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Dual Frame, Mixed Mode Survey Designs

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Abstract: Dual frame, mixed mode designs are described for household surveys in the United States. These combine traditional area probability sampling and face-to-face interviewing with telephone sampling and telephone interviewing. These designs offer cost savings of telephone interviewing while overcoming the coverage problems of sampling telephone households alone to study the full household population. The optimal allocation of resources to the two sampling frames is investigated using four administrative structures under which such designs might be conducted in the United States. The U.S. National Crime Survey is used to illustrate the characteristics of the dual frame, mixed mode design. Sensitivity analyses are summarized which indicate design characteristics that are most likely to influence the precision of survey statistics, given fixed resources, and hence most likely to require careful specification. For some statistics, twenty to thirty percent gains in sampling variance are enjoyed by the dual frame mixed mode design over the traditional area frame design, given the cost and error models employed.

Key words: Telephone surveys; sensitivity analysis; optimal allocation; cost models.

1. Telephone and Face-To-Face Surveys in the United States

Sample survey designs for the United States household population have traditionally utilized area probability sampling and face-to-face interviewing (e.g., U.S. Bureau of the Census (1978)). However, telephone sampling and centralized telephone interviewing have begun to replace the traditional design because they offer substantial cost savings over face-to-face methods. Some survey researchers also assert that centralized interviewing offers benefits of lower response errors since interviewers can be continuously supervised and monitored in a centralized facility. In experimental studies that compare the two methods of data collection few differences in survey estimates are found, despite apparent lower response rates in the telephone survey (Groves and Kahn (1979); Cannell et al. (1984)).

A principal shortcoming of telephone surveys in the United States is that approximately seven percent of households are without telephones and thus are not covered by the telephone sampling frame. The nontelephone population tends to be younger, poorer, more rural, and more likely to be single person households than the total household population (Thornberry and Massey (1983)). In

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some surveys the nontelephone population has also been found to differ markedly with respect to crime victimization (see, for example, McGowan (1982)) and health characteristics (Cannell et al. (1984)). Thus, surveys conducted entirely by telephone may be subject to large noncoverage bias.

A dual frame, mixed mode design would retain the cost savings of telephone interviewing and also enjoy the increased coverage of area probability sampling. The dual frame character of the design selects both an area sample and a telephone sample, and the mixed mode character conducts face-to-face interviews with area sample households and telephone interviews with telephone sample households. Subsequent survey estimation combines data from both frames.

The optimal allocation of survey resources to the two frames depends on the costs and errors associated with each. Unfortunately, there is often uncertainty about the magnitudes of these costs and errors. In addition, several administrative structures may be proposed for the dual frame, mixed mode design, with each structure potentially affecting the cost and error characteristics of the survey. To the extent that the optimal allocation is sensitive to changes in the values of parameters in the cost or error models, greater emphasis should be placed on obtaining accurate estimates for those parameters before a complete dual frame design can be specified. The cost and error models are likely to be applicable with modest changes to other large scale survey designs in the United States. The models' applicability to other countries, however, is dependent on the costs, administrative structures, telephone coverage, and sample designs for telephone and personal interview surveys in those countries. It is likely that the coverage of the household population by telephones in many countries is sufficiently low, and the cost advantages of telephone interviewing sufficiently small, that little advantage would be gained by departing from a single frame design using personal visit interviews.

This paper reviews the effects of administrative structure, costs, and errors on the desirable allocation of survey resources in a dual frame, mixed mode design. A review of dual frame designs is presented in Section 2, and four administrative structures for dual frame surveys are discussed in Section 3. Cost models are summarized for each administrative structure in Section 4, together with an illustration of a dual frame, mixed mode design which might be applied to a large national sample survey conducted by the U.S. Bureau of the Census, the National Crime Survey (NCS). Optimal allocations under various assumptions about administrative structures, costs, and errors in the NCS are presented in Section 5. The last section discusses the implications of the findings for future survey design and suggests further areas for research.

