COMPENSATING FOR NONRESPONSE BIAS IN THE NATIONAL IMMUNIZATION SURVEY USING RESPONSE PROPENSITIES

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1 . Introduction

One goal of the Childhood Immunization Initiative[1] is to achieve a rate of 90% of being adequately vaccinated with four critical vaccines - diphtheria and tetanus toxoids and pertussis (DTP), poliovirus (polio), measles containing vaccine (MCV), and Haemophilus Influenzae type B (Hib). In the parlance of immunization research, the rate of being adequately vaccinated is referred to as the vaccination "coverage" rate.

To monitor progress toward achieving the vaccination coverage level goals and to assist the CDC in directing resources, the National Immunization Survey (NIS) was initiated in April 1994 to monitor National, State, and local vaccination coverage rates in the United States on an ongoing basis. The NIS covers 78 Immunization Action Plan (IAP) areas which include the 50 states, and 28 urban areas, including the District of Columbia. Each IAP area represents a stratum of the sampling design within which households are independently sampled. Within each IAP area, the design of the NIS includes 2 phases of sampling: a list-assisted random digit-dialing (RDD) telephone survey among households having children between the ages of 19 and 35 months followed by a mail survey of respondent identified vaccination providers of the age-eligible children. The mail survey is administered only to those providers for whom verbal consent is obtained from the survey respondent. A more detailed description of the sample design is given by Smith et al.,[2,3] Ezzati-Rice et al.,[4] and Zell et al.[5]

In the RDD sampling phase of the NIS, the interviewer asks to speak with the person in the sampled household who is the most knowledgeable about the vaccination histories of the household's children. This person is asked serve as the respondent for the RDD sampling phase and is asked to report their knowledge about the vaccination histories of the age-eligible children in the household. Also, information on the demographic and socio-economic characteristics of the household are obtained.

In 1994, vaccination coverage rates were estimated using household reported vaccination histories. In 1995, a study conducted by Ezzati-Rice et al.[6] revealed a low correlation between household reported vaccination histories and vaccination histories reported by children's vaccination providers, which were thought to be more reliable, particularly compared to households in which no written vaccination histories were kept. As a result, in 1995 NIS began to ask RDD respondents for consent to contact age-eligible children's vaccination providers to obtain provider reported vaccination histories. This practice has continued to date.

If verbal consent is obtained, the vaccination providers are mailed a questionnaire from which vaccination histories are obtained. It is important to understand that consent is not obtained from the parents/guardians of all sampled age-eligible children and that some providers either do not respond or do not provide adequate vaccination data that allows vaccination up-to-date status to be determined from provider records. Because of this, bias may be incurred in the estimated vaccination coverage rates, if the estimates are prepared using data from children for whom adequate provider vaccination histories are available, only, and without adjusting for differences between these children and children for whom inadequate or no vaccination data are obtained from providers. The purpose of this paper is to describe statistical methods that are being used to adjust vaccination coverage rates for these differences and to evaluate the extent to which the adjusted estimates reduce "provider reported vaccination history nonresponse" bias in the NIS.

2. Background

In 1998, adequate provider data was obtained from 67% of all children for whom completed NIS RDD interviews were obtained.

Data obtained from sampled children with adequate provider data includes data indicating whether the sampled children received a sufficient number of doses so as to be considered up-to-date with respect to vaccination recommendations for DTP, polio, MCV, and Hib. A child is said to be "4:3:1:3" up-to-date provided he/she has received 4 or more doses of DTP, 3 or more doses of polio, 1 or more doses of MCV and 1 or more doses of Hib. Empirical results suggest that sampled children for whom vaccination histories are obtained have characteristics that are associated with a greater

likelihood of being up-to-date for the 4:3:1:3 vaccination series, as compared to sampled children for whom vaccination histories are not obtained. These results indicate that children whose providers give adequate vaccination histories are more likely to live in households that have higher total incomes, more likely to have a white mother, and more likely to live outside of a central city of a Metropolitan Statistical Area. These factors are known to be associated with higher vaccination rates. Also, children whose providers do not give adequate vaccination histories are less likely to live in the same state as the one in which they were born and less likely to come from a household where the respondent could locate a written record (shot card) of the child's vaccination history.

