An Assessment of Bias due to Noncoverage of Wireless Only Households in RDD Surveys

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Abstract[1]

The prevalence of wireless-only households is rapidly growing in the US. Estimates from random-digit-dialed (RDD) surveys are subject to potential bias due to noncoverage of phoneless and wireless-only households, with the latter group accounting for more than 80% of the total noncoverage. Previous studies have shown that characteristics of adults living in wireless-only households differ from those living in phoneless households or in households with landline telephones. The purpose of this paper is to evaluate noncoverage bias in the National Immunization Survey (NIS), a large RDD survey of households with children aged 19-35 months followed by a mail survey of providers to obtain vaccination records. We analyze data on households with children aged ≤3 years from the 2005 National Health Interview Survey (NHIS) by type of telephone service to evaluate potential noncoverage bias relevant to the NIS. Noncoverage bias is estimated by comparing selected outcome measures associated with vaccination coverage, and imputed vaccination status, between all children in the NHIS sample with children in households with landline telephones. Differences in outcome rates between all children living in landline telephone households and children living in landline or wireless-only households are computed using the NHIS weights adjusted for noncoverage using the current NIS methodology. Using 2005 NHIS data, we found marginal bias in proxy measures related to vaccination status resulting from restriction of the sample to only households with landline telephone service. However, regular monitoring is needed as an increasing proportion of households with young children substitute wireless telephone service for landline service.

Keywords: NIS, RDD survey, direct ratio adjustments

Introduction

The prevalence of households with access only to wireless telephone service is increasing rapidly in the United States. For legal and operational reasons, wireless telephone numbers are usually excluded from random-digit-dialing (RDD) telephone surveys. Thus, estimates from RDD surveys are subject to potential bias due to noncoverage of phoneless and wireless-only households, with the latter group accounting for more than 80% of the total noncoverage. The National Health Interview Survey (NHIS), based on an area sampling frame, has been used to monitor telephone status of households (Blumberg *et al*. 2006). Based on the NHIS data, the prevalence of households with wireless-only telephone service among children under 18 years of age increased from 2.8% in 2003 to 7.6% in 2005 and to 11.6% in 2006, while the prevalence of phoneless households remained almost unchanged and ranged from 1.6 to 2.3% (Blumberg *et al*., 2007). The characteristics of persons living in wireless-only households differ significantly from those living in phoneless households or in households with landline telephones, by geography, demography, and socioeconomic status (Blumberg et al., 2006). Thus, the impact of these differences on estimates from RDD surveys must be assessed, and current methods for adjusting survey weights to account for noncoverage of increasing wireless-only households in RDD surveys must be evaluated. Khare and Chowdhury (2006) evaluated alternative weight adjustment methods and found that the current NIS method is adequate in reducing bias due to noncoverage of households without landline service (i.e., phoneless and wireless-only households).

The purpose of this paper is to evaluate potential bias in estimates due to exclusion of wireless-only households from RDD surveys such as the National Immunization Survey (NIS) (Singleton et al., 2007). NIS is a large RDD survey of telephone households with children aged 19-35 months followed by a mail survey of providers to obtain children's vaccination histories (Smith *et. al.*, 2005). For this evaluation, we use data from the 2005 NHIS to estimate the prevalence of households with children aged ≤3 years by type of telephone service (phoneless, wireless-only, or landline). Potential bias due to exclusion of wireless-only households is estimated by comparing selected outcome measures, possibly associated with children's vaccination status, from the landline and landline-plus-wireless-only households.

[1] "The findings and conclusions in this paper are those of the authors and do not necessarily represent the views of the Centers for Disease Control and Prevention."