2. Dual Frame Survey Design

Dual or multiple frame sampling is used frequently in fields studying rare populations (e.g., farmers in the United States), where area probability sampling methods alone would be very expensive (Steinberg (1965)). In such cases a list frame may permit inexpensive access to a large share of the members of the population, a sample from a frame with complete coverage of the population (e.g., an area frame) can be drawn to supplement this list frame sample, and the selected units can be screened to locate eligible ones. Some units would have a chance of entering the final sample through both the list frame and the more complete frame, while others could enter the sample only through the complete frame.

The optimal allocation of sample size to the frames must usually be made in a situation

where the frames cover different portions of the population, where they entail different data collection costs, where the element variance of the survey variables might differ across frames, and where the efficiencies of the possible sample designs vary across frames. Hartley (1962, 1974) examined dual frame designs in which simple random samples were drawn from both frames. In the case where an inexpensive frame, b, was a subset of a complete but more expensive frame, a, Hartley proposed a post-stratified estimator for the population mean

$$\bar{y} = p\bar{y}_{a1} + (1-p)\,[\theta\bar{y}_{a2} + (1-\theta)\bar{y}_b] \qquad (1)$$

where

p = the proportion of sample elements in frame a that are not in frame b;
$\bar{y}_{a1}$ = the sample mean for elements covered only by the expensive frame a;
$\bar{y}_{a2}$ = the sample mean for elements covered by both frames but selected from frame a;
$\bar{y}_b$ = the sample mean for elements covered by both frames but selected from frame b; and
θ = a mixing parameter.

The estimator is a weighted average of means from two domains, those covered by the expensive frame only (i.e., frame a) and those covered by both frames. The mean for the latter domain is itself a combination (using the mixing parameter θ) of the domain means from the samples from the two frames.

One application of the dual frame estimator in expression (1) is, of course, to mixes of telephone and area frame samples. A consideration of stratified multistage sample designs in both of these sampling frames must be made in the development of appropriate variance estimators. In the area frame, the sample may be clustered to reduce the costs of interviewer travel from one sample unit to another. In telephone samples in the United States, clustered sample selection is also employed to reduce the costs of data collection. Typically, telephone numbers are randomly generated within geographically assigned number codes in order to select a sample of telephone households. Often called "random digit dialed" or RDD samples, they are preferred to sample designs which select numbers directly from telephone directories. A large percentage of telephone households in the U.S. are not listed in directories since subscribers may request an unlisted number or obtain a number after the latest directory is published. On the other hand, many of the telephone numbers generated by RDD methods are not assigned to any subscriber; hence, RDD samples often contain large proportions of nonworking numbers. Clustered selection by sets of 100 consecutive numbers is often introduced to increase the proportion of sample numbers generated that are connected to households (see, for example, Waksberg (1978)).

Casady, Snowden, and Sirken (1981) examined a dual frame design in which both the area and telephone frames have stratified cluster sample designs. They expressed the sampling variance of the dual frame estimator by using design effects to account for the complex design features in each frame. Following Lund (1968), they obtained the sampling variance of the dual frame estimator as approximately

$$\begin{aligned}\mathrm{Var}(\bar{y}) \cong\ & \frac{p\,\sigma_a^2\,\delta_{a1}}{m_A\bar{N}_A} \\ & + \frac{(1-p)^2\,\delta_{a1}\,\delta_b\,\sigma_b^2}{\{(1-p)\,m_A\bar{N}_A\delta_b + m_B\bar{N}_B\delta_{a2}\}} \\ & + \frac{p(1-p)\,\gamma\,[E(\bar{y}_{a1}) - E(\bar{y}_{a2})]^2}{m_A\bar{N}_A}\end{aligned} \qquad (2)$$

Here

m_A = the number of clusters from the area frame;

m_B = the number of clusters from the telephone frame;

$\bar{N}_A$ = the number of sample households per cluster from the area frame (i.e., $m_A\bar{N}_A = n_{a1} + n_{a2}$);

$\bar{N}_B$ = the number of sample households per cluster from the telephone frame;

γ = the design effect for the estimated proportion of nontelephone households;

δ_{a1} = the design effect for a mean across nontelephone households;

δ_{a2} = the design effect for a mean across telephone households from the area frame;

δ_b = the design effect for a mean across telephone households from the telephone frame;

σ_a = the element standard deviation for nontelephone households; and

σ_b = the element standard deviation for telephone households.