As a consequence, estimates of vaccination coverage that are not adjusted for these differences may be high, and mislead immunization program managers about the success of their efforts to increase vaccination coverage rates and maintain them above levels required to eradicate disease.

In Section 3, we sketch how the RDD phase sampling weights are determined and describe the rationale and give details about how first phase sampling weights are adjusted to obtain coverage estimates that reduce "provider reported vaccination history nonresponse" bias. These methods are based on grouping sampled children into adjustment cells according to the similarity of their response propensities to have a provider reported vaccination history. In an econometric application, David et al.[7] describe the use of adjustment cells based on the use of response propensities. Little[8] describes how nonresponse bias can be reduced by using response propensities to form adjustment cells. Also, Yansaneh and Eltinge[9] and Eltinge and Yansaneh[10] described methods for assessing the extent to which adjustment cells should be formed using response propensities. In Section 5, we summarize Eltinge and Yansaneh's methods.

In Section 6, we apply these methods to data obtained from the 1998 NIS to illustrate their use. Specifically, we show the extent to which unadjusted estimates may be biased for the NIS coverage rates and how these rates' bias may be reduced.

3. The RDD Phase Sampling Weights

For children sampled in the RDD phase of the NIS, sampling weights have been developed that account for:

• the selection probability of a telephone number within an IAP area,

• unit nonresponse arising from telephone numbers with an unresolved residential status,

• unit nonresponse arising from residential sample telephone numbers where the presence of age-eligible children is never determined,

• unit nonresponse attributable to incomplete household interviews among households with age-eligible children, and

• multiple telephone numbers within households with age-eligible,

In this paper, we refer to these weights as RDD phase sampling weights.

Also, using NHIS data, RDD phase sampling weights have been adjusted to account for expected differences between eligible households with telephones and eligible households without telephones with respect to immunization coverage rates. Frankel et al.[11], Hoaglin and Battaglia[12], and Battaglia et al.[13] give details for this specific adjustment. Finally, within each IAP area the RDD phase sampling weights have been adjusted using poststratification to published totals according to race/ethnicity of the mother, educational status of the mother, and age of the age-eligible child.

In the next section we describe the statistical methodology used to adjust these sampling weights further for nonresponse attributable to failure to obtain adequate provider data that is required to ascertain vaccination status.

4. Adjustment for Vaccination History Nonresponse Bias Using Response Propensities

The NIS statistical estimation methodology implemented in 1998 has been designed specifically to adjust estimated coverage estimates for "provider reported vaccination history nonresponse bias" using adjustment cells formed using estimated response propensities. Smith[2] and Zell[5] describe the statistical methods that were used prior to 1998 to obtain official estimates of vaccination coverage rates. For the NIS, estimated response propensities are the predicted probabilities obtained from an estimated logistic regression model that uses a binary response variable indicating whether or not a child has adequate provider data.

Within each IAP area, the methods achieve this by grouping sampled children into adjustment cells according to the similarity of their response propensities to have a provider reported vaccination history.

A group of children who have similar estimated response propensities will also be similar with respect to the background variables that are predictive for this factor. In this important respect, children within each adjustment cell are comparable. Because of this, all of the sampled children in the cell may be represented fairly by the sampled children within the cell who have adequate provider reported immunization histories. In particular, by dividing the RDD phase sampling weights of children with adequate provider data by the cell's weighted response rate, these childrens' weights are adjusted to represent all of the children belonging to the cell. As a result, statistical analyses may proceed using data from children with adequate provider data, only, along with their adjusted RDD phase sample weights. A consequence of this is that the bias in estimated vaccination coverage rates attributable to differences in up–to–date status between sampled children who have and do not have adequate provider data is reduced. The effectiveness of this approach toward achieving bias reduction depends upon whether missingness of provider reported vaccination histories is a function of the histories. Lacking data to assess this, we will make this assumption in this paper.

As a first step in forming adjustment cells, a national response propensity model was developed using logistic regression. Within each IAP area, sampling weights were rescaled to add to the IAP area specific sample size by multiplying each weight by the unweighted sample size within the IAP area and dividing by the sum of the weights within the IAP area.

As candidates for predictors to the response propensity logistic model, we used variables that have been found to be associated with immunization status in other research conducted by Coronado et al.[14] Forward stepwise logistic regression was used to select predictors among these candidates.