Data and Methods

The target population for the NHIS is the U.S. civilian non-institutionalized resident population (with or without access to telephones) and data are collected for approximately 80,000 respondents through face-to-face in-person interviews (NHIS, 2005). In 2003, a question about access to wireless telephones was added to the NHIS questionnaire. We used data from the 2005 NHIS and restricted our analysis to sample children aged ≤3 years. We defined subgroups of children according to the type of telephone service reported in the household including landline, wireless-only, and phoneless households. To assess bias in the estimates, we created two RDD-type samples using the telephone status reported in the NHIS. The first sample consisted only of children from the households with landline service (i.e., excluding wireless-only and phoneless households). The second sample consisted of children from the households with access to landline or wireless service (i.e., including wireless-only households). In both samples, landline households are further classified based on whether they had experienced interruption of one week or more in their landline telephone service during the past 12 months; wireless-only households are assumed to be without interruption in telephone service.

Outcome Measures

Because vaccination status for the recommended childhood vaccines is not assessed by the NHIS, we selected proxy measures that may be correlated with vaccination status as outcome measures for evaluation of noncoverage bias, including number of visits to provider offices in the past 12 months, history of chickenpox, asthma (ever told by provider), respiratory allergy in the past 12 months, and influenza vaccination in the past 12 months. These measures are available from the Sample Child module, which collects additional health information on a randomly selected child (age ≤ 17 years) from a responding household with children.

We also imputed the vaccination status for children aged ≤3 years in the NHIS sample and considered children aged 0-19 months as 19 months old to simulate the age groups covered by the NIS. Also, a composite variable from the NHIS on parent's education is used to represent mother's education from the NIS. Specifically, we developed a logistic regression model using limited geographic, demographic, and socio-economic information from the 2005 NIS data to predict a binary vaccination status of children for the vaccine series 4:3:1:3:3 (with 4+ doses of DTaP, 3+ doses of Polio, 1+ doses of MMR, 3 + doses of Hib, and 3+ doses of Hepatitis B; for details, see NIS, 2005). Table 1 lists the predictor variables included in the NIS model to predict vaccination status for the 4:3:1:3:3 vaccine series. It also presents the analysis of maximum likelihood estimates from the logistic regression model and the model fit statistics (SAS v9.1, 2002-2003). It shows that all predictor variables included in the model are highly significant. However, the association of predicted probabilities and observed responses shows a moderate concordance of 61%. The objective of developing this model is not to predict the 'true' vaccination status of individual cases rather to predict the vaccination coverage rates within the domains defined by the predictor variables. Table 2 presents a comparison of the predicted 4:3:1:3:3 vaccine series rates by the three predictor variables (MSA-Central city, race/ethnicity, and poverty status) associated with both vaccination coverage and wireless-only household status. It shows that the differences between the observed 2005 NIS estimates and the predicted estimates are not significant at the 5% level of significance for the majority of the cells included in the table. This also shows that the goodness of fit of the model for predicting vaccination rates within these cells is reasonable for the purpose of assessing large bias within a domain. In the absence of a best fit model, it may not be possible to detect smaller degree of bias but we decided to use the predicted values based on this model along with other NHIS variables to make an overall assessment of the bias in estimates due to exclusion of wireless-only households for the NIS. Parameter estimates from the NIS model were then applied to the children with complete interviews from the 2005 NHIS to predict if they were up-to-date with the vaccines in the 4:3:1:3:3 series. We used the predicted propensities to create an outcome measure. The proportion of children up-to-date for the 4:3:1:3:3 series in the NHIS is estimated by computing the weighted average of the predicted propensity scores for children within selected domains in each sample.

Adjustments to Sample Weights

To reduce bias in RDD survey estimates, sampling weights of the responding cases are adjusted for nonresponse and noncoverage. Basic weights of sampled telephone numbers are generally adjusted for unresolved residential status, nonresponse to the household screener and interview, for multiple phone lines per household, for selecting one or more children from an age-eligible household, noncoverage of households without landline telephones by using households with interruption in telephone service to represent households without landlines, and finally, poststratification adjustment by demographic characteristics of the U.S. population (Smith et al., 2005).

To adjust for noncoverage, the NIS method assumes that children in households with interruption of landline service for one week or more in the past 12

months are representative of children who live in households without landline service, within weighting classes. We applied this NIS assumption (i.e, the interruption method) to adjust the nonresponse adjusted initial NHIS weights of children from the interrupted group for the noncoverage of households without landline telephones for both samples. Because NHIS is a national survey, we could not adjust the weights within each state in order to replicate the exact NIS weight adjustment method. However, we used the direct ratio adjustment method to adjust for the noncoverage at the national level and applied the NIS interruption method to both RDD-type samples, separately.