The variance expression (2) for the dual frame estimator has three terms which reflect features of the dual frame design: a) the variance of the mean of the nontelephone households, b) the variance of the mean of telephone households, and c) a function of the variance of the estimated proportion of nontelephone households (i.e., the parameter p) and the difference of population means for nontelephone and telephone households. The sampling design effects appearing in the variance expression can reflect the use of stratification, multistage selection, unequal probabilities of selection and compensating weights, and finite population correction factors. Thus, they are not simply "clustering" effects but actual ratios of variances (Kish (1965)). The variance expression has also been simplified by an assumption that the sampling covariance between telephone and nontelephone households in the area frame is small and can be ignored. (This assumption has been verified empirically for the example used later in the paper.) The investigation reported in this paper used the variance estimate derived by Casady, Snowden, and Sirken as the basic error model in the study of the dual frame allocation problem.

3. Administrative Structures For Dual Frame, Mixed Mode Designs

Most organizations that conduct national personal interview surveys in the United States maintain regional offices for the supervision of field interviewers. When telephone interviewing is first introduced into such an organization, several decisions regarding the administration of the new mode of data collection are required. First, a decision must be made concerning which personnel will conduct telephone interviewing. Second, the organization must decide whether interviewers will be centralized in telephone interviewing facilities or will use telephones in their own homes for interviewing.

As with most survey design issues, these decisions involve an interplay of costs and errors. The cost of telephone interviewing from interviewers' homes can be lower than that from a centralized facility if their assignments are clustered into areas near the interviewer's home. For random digit dialing samples distributed independently of the primary areas of an area probability sample, the cost advantage of home-based telephone interviewing diminishes with low cost long distance communication services available in the United States. The centralized facilities also offer advantages of size that permit large scale training activities and continuous concentration on interviewing while the staff is in the facility, a feature that can reduce the number of hours spent on each completed

case. The errors related to survey administration — nonresponse, response, and recording errors — might also be more effectively controlled in a centralized environment where constant supervision and monitoring are possible.

Representations of four dual frame, mixed mode survey administrative structures are shown in Figures 1, 2, 3, and 4. These structures vary in which interviewers do the work and from what locations the interviewing is conducted. In each, a central office (denoted by the large rectangle) is attached to several regional offices (denoted by triangles), which in turn supervise individual interviewers (denoted by small rectangles appended to each triangle) working in different primary areas. In addition, centralized telephone interviewing facilities (denoted by circles of various sizes) are attached either to the central or regional offices.

The administrative structure depicted in Fig. 1 is used by many survey organizations to administer face-to-face surveys and thus is an important structure for the dual frame, mixed mode survey designs. Interviewers conduct personal visit interviews at selected area frame households within the primary areas where they reside; they also interview a sample of telephone households using their own home telephones. The regional office personnel supervise both modes of interviewing. The location of telephone sample households may be clustered within area frame primary sampling units, at the cost of increased variance for survey estimates. On the other hand, if such clustering is used, transfer of survey materials is facilitated when telephone sample respondents request a face-to-face interview.

The structure in Fig. 2 requires each interviewer to conduct interviews in only one

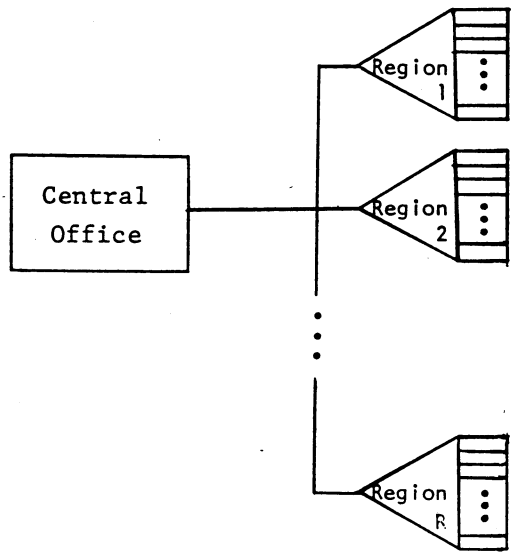

Fig. 1. Administrative Structure I: Dispersed Telephone Interviewing.
Regular personal visit interviewer conducts personal visit interviews at area sample addresses and telephone interviews with telephone sample numbers. Assignments are processed through regional offices before shipment to the central office.