At each step of the stepwise selection process, the logistic regression examined all possible and allowable second order interactions between predictors. Also, at each step after adding regressors to the model, the model selection method reexamined each regressor included in the model to determine whether any predictor entered at a previous step of the process could be dropped. Akaike's AIC statistic[15] was used as the criterion by which the optimal set of candidate regressors was chosen or retained at each step of the process.

Using the final model obtained from the variable selection process, predicted response propensities were obtained for each of the 32,510 children sampled in 1998 with completed NIS RDD interviews. Within each IAP area, adjustment cells were formed, the boundaries of which were defined by quantiles of the distribution of the predicted response propensities of children belonging the IAP area. Within each IAP area, each child was assigned to one of the IAP area-specific adjustment cells. Within each of these cells, the RDD phase sampling weights of children with adequate provider data were divided by their adjustment cell's specific weighted response rate to obtain revised weights. In 1998, 21,827 children had adequate provider data and received revised weights.

4.1 Raking to Control Bias and to Maintain the Adjustment

By dividing the RDD phase sampling weights of children who have provider reported immunization histories by their adjustment cell specific weighted response rate, these children represent all of the children in the cell as a whole.

However, the revised weights may not match poststratification totals used to construct RDD phase sampling weights. Also. the revised weights may not match the RDD phase sample weighted totals of other variables that are known to be important predictors of being up-to-date.

To reduce bias attributable to these differences, we raked the revised weights to match post-stratification totals, outcome predictor totals, and other variable totals. Equally as important, we raked on the adjustment cell specific RDD phase sampling weight totals to maintain the effect of the nonresponse adjustment.

5. Choosing the Number of Adjustment Cells

Yansaneh and Eltinge[16] and Eltinge and Yansaneh[17] have described methods for choosing the number of adjustment cells for the purposes of bias reduction for the case where cells are constructed using response propensities. For the NIS data this method proceeds in a sequence of stages within each IAP area.

At stage k, k = 1, . . . , the estimated vaccination rate $\overline{Y}_k$ obtained by using k adjustment cells is compared to the estimated rate $\overline{Y}_{k-1}$ obtained by using k - 1 adjustment cells. Note that $\overline{Y}_1$ is the estimated rate that is unadjusted for nonresponse bias.

The estimated incremental bias reduction obtained by increasing the number of adjustment cells from k - 1 to k is

$$\hat{\Delta}_k = \hat{\bar{Y}}_k - \hat{\bar{Y}}_{k-1}$$

and the estimated standard error of the estimated bias is

$$\hat{\sigma}(\hat{\Delta}_k) = \left[\hat{V}(\hat{\bar{Y}}_k) + \hat{V}(\hat{\bar{Y}}_{k-1}) - 2\hat{C}(\hat{\bar{Y}}_k, \hat{\bar{Y}}_{k-1})\right]^{1/2}$$

We estimate this quantity using a Taylor linearization to the estimated variance.[18]

As discussed in Section 1, estimates of vaccination coverage that are not adjusted for provider vaccination history may be high. Because of this, we are particularly interested in estimates $\bar{Y}_k$ that yield negative values of $\hat{\Delta}_k$ which measures the extent to which the estimate corrects the positive bias by using one more adjustment cell. Because of this, we compute 1-sided p-values

$$p_k = \Phi\left(\frac{\Delta_k}{\sigma(\Delta_k)}\right)$$

to evaluate the significance of the incremental bias correction for each value of k. Here, $\Phi(\cdot)$ denotes the cumulative standard normal distribution function. We define the "best " value of k as the smallest value k' such that $p_l < 0.05$ $l = 2, \ldots,$ k' and $p_{k'+1} > 0.05$.

6. An Application of the Sequential Method to Data Obtained from the 1998 NIS

Table 1 gives an example of the strategy of selecting best value of k for the 4:3:1:3 series for Illinois-Rest of State (i.e., Illinois, excluding the City of Chicago). This table shows that a statistically significant reduction in bias can be accrued by using 2 adjustment cells and that no further significant reduction in bias is obtained by using 3 or more adjustment cells. Overall, in going from no adjustment to 2 adjustment cells, bias is reduced by 0.5%.