For the first sample consisting of only children living in households with landline telephone service, weights of the children from households without interruptions (i.e., with continuous landline telephone service) remained the same to self-represent the children from the households with landline telephones service in the population; only weights of the children from interrupted households are adjusted for noncoverage of phoneless and wireless-only households. Specifically, weights of the children from the interrupted households are ratio-adjusted to represent the total number of children living in interrupted households, phoneless households, and wireless-only households, within the respective weighting cells.

For the second sample consisting of children from the landline-plus-wireless-only households, weights of children from wireless-only households and households without interruptions in landline service remained the same and self-represented the children in the population; only weights of children from interrupted households are adjusted for noncoverage of phoneless households. Specifically, weights of the children from the interrupted households are ratio adjusted to represent the total number of children living in interrupted and phoneless households, within the respective weighting cells. Finally, for both samples, a poststratification adjustment is applied to adjust the sum of the weights in the demographic cells to the total U.S. population. These final poststratified weights are then used to compute the weighted population estimates from the two samples.

Analysis

We describe the percentage distribution of children aged $\leq$3 years by household telephone status (landline, wireless-only, phoneless) by selected health and socio-demographic characteristics. We compare the prevalence of selected socio-demographic characteristics and outcome measures for the children from the two RDD-type samples. To assess potential noncoverage bias due to exclusion of households with wireless-only telephones in RDD surveys, we compute the difference in prevalence of outcome measures from the two RDD-type samples (landline and landline-plus-wireless-only), after adjusting weights for noncoverage as described above. Differences are also computed between weighted estimates based on all children using the original NHIS weights and the new weights for children from the two RDD-type samples. To evaluate impact of the noncoverage adjustments, mean squared errors (MSE = Bias^2 + Standard Error^2) for the two samples are compared with the NHIS estimates including all age-eligible children and using the original NHIS weights (considering the NHIS estimate as the "true" estimates). In order to account for the complex sample design of the NHIS, SUDAAN (Shah *et al*., 1999) SAS (v9.1, 2002-2003) software are used for all analyses.

Results

There are 4,329 children aged $\leq$3 years from the 2005 NHIS. Of those 4,329 children, 3,704 lived in households with landline service, 444 in wireless-only households and 181 in phoneless households. Thus, the landline sample included 3,704 (86.9%) children and landline-plus-wireless-only sample contained 4,418 (96.6%) children.

Percentage Distribution of Children by Household Telephone Status

According to the 2005 NHIS, 9.7% age-eligible children lived in wireless-only households, 3.4% lived in phoneless households, and 86.9% lived in households with landline service. Table 3 shows the estimated percentage distribution of children by household telephone status for selected demographic and socio-economic characteristics. Children living in households with only two people (e.g., single parent and a child) are most likely to live in wireless-only (23.3%) or phoneless (11.2%) households. Other subgroups with a higher wireless-only prevalence than the overall average of 9.7%, include girls, Hispanic children, non-Hispanic black children, children with mother/parents who are not college graduates, children living in households of size equal to 2 or 3, children living in households with income below 200% poverty level, children living in a rented house, children with no private insurance, or children with either no health insurance coverage or covered by Medicaid/SCHIP programs, and children living in the Midwest or the South (Table 3).

Comparison of characteristics of the children from the two samples

We also compared the characteristics of the children from the landline and landline-plus-wireless-only samples (data not shown). The difference in the

characteristics of children from the landline-plus-wireless-only and the landline samples show that children living in rented houses, children without health insurance or receiving health care under Medicaid/SCHIP programs are over-represented by ~3% in the landline-plus-wireless-only sample due to inclusion of wireless-only households in the sample.

