# BIAS IN LIST-ASSISTED TELEPHONE SAMPLES

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Key Words: Random Digit Dialing, Coverage Error, Truncated Sample Design

## Introduction

The percentage of households with telephones in the United States has increased over the last thirty years and approximately 94 percent of all persons now live in such households. As a result of this increased level of telephone coverage, there is less potential for bias in estimates from telephone surveys on most subjects and surveys conducted by telephone are quite attractive. Several different methods have been developed to select random samples of telephone households. The Mitofsky-Waksberg method of random digit dialing (RDD) is the best known and probably most widely used of the methods. Waksberg (1978) describes this method in some detail, pointing out that the key attribute is that it provides a self-weighting sample of all telephone households while substantially reducing the proportion of nonresidential telephone numbers that have to be dialed below the amounts needed with simple random or systematic sampling.

Despite its utility, the Mitofsky-Waksberg method does have some undesirable features. It is a two-stage sample. The first stage consists of clusters of telephone numbers (or 100-banks) defined as sets of numbers with the same first 8 digits of the 10-digit telephone number. If a randomly sampled number in the cluster is residential, then the cluster is retained in the sample. Otherwise, the cluster is rejected. The second stage is the sampling of telephone numbers within the retained 100-banks. A fixed number of residential telephone numbers must be contacted in each retained 100-bank in order for the sample to be self-weighting. One, often minor, disadvantage of the method is the variance increase associated with the clustering of the sample in banks of telephone numbers.

The sequential nature of the second stage sampling, however, is a very troublesome feature of the Mitofsky-Waksberg method. Resources must be devoted to monitor the sample yield in each cluster to make sure that the fixed number of households is interviewed in each cluster. This makes it difficult to complete data collection on a tight time schedule since the decision on when to work additional telephone numbers in the cluster is dependent on the yield in the cluster. Many telephone calls at different times may have to be made to some telephone numbers to determine if the number is residential. If a larger sample is selected and worked any excess completed interviews in a cluster must be dropped. Several modifications of the Mitofsky-Waksberg method have attempted to eliminate the sequential nature of the method (Pothoff, 1987 and Brick and Waksberg, 1991), but these methods also have limitations.

A different approach to RDD that also avoids a great number of unproductive calls to nonworking or nonresidential numbers, but eliminates many of the disadvantages of the Mitofsky-Waksberg method is referred to as list-assisted sampling. A variety of procedures falling into this category are described by Lepkowski (1988). Some of these methods have been used by market research companies and in other commercial surveys for many years, but their use in nationally representative surveys for government agencies has been very limited because most either exclude relatively large portions of the sample or are not probability samples.

This paper considers the potential coverage bias associated with a particular method of list-assisted sampling consisting of a truncated sample design. The procedure first defines 100-banks in the same way as Mitofsky-Waksberg. A simple random sample of telephone numbers is selected from all telephone numbers that are in 100-banks in which there is at least one White Page directory listed telephone number. Telephone numbers in 100-banks with no listed telephone numbers are not sampled. The percentage of calls to residential numbers is almost as great as with the Mitofsky-Waksberg method. However, a coverage bias arises because households in the 100-banks without listed numbers have no chance of being included in the sample. This list-assisted sampling method is discussed at some length by Casady and Lepkowski (1993).

The two key determinants of coverage bias are the proportion of households which are not eligible for the sample and the differences in the characteristics of the covered and not covered populations. This research addresses primarily the first question, but some of the differences in characteristics, as well as conclusions about the utility of the truncated design are presented.

## Coverage in the Truncated Sample Design

The method of list-assisted RDD sampling we examined involves dividing the entire frame of

telephone numbers from the Bellcore file[1] into two strata. The first stratum consists of all telephone numbers in 100-banks that have at least one listed residential telephone number. This stratum is called the listed stratum. Despite the nomenclature, it should be recognized that this stratum includes both listed and unlisted telephone numbers. The second stratum is the zero-listed stratum, containing telephone numbers in 100-banks that have no listed, residential telephone numbers.

A key aspect of this process is the stratification of 100-banks into the listed and zero-listed strata. Approximately 70 percent of all telephone households in the U.S. are classified as listed. The proportion of households in 100-banks in the listed stratum is much higher, as discussed later. The primary source for the classification is the compilation of data from the White Pages which is then supplemented by records from secondary sources such as state automotive registrations, driver's license data, voter registrations, birth records, and other proprietary data files. There are several firms that provide this information on a commercial basis. We used the GENESYS Sampling System. GENESYS utilizes the Donnelley Listed Household Database (DQI[2]) for the stratification of 100-banks (GENESYS, 1994). Other suppliers also base their classification on the White Pages but may have different supplemental sources. Since we used only one system, we cannot evaluate the generality of our results to these other systems.

