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Within-Household Sampling of Multiple Target Groups in Computer-Assisted Telephone Surveys

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Abstract: Random digit dialing (RDD) telephone samples provide a cost-effective mechanism for surveying the populations of countries in which the rate of telephone ownership is high. Two-stage sampling designs are often used to improve the efficiency of RDD samples of households. This paper discusses efficient methods for achieving target sample sizes in subsequent stages of the sampling design when the ultimate sampling units are household members belonging to disjoint domains.

Key words: Random digit dialing; computer-assisted telephone interviewing; multi-stage sampling; domain estimates; sample weighting.

1. Introduction

Telephone interviews are commonly used in the United States (and other countries with a high level of telephone ownership) because they have proved an efficient way to interview the general public. The questionnaires used in such interviews are often programmed to appear on computer screens in front of the interviewers, who key in the responses as the interviews are conducted. This process is referred to as computer-assisted telephone interviewing (CATI).

The use of the computer in telephone interviewing provides an opportunity for implementing real-time sampling algorithms. For example, the computer can be programmed to select a sample person using a prespecified algorithm as soon as the roster of family members has been completed. The sampling methods described in this paper concern real-time sampling of household members for computer-assisted telephone interviews in which mutually exclusive target groups (e.g., distinct age groups) are to be surveyed.

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This paper discusses two methods for using computers to vary within-household sampling rates during CATI surveys. One method allows the sampling rates to be changed at any time, as long as the sampling rate currently in effect is recorded in the CATI record for each sample member. This method is called the *continual adjustment method* because it allows the sampling rates to be changed for the remaining sample whenever needed. (This sampling method was discussed briefly by Dutka and Frankel (1980).)

The other method partitions the sample into probability subsamples and sets fixed (but possibly different) sampling rates for each subsample. The sampling rates for each subsample remain constant throughout data collection. To obtain multiple sampling rates, the subsamples are processed in waves (e.g., every two weeks) and appropriate rates are set for each wave as processing begins. This method is called the *incremental adjustment method* because it only allows new sampling rates to be introduced when processing begins for a new subsample.

The Research Triangle Institute (RTI) used the continual adjustment method for a survey conducted for the Corporation for Public Broadcasting (CPB) in 1985 (Burkheimer et al. (1986)). The CPB study is used in Section 2 to illustrate the continual adjustment method for efficiently achieving target sample sizes for mutually exclusive domains. Procedures for implementing the incremental adjustment method are then developed in Section 3. Sample weighting procedures for the two sampling methods are compared in Section 4. In the concluding section, the relative advantages of the two real-time sampling methods are compared, and recommendations are provided for any future studies that survey mutually exclusive target groups.

2. The Continual Adjustment Method

The primary objectives of the CPB study were to determine (1) the types of learning resources used in homes in the United States and (2) the reasons particular learning resources were preferred over others. Because the types of learning activities in which people are involved vary greatly with age, separate questionnaires were used for each of four age groups. Target sample sizes were established for the age groups as follows:

Target sample size	Age group
1 800	2- to 5-year-olds,
900	6- to 11-year-olds,
450	12- to 17-year-olds,
1 350	Adults

Proxy interviews with parents were conducted for children aged 2 to 17.

A multi-stage probability sampling design was implemented. The two-stage Mitofsky-Waksberg design was used to select an equal-probability sample of telephone households in the 48 coterminous states of the United States (Waksberg (1978)). Telephone numbers in the United States consist of 10 digits: a 3-digit NPA or area code, a 3-digit NXX or exchange code, and 4 terminal digits. The first-stage sampling units (FSUs) were clusters of housing units having residential telephone numbers with the same leading eight digits (NPA, NXX, and next two digits). The FSUs were selected with probabilities proportional to size (PPS), where the size of an FSU was the number of residences contained in the FSU. At the second stage, 21 sample households were selected at random with replacement within each sample FSU. This two-stage design decreased survey costs with minimal loss of precision relative to a simple random sample of telephone numbers by increasing the proportion of the sample telephone numbers that were residences from ment to guarantee that we could achieve the requisite sample size, 21 households, within each cluster. The only additional effort relative to sampling without replacement was to around 20 % to about 50 %. We chose to select the second-stage sample *with* replace-

Table 1. Overall sampling rates for the CPB study

Age group	Desired sample sizes	1980 population prevalences[1]	Overall sampling rate[2] (%)	Relative sampling rate[3] (%)
2-5	1 800	12 707 696	0.014	100.0
6-11	900	20 834 439	0.004	30.5
12-17	450	23 409 576	0.002	13.6
Adults (18+)	1 350	162 790 845	0.001	5.9

[1] Based on 1980 Decennial Census data from:
1980 Census of Population, Volume 1: Characteristics of the Population (1983): Chapter B: General Population Characteristics, Part 1: United States Summary. U.S. Census Bureau Publication PC80-1-B1. U.S. Government Printing Office, Washington, D.C.
[2] Ratio of the desired sample size divided by the population prevalence.
[3] Ratio of overall sampling rate for the age group divided by that for 2- to 5-year olds.

program the CATI software to record the occurrence of multiple selections.