Comparison of Outcome Measures from the NHIS Sample Child file

The NHIS randomly selects one child (age ≤ 17 years) from the responding households with children. There are 3917 children aged ≤3 years in the 2005 NHIS sample child file. Table 4 presents the prevalence of outcome measures and the difference in prevalence from the two samples using the sample child weight. The estimated prevalence of outcome measures based on the landline-plus-wireless-only sample are within 0.5 percentage points of estimates based on the landline sample.

Assessment of bias in vaccination status:

Table 5 presents weighted estimates of the imputed prevalence of children who are up-to-date with the 4:3:1:3:3 vaccine series, based on the predicted value of the vaccination status, and after adjusting weights for noncoverage of children not included in the landline or landline-plus-wireless-only samples. Table 5 presents estimates of 4:3:1:3:3 series vaccination coverage by selected characteristics expected to be correlated with the vaccination status from the 2005 NIS, the 2005 NHIS (predicted), the landline sample (predicted), and the landline-plus-wireless-only sample (predicted). There are no statistically significant differences between estimates from the landline and landline-plus-wireless-only samples, nor between the NHIS and landline-plus-wireless-only samples. Marginal differences are observed between the landline and the NHIS samples for Midwest and South regions and among non-Hispanic white children; all differences are between -0.6 and 0.2 percentage points. Estimates from the 2005 NIS are slightly higher than the estimates from the 2005 NHIS for the characteristics included in the analysis. This could be because the NIS weights are adjusted for nonresponse and noncoverage at the state level and NHIS weights at the national level.

A comparison of the mean-squared-errors (MSEs) between the landline and the landline-plus-wireless-only samples, using the NHIS estimates as the "true" values shows small differences between the estimated MSEs. The estimates from the landline-plus-wireless-only sample have smaller bias and MSE than the corresponding estimates from the landline sample because the landline-plus-wireless-only sample covers 96.6% of the NHIS sample while the landline telephone sample covers only 86.9% of the NHIS sample.

Discussion

The prevalence of children living in wireless-only households is increasing and varies substantially by geography and socio-demographic characteristics of children and the household respondent. Among children aged ≤3 years, small differences are observed in the distribution from the landline and the landline-plus-wireless-only samples for most characteristics except for house tenure, household size, poverty level, being uninsured and receiving health care under Medicaid/SCHIP programs. With about 9.7% of age-eligible children living in wireless-only households, bias in imputed 4:3:1:3:3 vaccination coverage and other outcome measures by selected characteristics appears to be marginal after appropriately adjusting for noncoverage of wireless-only and/or phoneless households.

One of the limitations of this analysis is that estimates are based on the predicted values of vaccination status from the NIS cases and the logistic regression model used only limited information that was common to both the NIS and the NHIS. The estimates are, therefore, subject to both prediction and sampling errors. The imputed vaccination status for each child can be viewed as a propensity score combining information from several variables associated with vaccination into one numeric value, for purposes of evaluating potential bias. Another limitation is that we are not measuring noncoverage bias in the NIS estimates directly, nor accounting for nonresponse in the NIS. The NIS is stratified by states and selected local areas, but we are not able to evaluate potential state-specific bias using the NHIS. Finally, the NHIS itself is subject to bias arising from errors in telephone status and other variables based on self-report, and from nonresponse bias.

With increasing trends in the prevalence of wireless only households, using separate adjustments for wireless-only and phoneless household may control potentially larger bias in population estimates that are correlated to characteristics of wireless-only households. Adjustments based on interruptions in telephone service generally reduce the noncoverage bias especially for those variables that are highly correlated with the presence or absence of landline telephone service.

To continue evaluation for further reduction in bias with increasing substitution with wireless telephones, and to adjust for the noncoverage of wireless-only households in RDD surveys, the 2007 NIS added a question on access to wireless telephones during the interruption in landline service. Also, a pilot study has been conducted in the 2007 NIS by including a sample of wireless phone numbers that are hand-dialed to interview households with access to wireless phones. In 2008, the NIS is also adding a question on household

tenure (rented or owned) to evaluate potential bias due to noncoverage of wireless-only households. Annual evaluation of potential non-coverage bias in the NIS is needed as the prevalence of wireless-only households continues to increase. The NHIS provides a unique source of data for this evaluation and could be used in a similar way by other RDD surveys.