If a telephone sample is selected only from the listed stratum, then the proportion of nonresidential telephone numbers that have to be dialed is drastically reduced. The September 1993 Bellcore file contained 453 million telephone numbers[2], but only 179 million, or less than 40 percent, were in the listed stratum. The exclusion of the 60 percent of telephone numbers in the zero-listed stratum makes the list-assisted method very efficient. Furthermore, the sample can be selected in a single stage using equal probability sampling methods that don't require clustering.

The benefits of sampling only in the listed stratum must be weighed against the coverage bias introduced by the method. The coverage bias is the expected difference between the estimates from such a truncated sample and the estimates from the universe of all telephone numbers. The proportion of households excluded from the sample is a key factor in the assessment of the potential coverage bias of the list-assisted method.

Connor and Herringa (1992) addressed this issue by using data collected in a previously conducted survey done using the Mitofsky-Waksberg method. They estimated that 3.4 percent of all residential telephone numbers were in the zero-listed stratum. They also noted the estimates were partially dependent on the elapsed time between the conduct of the study and the development of the frame for the listed stratum. Tucker, Casady, and Lepkowski (1993) used a more direct approach of sampling the zero-listed stratum to estimate the proportion of households contained therein, but their efforts were based on 10-banks rather than 100-banks and used different strata definitions.

We replicated the approach of the Connor and Herringa study using two national samples conducted by Westat in 1993. Both of the Westat studies used a modified version of the Mitofsky-Waksberg method of RDD sampling (Brick and Waksberg, 1991). Using procedures similar to Connor and Herringa, we estimated the percentage of telephone households in the zero-listed stratum was over 6 percent for an education study and less than 4 percent for a study on Veterans. The large difference in these estimates of undercoverage motivated us to conduct a more direct study of the percentage of households in the zero-listed stratum.

Westat, Inc. and GENESYS Sampling Systems collaborated to directly estimate the proportion of telephone households in the zero-listed stratum. A single-stage, *epsem* sample of 10,000 telephone numbers was sampled from the zero-listed stratum using the GENESYS Sampling System. Westat staff dialed the sampled telephone numbers to determine which were residential.

Of the 10,000 sampled telephone numbers, only 135 were found to be residential for a residential hit rate in the zero-listed stratum of 1.4 percent. This estimate along with estimates of the residential hit rate in the listed stratum and the proportion of telephone numbers in each stratum, can be used to estimate the percentage of households[3] in the zero-listed stratum. The estimated percentage of households that are in the zero-listed stratum is given by:

$$\hat{P}_z = 100 \frac{h_z W_z}{h_z W_z + h_l (1 - W_z)} \qquad (1)$$

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1 The numbers in the Bellcore frame that fall into categories that are not available for general residential usage, such as 800 numbers and cellular telephones, were excluded. The exclusion of these numbers is done for virtually all RDD samples, irrespective of the sampling method.

2 As noted earlier, this includes only those exchanges that are available for general residential usage, in particular Types '00' and '52'.

3 We used the terms 'household' and 'residential telephone number' interchangeably, although there is a difference. A household may have more than one telephone number and some or all of these numbers may be nonbusiness use.

where $h_z$ is the estimated proportion of residential telephone numbers in the zero-listed stratum (1.35%), $h_l$ is the estimated proportion of residential telephone numbers in the listed stratum (54% based on other studies), and $W_z$ is the proportion of telephone numbers in the zero listed stratum (60.5%).

Using these values, we estimated that 3.7 percent of all telephone households are not covered when the sample is restricted to the listed stratum. An approximate 95 percent confidence interval is from 3.0 percent to 4.3 percent. Three of the four studies (the direct dialing of the zero-listed bank, the estimate reported by Connor and Herringa (1992), and one of the two 1993 studies described above) are in this estimated range. Thus, we are fairly confident that only 3.0 to 4.3 percent of all telephone households are in the zero-listed stratum. Table 1 summarizes the findings from these studies with respect to the percentage of telephone households in the zero-listed stratum.

Table 1. Estimated percentage of telephone households in 100-banks with no listed telephone numbers

| Study | Estimated percentage | Sample size* |
|---|---|---|
| Direct dialing in zero-listed stratum | 3.7% | 10,000 |
| Connor and Herringa (1992) | 3.4% | 4,243 |
| Westat education study | 6.5% | 10,167 |
| Westat Veteran study | 3.5% | 5,708 |

*The sample size for the studies is the number of telephone numbers dialed from the zero-listed stratum.