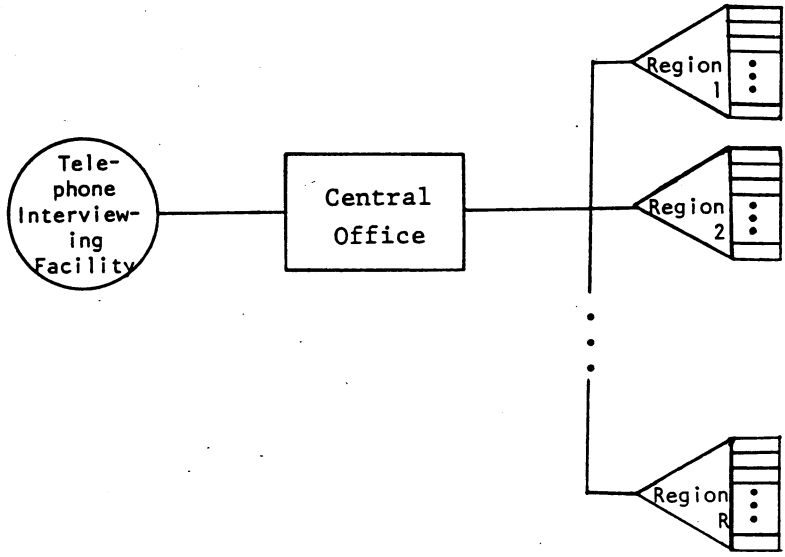

Fig. 2. Administrative Structure II: Centralized Telephone Interviewing Facility.
Personal visit interviews are conducted through regional offices at area sample addresses. Telephone interviews are conducted with telephone sample numbers from a single centralized facility.

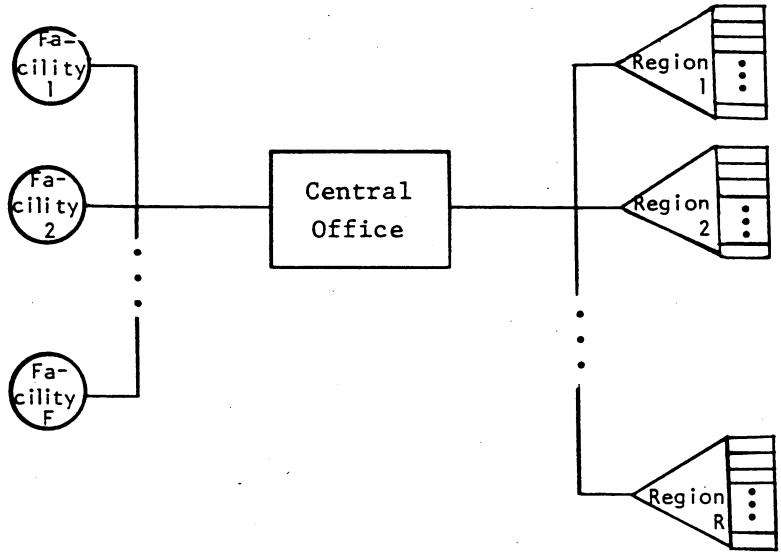

Fig. 3. Administrative Structure III: Multiple Centralized Facilities.
Personal visit interviews are conducted through regional offices at area sample addresses. Telephone interviews are conducted through multiple centralized facilities which are not administratively linked to the regional office.