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Table 1: Model Fit Statistics and Analysis of Effects for a Logistic Regression Model to Predict Up-To-Date Status of the 4:3:1:3:3 Vaccine Series, 2005 National Immunization Survey

Analysis of Effects*

Effect	DF	Wald Chi-Square	Pr > Chi-Square
Census region	3	33.46	<.0001
Mother's Education	3	31.09	<.0001
MSA	2	10.56	0.0051
AGE-YEAR	1	161.10	<.0001
POVERTY status	4	41.76	<.0001
RACE/ethnicity	4	6.91	0.1406
Household size	2	100.73	<.0001

Model Fit Statistics

Criterion	Intercept Only	Intercept and Covariates
AIC	17205.67	16740.10
SC	17213.44	16895.57
-2 Log L	17203.67	16700.10

Association of Predicted Probabilities and Observed Responses*

Percent Concordant	60.5	Percent Discordant	38.5
Pairs	46638822	c	0.61

Testing Global Null Hypothesis: BETA=0

Test	Chi-Square	DF	Pr > Chi-Square
Likelihood Ratio	503.56	19	<.0001
Score	492.01	19	<.0001
Wald	475.61	19	<.0001

***Output from the logistic regression procedure, SAS v9.1**

Table 2: Comparison of the Predicted Coverage of 4:3:1:3:3 Vaccine Series with the Observed Coverage by Three Selected Characteristics*, 2005 National Immunization Survey.

MSA Status	RACE /Ethnicity	POVERTY Status (%)	Observed: 2005 NIS			Predicted: 2005 NIS Model	Difference in Estimates
			Vaccination Coverage (%)	SE (%)	95% Confidence Interval	Vaccination Coverage (%)	Observed - Predicted (%)
MSA-Central City	**Hispanic**	**<100**	77.6	2.6	72.5 , 82.8	75.3	2.3
		100-199	74.6	4.0	66.8, 82.4	77.4	-2.9
		200-399	85.2	4.9	75.6, 94.9	82.4	2.9
		400+	89.6	2.8	84.2, 95.1	85.9	3.7
	NH White	**<100**	76.0	4.8	66.7, 85.4	76.3	-0.3
		100-199	78.6	2.0	74.6, 82.5	77.6	0.9
		200-399	80.6	2.8	75.1, 86.2	83.1	-2.5
		400+	86.3	1.4	83.5, 89.0	85.4	0.9
	NH Black	**<100**	71.2	3.4	64.6, 77.9	75.9	-4.6
		100-199	82.4	2.4	77.7, 87.2	78.7	3.7
		200-399	90.4	3.0	84.6, 96.2	84.6	5.8
		400+	85.0	4.7	75.9, 94.1	85.5	-0.5

*** This is a subset of a large 3-way table MSA x race/ethnicity x poverty status**

Table 3: Prevalence of Children Aged 0-3 Years Living in Landline, Wireless Phone Only, and Phoneless Households by Selected Characteristics, National Health Interview Survey, 2005

	Nontelephone Household		
Characteristics	**Landline Telephone Service (%)**	**Wireless only* households (%)**	**Phoneless households (%)**
All Children, (n=4329)	86.9	9.7	3.4
Gender			
Males	87.3	9.6	3.1
Female	86.6	**9.8**	3.6
Race/Ethnicity			
Hispanic	82.6	**12**.0	5.4
NH-White	89.6	8.0	2.4
NH-Black	81.6	**14**.0	4.4
Parent's Education			
<12 yrs	77.0	**13.4**	9.6
12 yrs	81.2	**14.8**	3.9
>12 yr, no college grads	87.7	**10.7**	1.7
College grads	96.7	3.1	0.3
Health Status			
Excellent to good	87.0	9.7	3.4
Fair or poor	84.1	**12**.0	3.9
Census Region			
Northeast	94.3	2.9	2.7
Midwest	85.5	**12**	2.6
South	83.4	**12.2**	4.4
West	89.5	7.7	2.8
MSA			
Central city	84.0	**11.3**	4.7
Non- Central city	89.1	8.3	2.6
Non-MSA	85.7	**11.1**	3,2
Household Size			
2	65.5	**23.3**	11.2
3	84.2	**12.1**	3.7
4+	88.8	8.3	2.0
House Tenure			
Rented	75.2	**17.7**	7.1
Owned or other	93.9	5.3	0.8
Poverty Status			
<100%	75.4	**16.4**	8.3
100-199%	80.2	**16.8**	3.0
200-399%	89.6	9.0	1.4
400+%	97.4	2.6	0.0
Private Insurance?			
Yes	93.8	5.4	0.9
No	77.9	**15.6**	6.5
Uninsured/Medicaid/ /SCHIP: Yes	79.3	**14.7**	6.0