In the three studies that classified the sample selected by the Mitofsky-Waksberg procedure as being in or out of the zero-listed stratum, two different methods can be used to estimate the percent of households in the zero-listed stratum. One method is to estimate the percentage of all the residential prime numbers (the first stage numbers in the Mitofsky-Waksberg scheme) which are in the zero-listed stratum. This method was used to produce the estimates in Table 1. The second method is to compute the estimates from all sample cases in the survey, both the primary and secondary numbers. It is important to note that with the first method we estimate the percentage of households and with the second method we estimate the percentage of persons (households could be estimated but would have required additional estimation procedures). In the three studies for which both methods are appropriate (all but the direct dialing of the zero-listed stratum), the estimates of the percentage of persons in the zero-listed stratum are lower than the estimates of the percentage of households using the prime numbers.

The difference can be partially explained by the estimation procedures used. In the modified Mitofsky-Waksberg scheme, the weights assigned to each case depend on the number of residential telephone numbers in the sampled cluster. The weights are generally truncated if the weight would be very large (three times the average weight), see Brick and Waksberg (1991). Since the zero-listed clusters have generally fewer residential telephone numbers, truncation is more frequently applied. We estimate the truncation could bias the estimates down by as much as one percent.

Other factors also contribute to the differences between the methods. Of course, there is a difference between households and persons. In addition nonresponse bias, weighting adjustments, and differences in the screened and eligible populations for one of the studies are potential reasons for the differences. It is interesting to note that the education survey which had the highest estimate of the percent in the zero-listed stratum shows the most significant differences by the two methods. The 6.5 percent reported in Table 1 is approximately halved using the second method.

## Characteristics of the Uncovered Population

While we have a reliable estimate of the percentage of excluded telephone households using the truncated design, this is only one of the two quantities needed to estimate the size of the bias. The other is an estimate of the difference between the characteristics in the listed and zero-listed stratum.

The relationship between these two quantities can be most easily seen by expressing the coverage bias of an estimate as:

$$Bias(\hat{y}_l) = P_z\{E(\hat{y}_l - \hat{y}_z)\}, \quad (2)$$

where $\hat{y}_l$ is the estimated characteristic based on the sample from the listed stratum only, $P_z$ is the proportion of households in the zero-listed stratum, $\hat{y}_z$ is the estimated characteristic based on the sample from the zero-listed stratum only, and $E$ is the expectation operator for averaging over all possible samples.

Even though we have a good estimate of $P_z$, it is still difficult to estimate the undercoverage bias because we do not have reliable estimates of characteristics from the zero-listed stratum. In our calls to the 10,000 telephone numbers in the zero-listed stratum, we did not collect any characteristics of the households and their members. Since the number of completed interviews was expected to be less than 150, the reliability of the results did not seem to warrant such an effort.

The three national studies from which the percent in the zero-listed stratum were estimated do provide limited estimates. Connor and Herringa (1992) gave estimates of some characteristics from their study which included 202 sampled persons from the zero-listed stratum. The Westat conducted survey about veterans included 102 persons from the zero-listed stratum. For the education survey conducted by Westat, the characteristics were only collected for persons between 3 years old through high school. In this study, a total of 948 children were from the zero-listed stratum.

The differences between the estimates in the two strata for all three studies were relatively small and generally not statistically significant. The age, sex, race and region distributions of the household members were not statistically different in any of the three studies. The differences by Hispanic origin were not statistically significant, but for all three studies the percentage of Hispanics was higher in the zero-listed stratum. The differences by education level of the members were not statistically significant but in all three studies the higher education persons were more likely to be in the listed stratum.

The distribution by urban and rural did differ for the education survey and it was not measured in the other two studies. Persons in rural areas, using a classification based on the household's ZIP Code and the 1990 Census of Population ZIP Code data, were under-represented in the listed stratum.

In addition to these demographic items, a few of the important substantive estimates from each of the studies were examined. There were virtually no statistically significant differences between the estimates from the zero-listed and the listed stratum. Importantly, differences for variables that are highly correlated with income, such as participation in Food Stamps, AFDC, and WIC were not statistically significant.

One possible reason for a 100-bank being in the zero-listed stratum is related to the opening of new banks (i.e., since the establishment of the most recent white page listings) by telephone companies and the assignment of new numbers to these banks. Assuming that persons who move will be more likely to be assigned to newly opened banks, it is reasonable to speculate that more mobile persons will be over-represented in the zero-listed stratum.