The second-stage sample size, 21 households, seems large until we consider the sampling rates and prevalences of the target age groups. As shown in Table 1, the overall sampling rate for 2- to 5-year-olds was considerably greater than that for any other age group. Hence, the survey was designed to yield the required number of 2- to 5-year-olds by selecting one from every household containing a member of the age group. Households were subsampled for representing the other age groups. When a household was selected to represent an age group, one member of the age group was selected at random from the household roster. Because about 12 to 13 % of all households contained a 2- to 5-year-old, the average number of sampled age-group members per FSU was about 2.5 for 2- to 5-year-olds and less than 2.0 for the other age groups. Thus, the second-stage sample size was not unusually large for any of the four age groups.

The unequal weighting effects resulting from selecting one sample subject from the age-eligible members of selected households (for age groups other than 2- to 5-year-olds) were minimized by selecting households for the age-group samples with probabilities proportional to the numbers of age-group members in each household. In particular, the jth household was selected into the sample for the ith age-group with probability

$$P(i,j) = \text{Min}\,\{1\,,\, S(i,j)\, R(i)\}, \qquad (1)$$

where $S(i,j)$ is the number of members of the ith age group in the jth household and $R(i)$ is the sampling rate for the ith age group.

The age-group sampling rates, $R(i)$, were initially set at 23.12 % for 6- to 11-year-olds, 11.82 % for 12- to 17-year-olds, and 4.46 % for adults. To predict accurately the number of respondents for any age group – given any fixed number of sample households and age-group sampling rates – the statistician would need to know the response rate for household rostering, the household-prevalence of each age group, and the response rates for age-group-specific interviews. The initially expected household-prevalences and response rates for the target age groups are shown in Table 2 along with the rates actually obtained in the CPB study. The anticipated rates of occurence of the age groups in rostered households were very close to the realized rates. However, the marginal response rates for the younger age groups were higher than expected. Apparently, parents were more willing to discuss their children's learning activities than their own.

Knowing that age-group prevalences and response rates could not be predicted accu-

Table 2. Comparison of initially projected and obtained rates

Rate estimated	Projected rate (%)	Obtained rate[1] (%)
Primary household identification rate	22	18.7
Secondary household identification rate	58	48.0
Household rostering rate	88	89.2
Household inclusion rates for:		
2- to 5-year-olds	12	13.0
6- to 11-year-olds	18	16.9
12- to 17-year-olds	20	19.3
Adults (18+)	100	99.9
Interview rates for:		
2- to 5-year-olds	77	95.9
6- to 11-year olds	77	91.3
12- to 17-year-olds	77	90.5
Adults (18+)	77	76.0

[1] Based on the with-replacement sample yields.

Table 3. Age-specific sampling rates, R(i), used throughout the CPB study

Time during which rate was effective	Age group			
	2–5	6–11	12–17	18+
1985 February 12 – 26[1]	1	0.2314	0.2361	0.0298
1985 February 26 – April 8	1	0.2312	0.1182	0.0446
1985 April 8 – May 3	1	0.3616	0.1393	0.0706
1985 May 3 – June 23	1	0.3782	0.1273	0.0828

[1] Prior to February 26, 1985 the survey was designed to yield 900 unique respondents for the 2- to 5-year-old age group and 450 for each of the other age groups. The sampling rates in effect from February 26, 1985 through April 8, 1985 are discussed as the initial sampling rates in this paper because they are the rates implemented when the target sample sizes were revised to the sample sizes shown in Table 1.

rately, RTI designed the CATI software to allow for modification of the age-group sampling rates, $R(i)$, and for storage of the actual rate used for each sample member for sample weighting. The sampling rates were changed three times during 4.5 months of survey operations, as shown in Table 3. None of the sampling rates was changed by more than a factor of three. However, these modifications to the sampling rates enabled RTI to efficiently achieve the targeted number of respondents for each age group.

3. The Incremental Adjustment Method

As noted earlier, the incremental adjustment method partitions the sample into probability subsamples and sets fixed sampling rates for each subsample. The sampling rates for each subsample remain constant throughout data collection. This design is easily implemented for a single-stage random sample of telephone numbers. However, the sequential nature of the first stage of the Mitofsky-Waksberg sampling design can also be exploited to efficiently implement the incremental adjustment method.

In a classical application of the Mitofsky-Waksberg sampling method, a sample of n_1 FSUs is selected by: (1) randomly generating a large number of telephone numbers for the first-stage sample; (2) randomly ordering these telephone numbers; (3) fielding the first n_1 numbers; and (4) replacing each number identified as a nonhousehold with the next number on the list until n_1 households have been identified. The sample can be implemented efficiently in waves by defining the waves as simple random subsamples chosen without replacement from the telephone numbers generated for first-stage sampling.

