	24.92 (24.68-25.16) *	25.16 (25.12-25.20) *	19.89 (19.79-19.99) *
Range of CI	.12	.48 $^{\delta}$	.08	.20
Moderate PA				
Yes	40.83 (40.79-40.87)	46.38 (46.18-46.57) *	48.60 (48.57-48.63) *	52.97 (52.88-53.06) *
Range of CI	.08	.39 $^{\delta}$	.06	.18
Had high BP				
Yes	47.54 (47.45-47.64)	43.06 (42.57-43.54) *	34.84 (34.78-34.90) *	34.77 (34.55-34.98) *
Range of CI	.19	.97 $^{\delta}$	.12	.43
Had high Cholesterol				
Yes	46.39 (46.34-46.45)	44.97 (44.67-45.27) *	40.93 (40.89-40.97) *	42.24 (42.10-42.38) *
Range of CI	.11	.60 $^{\delta}$	.08	.28

Percent adjusted for sex, race/ethnicity, age, education, marital status, and health plan.
*Significant differences in estimates when compared to one phone/one adult.
$^{\delta}$ Significant difference in variance when compared to one phone/ one adult.

Weighted data by category of frame-to-population linkage are presented in Table 3. Comparisons of prevalence estimates and variance to one phone/one adult households are noted in Table 3. Weighting did compensate for many of the differences in prevalence which were evident in the unweighted data. Unweighted data produced significant differences in all categories, while weighted data show less than half of the categories as different from the one phone/one adult benchmark. Table 3 includes confidence intervals of prevalence estimates to illustrate variance differences. Weighting had less of an impact on whether variances would be significant.

Table 3. Weighted prevalence and confidence intervals of health behaviors and chronic conditions by number of adults and number of phone lines in household after adjusting for demographic factors, BRFSS 2009.

	One phone/ one adult	Multiple phones/ one adult	One phone line/multiple adults	Multiple phones/multiple adults
Anticipated difference	Baseline (no difference)	Variance difference expected	Estimate difference expected	Variance and estimate differences expected
	Weighted % (95% CI) #	Weighted % (95% CI) #	Weighted % (95% CI) #	Weighted % (95% CI) #
Current smoker				
Yes	17.55 (17.01-18.13)	14.97 (13.28-16.72) *	18.2 3 (17.89-18.51)	16.26 (15.05-17.55)
Range of CI	1.12	3.44 $^{\delta}$	.62	2.50
Binge drinking				
Yes	14.39 (13.81-14.99)	15.27 (12.79-17.81)	15.20 (14.91-15.49)	16.23 (14.87-17.33)
Range of CI	1.18	5.02 $^{\delta}$	.58	2.46
Weight Status				
Overweight/Obese	67.19 (66.49-67.91)	64.69 (62.07-67.33)	63.27 (62.89-63.71)*	61.91 (60.53-63.27)*
Range of CI	1.42	5.26 $^{\delta}$	.82	2.74
Leisure time PA				
No	25.76 (25.19-26.41)	21.87 (19.70-24.10) *	24.58 (24.27-24.93)*	20.91 (19.74-22.06)*
Range of CI	1.22	4.40 $^{\delta}$	.66	2.32
Moderate PA				
Yes	46.63 (45.82-47.38)	49.67 (46.82-52.58)	49.41 (48.99-49.81)*	53.28 (51.51-54.49) *
Range of CI	1.56	5.76 $^{\delta}$	.82	2.98
Had high BP				
Yes	30.69 (31.09-32.31)	30.38 (28.26-32.54)	29.13 (28.77-29.43)*	27.90 (26.80-29.00)*
Range of CI	1.22	4.28 $^{\delta}$	.66	2.20
Had high Cholesterol				
Yes	39.14 (38.34-39.86)	39.64 (37.09-42.11)	37.92 (37.51-38.29)*	37.76 (36.47-39.13)
Range of CI	1.52	5.02 $^{\delta}$	.78	2.66

Percent adjusted for sex, race/ethnicity, age, education, marital status, and health plan.
*Significant differences in estimates when compared to one phone/ one adult.
$^{\delta}$ Significant difference in variance when compared to one phone/one adult.