Two indirect measures were used to assess the mobility hypothesis. For the education survey, areas were classified by 1990 Census of Population data on the percentage of persons in the area who had moved in the previous 5 years. The estimates in the listed and zero-listed strata were not statistically different by this classification, but this is not unexpected because this is a relatively poor measure of mobility at the individual level.

The second indirect measure of mobility was a question about interruptions in telephone service that lasted more than 24 hours during the past 12 months in the veterans survey. While interruptions in telephone service happen for a variety of reasons related to economic conditions, changes in residences are also very highly related to this phenomenon. The estimates of the percentage of adults who experienced an interruption in the telephone service did differ by stratum. The adults with an interruption in service were under-represented in the listed stratum.

These results imply that although distributions in the two strata are not exactly the same, the differences are generally small. The lack of statistical significance for many of the characteristics is probably due to the small number of cases in the zero-listed stratum. The standard errors of the estimates are relatively large for most of the estimates from the zero-listed stratum. The standard errors of the estimates are also inflated because the samples are all clustered, and one of the variables being estimated (zero-listed or not) is a characteristic of the cluster.

As a way of illustrating the size of the bias, suppose that the difference in a characteristic in the two strata is quite pronounced. For example, let the percentage of persons in the zero listed stratum be 15 percent and the percentage of persons in the listed stratum be 5 percent. Applying equation (2) to these two estimates, letting $P_z$ =3.7 percent, the bias is only

-0.4 percent. In other words, instead of estimating 5.4 percent, the estimate from the listed stratum only is 5 percent.

The small differences in the estimates for the two strata are in sharp contrast with some other types of coverage bias. For example, the differences between the characteristics of households with and without telephones are generally very large. Thornberry and Massey (1988) present estimates for health characteristics and Brick, Burke, and West (1992) present similar estimates for education characteristics. The coverage biases associated with sampling only telephone households are in some cases fairly large, particularly when the estimates are highly correlated with socio-economic status. The coverage biases from excluding the zero-listed stratum appear to be small and not highly correlated with economic variables.

## Summary and Conclusion

The results from this research indicate that the truncated, list-assisted RDD sampling method is efficient and the estimates from the design are not subject to important coverage bias. We believe the design is a valuable addition to RDD methods.

The efficiency gains arise because:

- the single stage design eliminates the sequential nature of the Mitofsky-Waksberg design and makes it possible to field a survey more quickly and with less chance of error. Since more time is available for followup, higher response rates are also possible;
- no telephone numbers are selected from the 60 percent of the frame (the zero-listed stratum) for which the residential hit rate is very low (1.4%);
- the percent of sampled telephone numbers that are residential in the listed stratum (54%) is only slightly lower than the percent for the second stage in the Mitofsky-Waksberg method (about 60%); and
- an equal probability sample design can be used and there is no clustering effect so estimates are more precise than in clustered RDD designs.

These efficiency gains are probably particularly useful for organizations which do not specialize in conducting RDD telephone surveys. The operational requirements associated with properly conducting a survey with the Mitofsky-Waksberg necessitate trained operations and statistical staffs and well designed procedures. Westat has found that it is more cost efficient to use designs that avoid the sequential operations even if they result in decreases in the effective sample size of 10 to 15 percent (Brick and Waksberg, 1991). Rather than accept this loss, the truncated list-assisted design gives more precise estimates.

A major concern of some survey designers is that these efficiency gains are obtained by accepting large coverage biases. Our studies indicate that the coverage biases are fairly small. Only about 3 to 4 percent of all residential households are excluded in this design. Furthermore, the differences in characteristics between the two strata are relatively small and not highly correlated with socio-economic status.

It is simple, but misleading, to add the undercoverage due to households without telephones (5%) to the households in the zero-listed stratum (3.7%). The bias due to households without telephones is comparatively large and highly related to income and education. The additional bias due to excluding the zero-listed stratum is minor compared to the nontelephone household bias.

The list-assisted design should also be clearly differentiated from designs that only sample listed households. A number of studies have shown that listed households are very different from unlisted households and the estimates from listed households are subject to large biases. See Glasser and Metzger (1975), for example. However, the research on the truncated, list-assisted design shows that it does not have these problems.

We believe the truncated, list-assisted design is appropriate for large scale national surveys. Although it would be useful to have more evidence that the national results apply as well to surveys in smaller geographic areas, we believe the list-assisted design is likely to be useful for these studies because the differences in the estimates in the two strata are generally small.

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