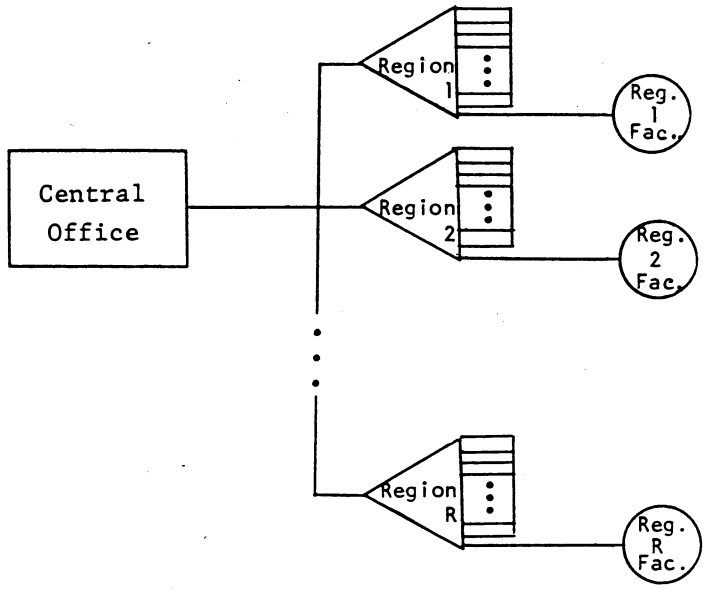

Fig. 4. Administrative Structure IV: Telephone Facilities Attached to Regional Office. Personal visit interviews with area sample addresses and telephone interviews with telephone sample numbers are conducted through regional offices. Telephone facilities are administered through and supervised by the regional offices.

mode. The personal visit interviewers conduct face-to-face interviews in the sample area segments near their homes, but all telephone interviews are conducted from one centralized facility attached to the central office. Administrative control over the centralized telephone facility lies within the central office. In contrast to the first administrative structure, transfer of survey materials from one mode to another by supervisory staff may be required. Some of these requests can be served by using the personal visit interviewing staff located within reasonable distance from the sample person's residence.

Administrative structure III is similar to II since it also has centralized interviewing facilities, but telephone interviewing is conducted at several facilities located across the country. The locations can be chosen to minimize long distance telephone charges and to increase access to labor markets with large numbers of potential interviewers. Each telephone facility hires, trains, schedules, and supervises its own work force.

The final administrative structure also maintains centralized telephone interviewing facilities, but in order to minimize redundancy within the survey administration, facilities are attached to regional offices which supervise personal visit interviewing. Such regional offices are responsible for both the personal visit interviewers and the local staff of telephone interviewers.

These four structures represent a wide range of possible organizational approaches to the administration of such surveys. As the discussion has indicated, each model has somewhat different cost requirements, some needing a consideration of transfer costs, others needing to maintain centralized telephone interviewing facilities. Yet each model might have appeal to different survey organizations.

4. An Application to the U.S. National Crime Survey

The U.S. National Crime Survey (NCS) is a large continuing household sample survey designed and conducted by the U.S. Bureau of the Census for the Bureau of Justice Statistics. The primary purpose of the NCS is the measurement of self-reported crime victimization of the U.S. civilian noninstitutionalized population aged 12 and older. The NCS collects information from a stratified multistage area probability sample of approximately 14 000 housing units, yielding about 25 800 personal interviews per month. Each person 14 years old and older is asked to complete an interview; proxy reports are taken for those 12 and 13 years old. A rotating panel design is employed in which each sample unit is visited every six months for a three and a half year period before being replaced.

The NCS collects data on many types of victimizations and on the characteristics of reported events. The types of crime covered include personal victimizations such as rape, robbery, assault, and personal larceny, as well as household victimizations such as burglary, motor vehicle theft, and household larceny. For the purposes of this investigation, five types of crime were selected to provide an opportunity to examine the problems of dual frame allocation in a multipurpose survey: total personal crimes, robbery, assault, total household crimes, and motor vehicle theft.

Cost models that are related to the parameters in an error model are necessary to determine the best allocation of the sample between the area and the telephone frames for a dual frame survey. Past work on dual frame designs has used relatively simple cost models with essentially three cost components, an administrative overhead cost, a per interview personal visit mode cost, and a per interview telephone mode cost. To apply the four administrative models described in the last section to the NCS, more detailed cost functions are needed that reflect the cost of regional offices, the cost of hiring and training personal visit and telephone interviewers, the cost of centralized telephone interviewing facilities, the cost of transferring sample cases from telephone to personal visit interviewing modes, and the per unit interviewing costs.