***Bolded values represent characteristics with estimated prevalence of wireless-only household >9.7 %**

Table 4: Percent Distribution of Children Aged ≤3 Years from the Landline Telephone and Landline-Plus-Wireless-Only Samples by Selected Health Characteristics, Sample-Child* Module, National Health Interview Survey, 2005

Characteristics	RDD-Type Samples		
Sample Child Variables	**Landline Telephone Sample (%)**	**Landline-plus-Wireless-only Sample (%)**	**Difference between Two Samples (%)**
Number of office visits, past 12 months?			
No visit	8.2	8.5	0.3
1-5 visits	69.5	69.3	-0.2
6-9 visits	16.5	16.5	0.0
Ever had chickenpox? Yes	14	13.6	-0.4
Ever been told child had asthma? Yes	8.9	9.4	0.5
Had respiratory allergy, past 12 months? Yes	5.8	5.5	-0.3
Flu shot, past 12 months? Yes	25.9	25.4	-0.5
Predicted 4:3:1:3:3 status? Yes	78.2	78.2	0.01

*One child selected per responding household; used final Sample Child weights in analysis

Table 5: Weighted Coverage of 4:3:1:3:3 Vaccine Series (based on predicted values) and Standard Errors after Adjusting for Noncoverage in the NIS, NHIS, Landline Telephone and Landline-Plus-Wireless-Only Samples, 2005

	Population Estimates of 4:3:1:3:3 Vaccine Series Coverage (Based on Predicted Sample Values)							
	2005 NIS (%)		**2005 NHIS (%)**		**Landline Telephone Sample (%)**		**Landline-Plus-Wireless-Only Sample (%)**	
	Est	**SE**	**Est**	**SE**	**Est**	**SE**	**Est**	**SE**
All Children	**80.75**	0.09	**79.35**	0.13	**79.05**	0.18	**79.26**	0.14
Census Region								
Northeast	83.14	0.20	81.10	0.34	81.30	0.41	81.14	0.36
Midwest	82.92	0.15	81.17	0.25	80.55	0.47	80.91	0.28
South	80.48	0.13	79.16	0.21	78.61	0.29	79.05	0.21
West	77.64	0.22	76.74	0.24	76.78	0.26	76.74	0.25
MSA								
Central City	79.31	0.15	77.58	0.24	77.26	0.28	77.49	0.19
Non Central City	82.56	0.14	80.69	0.18	80.46	0.25	80.64	0.19
Non-MSA	79.79	0.18	79.16	0.33	78.72	0.52	78.95	0.35
Race/Ethnicity								
Hispanic	78.79	0.20	78.25	0.22	77.97	0.27	78.23	0.23
NH-White	82.08	0.11	80.00	0.20	79.41	0.33	79.78	0.22
NH-Blacks	79.26	0.24	79.14	0.32	79.34	0.47	79.28	0.34
Poverty Status								
<100%	76.79	0.20	76.06	0.30	75.91	0.51	76.00	0.31
100-199%	78.93	0.15	77.25	0.26	76.65	0.32	77.05	0.27
200-399%	84.57	0.17	82.45	0.24	82.22	0.28	82.3	0.24
400+%	86.50	0.10	84.57	0.33	84.43	0.35	84.46	0.34
Uninsured/Medicaid/ /SCHIP: Yes	-	-	77.69	0.17	77.35	0.23	77.49	0.18