The "best" choice of the k was determined for each IAP area. These results showed a tendency for designating 2 or 3 adjustment cells formed using response propensities when a statistically significant decrease in bias reduction was possible. Also, these results showed that no adjustment was required for 57 of the 78 IAP areas in which case k = 1. Also, for the 1998 NIS, for states in which statistically significant bias reduction was possible, the decrease in bias from the unadjusted value was on the order of 0.5% indicating that the extent to which bias could be reduced using adjustment cells formed using response propensities was small.

Cochran[19] published an influential paper describing the use of stratification to control bias in observational studies. Empirical results of his investigation indicated that approximately 90% of the bias is reduced by using 5 strata. As a result of this empirical finding, a "lore" has been developed among statistical practitioners that indicates that "5" is a good choice for the number of strata required to reduce bias. Also, work conducted by Rosenbaum and Rubin[20] has been effective in showing the advantages of constructing these strata using response propensities.

In Table 2 results are given showing the estimated difference $\hat{\delta}$ in bias reduction between the estimated 4:3:1:3 coverage rate $\hat{\bar{Y}}_5$ obtained by using 5 adjustment cells within each stratum and the estimated rate obtained by using the "best" value of k in each State. In the production of estimates that are used for reporting official vaccination coverage rates, 5 adjustment cells formed using response propensities are used within each stratum. Results in Table 2 show that for the 1998 NIS data there are very few statistically significant differences in the bias reduction obtained using the "best" method of forming adjustment cells compared to using 5 adjustment cells formed using response propensities.

Table 1: IL-Rest of State: Nonresponse Adjusted Estimates $\bar{Y}_k$ of 4:3:1:3 Coverage, Estimated Bias Reduction Δ_k , statistical significance p_k Obtained by Using k Adjustment Cells: 1998 National Immunization Survey.

k	$\bar{Y}_k$	Δ_k	p_k
2	83.13	-0.5	0.03
3	82.73	-0.4	0.13
4	82.87	0.14	0.76
5	82.84	-0.03	0.46

Table 2. The estimated difference $\hat{\delta}$ in bias reduction between the estimated 4:3:1:3 coverage rate $\hat{\bar{Y}}_5$ obtained by using 5 adjustment cells within each stratum and the estimated rate obtained by using the "best" value of k in each State. The value p is the p-value measuring the statistical significance of $\hat{\delta}$. 1998 National Immunization Survey.

	$\bar{Y}_k$	$\hat{\delta}$	p
National	79.4	0.19	0.01
AK	80.72	-0.58	0.1
AL	82.14	0.02	0.95
AR	73.16	0.03	0.91
AZ	76.04	0.19	0.55
CA	75.77	-0.08	0.79
CO	75.79	-0.04	0.9
CT	89.47	-0.57	0.15
DC	71.76	0.33	0.61
DE	78.82	-0.12	0.69
FL	78.56	-0.09	0.75
GA	80.28	0.19	0.51
HI	79.59	0.31	0.27
IA	81.64	-0.02	0.84
ID	76.82	0.38	0.25
IL	77.97	0.46	0.13
IN	77.93	0.43	0.23
KS	82.09	0.33	0.12
KY	81.56	0.01	0.97
LA	78.89	0.53	0.17
MA	86.6	-0.1	0.64
MD	76.95	-0.07	0.8
ME	86.36	0.02	0.95
MI	77.96	0.23	0.61
MN	82.27	0.11	0.74
MO	84.07	-0.48	0.37
MS	83.9	0.21	0.37
MT	81.88	-0.04	0.81
NC	82.77	-0.03	0.85
ND	79.58	0.53	0.08
NE	76.55	0.14	0.61
NH	82.26	0.07	0.85
NJ	82.7	0.42	0.2
NM	71.91	0.81	0.26
NV	76.39	0.67	0.24
NY	84.93	0.39	0.22
OH	77.91	-0.12	0.82
OK	77.15	1.88	0.02
OR	76.19	0.66	0.17
PA	83.36	0.19	0.23
RI	86.16	-0.15	0.37
SC	88.09	0.21	0.63
SD	73.52	0.05	0.85
TN	81.46	0.01	0.96
TX	74.94	0.64	0.03
UT	75.83	0.19	0.47
VA	80.92	0.5	0.17
VT	85.47	-0.29	0.3
WA	81.18	0.34	0.36
WI	77.83	0.09	0.51
WV	82.46	0.08	0.77
WY	80.2	0.27	0.42

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