Table 3 indicates that, as anticipated, all of the variances for multiple phone/ one adult households related to health risk behaviors and/or chronic conditions have larger confidence intervals than corresponding variances for one adult/one phone households. In most instances variances for multiple phone/one adult households increased threefold, with CI ranges from 3.44-5.76, compared to 1.12-1.56 for one phone/one adult households. It was not anticipated that there would be differences in prevalence indicators between the one phone/one adult households and the multiple phone/one adult households. Only two of the seven variables showed differences in prevalence (current smoking and leisure time physical activity). All other variables used as dependent variables (binge drinking, obesity, moderate physical activity, high blood pressure, and high cholesterol) did not exhibit differences in prevalence over the estimates from the one adult/one phone households.

The third column of the table provides prevalence and confidence intervals for households with one phone and multiple adults. In this instance differences in prevalence were anticipated. Weighting eliminated significant differences for two (current smoking and binge drinking) of the seven prevalence estimates. The other majority of prevalence estimates (obesity, leisure physical activity, moderate physical activity, high blood pressure, and high cholesterol) continued to show significant differences from those of one phone/one adult households.

The final column in the table illustrates findings for multiple phones/multiple adult households. It is anticipated that prevalence estimates and variances for this category will be different from one phone/one adult households. As the table indicates, although variances were larger for all of the prevalence estimates in this group, they were not significantly larger when compared to the one adult/one phone households. Prevalence estimates were significantly different for four of the seven variables (obesity, no physical activity, moderate physical activity, and high blood pressure).

Overall findings for the research questions listed below produced mixed results.

1. Differences in prevalence estimates and variance were apparent with unweighted data.
2. In the unweighted data, the patterns suggested by literature were adhered to in the findings.
3. Weighting corrected for many of the differences, but not all. Variance difference remained a pattern for multiple phone/one adult households and prevalence estimates were different from one phone/one adult households for the majority of variables.
4. Variance differences were not corrected for multiple phone/one adult households. However weighted data did eliminate significant differences in variance for multiple phone/multiple adult households.

Limitations

The analyses presented here provide some support for the introduction of bias due to frame-to-population linkage. However, this support may be a function of other untested phenomena, such as variables not included in the analyses. One other potential explanation for variance differences is the difference in the sample size for the categories of frame-to-population linkage. Although all the groups were large (the smallest was over 4,300 subjects), the two with the relatively smaller number of respondents were also the two groups with the largest variance ranges. Although the impact of group size on variance may account for some of these patterns, it may not be the only explanation. Also if the differences in frame-to-reference effects are due to size of the groups, it can be assumed that we are less certain about the behaviors of some of the groups than other groups.

Conclusions

The findings presented in Table 3 illustrate the impacts of errors in frame-to-population linkage, despite steps taken to minimize the impact of linkages. Variance, as measured by increased confidence intervals, did increase, even when prevalence estimates remained relatively stable when one phone/one adult households are compared to multiple phone/one adult households. As anticipated, one phone/ multiple adult household prevalence estimates did not exhibit similar patterns. As suggested by Lessler and Kalsbeek (1992), prevalence differences were more likely to be evident in comparisons with these households and one phone/one adult households.

Although the results here are mixed they may provide direction to researchers interested in further minimizing the impact of frame-to-populations linkages. While these findings are based on data from landline telephone survey samples, in recent years, more potential respondents are relying exclusively on cell phones (Blumberg, 2010). Cell phones are less likely to be shared among groups of individuals and are generally used as personal communication devices, rather than communication devices for groups/households. Therefore cell phone samples generally have one-to-one linkages between samples and targeted populations, offering a potential solution to frame errors resulting from multiplicity. As telephone surveys meet coverage needs prompted by growing proportions of cell phone only households, a significant side benefit will be achieved.

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