Whenever processing begins for a new wave of telephone numbers, the experience from the previous waves is used to set the respondent selection rates for the new wave. Once established, the respondent selection rates for a wave are used without change throughout the remainder of the survey.

4. Sample Weighting Procedures

The critical difference between the two sampling methods is that unconditional probabilities of selection can be computed with the incremental adjustment method, but only conditional probabilities of selection can be computed with the continual adjustment method.

The sampling weights used to analyze the CPB data were based on probabilities of selection that were conditional on each household's date of rostering, which is consistent with the recommendations of Dutka and Frankel (1980). The weight component corresponding to the third stage of sampling was the reciprocal of the third-stage sampling rate given by Equation (1), using the $R(i)$ factors shown in Table 3, which were stored in each individual's CATI record. Unconditional probabilities of selection could not be computed because the subsamples to which the different sampling rates were applied were haphazardly determined samples rather than probability subsamples.

Conditioning on the date of rostering is intuitively undesirable. Nevertheless, given the standard assumption that the population characteristics being observed are constant during the period of data collection, such conditioning does not lead to biased results. Sample survey theory typically assumes that a finite population of elements is sampled and that the characteristics of the population are fixed constants, not random variables. However, the conditional weights do result in loss of efficiency because of additional variability in sampling weights. This additional variability would not occur if unconditional probabilities of selection could be calculated.

For the CPB study, the loss of precision caused by varying the sampling rates and using conditional probabilities of selection can be quantified by the design effect component for unequal weighting. The design effect for a statistic is the ratio of the variance achieved for that statistic divided by the variance that would have been achieved by a simple random sample of the same size. The design effect component due to varying the sampling rates can be computed for the ith age group as

$$d_g = n \sum_{i=1}^{n} [W(i)]^2 / [\sum_{i=1}^{n} W(i)]^2, \tag{2}$$

where n is the sample size achieved for age group g, and $W(i)$ is the reciprocal of the sampling rate, $R(i)$, that was in effect for the ith sample subject. These unequal weighting design effects were computed to be 1.07, 1.02, and 1.10 for the 6 to 11, 12 to 17, and adult age groups, respectively. These design effects are not large, indicating that the loss of precision was a minor price to pay for efficiently achieving the desired sample sizes.

In contrast to the CPB study's continual adjustment method, when the incremental adjustment method is used, unconditional probabilities of selection can be computed. Because each wave is a simple random subsample of a simple random sample of telephone numbers, the probability of selection into each wave can be calculated for every sample household.

For example, if w indexes the sample waves, then the probability that a given sample household belongs to wave w can be calculated as:

$$P(w) = n(w) \,/\, n(+), \tag{3}$$

where $n(w)$ is the number of telephone numbers assigned to the wave w sample and $n(+)$ is the total number of telephone numbers in the first-stage sample. Thus, if $P(i,j|w)$ is the selection probability for the ith age group in the jth household, given that the jth household was selected into the wave w sample, then the unconditional probability of selecting the jth household to contribute a sample member for the ith age group is

$$P(i,j) = \sum_{w=1}^{W} P(w)\, P(i,j|w). \tag{4}$$

Irrespective of the wave to which the jth household actually belongs, the unconditional third-stage selection probability given by Equation (4) can be used to weight the responses when the jth household is selected to contribute a member to the sample for the ith age group. Using these unconditional selection probabilities for sample weighting reduces the variability in sampling weights and increases the efficiency of parameter estimates.

5. Conclusions and Recommendations

As stated previously, the computers used for CATI provide the opportunity to implement real-time sampling algorithms. This capability, in turn, enables fine-tuning respondent selection rates as a survey progresses. This opportunity to adjust within-household sampling rates is important because the Mitofsky-Waksberg RDD sampling design fixes only the number of sample households. The numbers of respondents achieved for various target groups are random variables whose outcomes cannot always be predicted accurately before data collection begins. Nevertheless, target sample sizes can be achieved efficiently using either of the sampling methods discussed in this paper. These methods are recommended for CATI interviews of mutually exclusive target groups of people contacted in RDD surveys of telephone households.

The incremental adjustment method should be used whenever it is operationally feasible so that the sampling weights can be based on unconditional probabilities of selection. Use of unconditional probabilities of selection can increase precision by reducing unequal weighting effects. However, use of the continual adjustment method should not be precluded just because the sampling weights depend on conditional probabilities of selection. As previously noted, this does not lead to bias under the standard assumption that the population characteristics observed are constant during the period of data collection.

The primary disadvantage of the incremental adjustment method is that the sample must be processed in waves to adjust the sampling rates, which may not be possible when the data collection period is short. In other cases, the incremental adjustment method may not be sufficiently flexible to achieve the target sample sizes. Whenever the incremental adjustment method is operationally feasible, it is the preferred procedure. In retrospect, the incremental adjustment method may have been preferable for the CPB study.

6. References

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