Separate cost models were developed for each administrative structure, and are described in detail in the appendix. As an illustration of the nature of these cost models, consider the cost model for administrative structure III:

$$
\begin{aligned}
C = C_0 &+ C_{ro}\,\mathrm{INT}[(m_A/32) + 1] \\
&+ C_{tp}\,\mathrm{INT}[(m_A \bar{N}_A/W_A) + 1] \\
&+ C_{tf}\,\mathrm{INT}[(m_B\bar{N}_B/W_B)/50 + 1] \\
&+ C_{tt}\,\mathrm{INT}[(m_B\bar{N}_B/W_B) + 1] \\
&+ (10 + 0.5\,c_A)(m_B\bar{N}_B/20) \\
&+ c_A m_A \bar{N}_A + c_B m_B \bar{N}_B \quad ,
\end{aligned}
$$

where

C_0 = overhead or fixed costs;
C_{ro} = cost to operate a regional office;
$\mathrm{INT}[\cdot]$ = integer portion of the argument $[\cdot]$;
C_{tp} = annualized cost to hire and train a personal visit interviewer;
W_A = annual number of completed interviews for a personal visit interviewer;
C_{tf} = cost to operate a telephone facility of 50 interviewers;
W_B = annual number of completed interviews for a telephone interviewer;
C_{tt} = annualized cost to hire and train a telephone interviewer;
c_A = remaining cost per completed personal visit interview; and
c_B = remaining cost per completed telephone interview.

The model is deliberately complex, in order to capture as many types of costs as possible that can be manipulated in a survey design. The individual cost components are often multiplied by a step function (i.e., INT[·]) which reflects the fact that adding a new unit to a system is done in discrete steps, not in continuous increments. The values of the cost components are given in Table A1 in the appendix.

Table 1 presents a summary of the components used in the cost models for each administrative structure. Each cost model has a component for administrative overhead for conducting the combined survey operation and components for hiring and training costs. There is also a component for per unit costs of completing personal visit and telephone interviews in each model. Structure I does not have a cost for centralized telephone interviewing facilities since interviewers conduct telephone interviews from their homes. A detailed description of the functional form of the cost components, the survey functions covered by each, the cost values associated with each component, and the units the costs are applied to is contained in the appendix. The models themselves were developed through discussion with personnel at the U.S. Bureau of the Census, and, although not verifiable, they are considered to be reasonable representations of possible dual frame survey design structures for the NCS.

The cost models also were developed to represent the "steady state" dual frame design. Development and phase-in costs could have been estimated, amortized over the first years of the survey operation, and added to the per unit costs in the cost model. However, these costs are difficult to estimate, and their presence in the cost components would complicate subsequent examination of the dual frame allocation problem. Hence, the development or phase-in costs are not incorporated directly into the cost estimates, although the sensitivity analysis does allow one indirectly to

Table 1. Cost Components for Household Level Cost Models for Four Administrative Structures

Cost Component	I	II	III	IV
Overhead	X	X	X	X
Regional Offices	X	X	X	X
Hiring and Training, Personal Visit Interviewers	X	X	X	X
Supplementary Training (Personal Visit Interviewers in Telephone Interviewing Techniques)	X			
Hiring and Training, Telephone Interviewers		X	X	X
Centralized Telephone Interviewing Facility		X	X	X
Transfer of Cases from Telephone to Personal Visit Mode	X	X	X	X
Per Unit Costs for Personal Visit Interviewing	X	X	X	X
Per Unit Costs for Telephone Interviewing	X	X	X	X

speculate on the impact that such costs may have on the dual frame allocation.

Table 2 lists the values of error parameters used in the variance model presented in expression (2). The proportion of persons and households without telephones (i.e., p) was obtained from the 1980 U.S. Census of Population and Housing. The element variances (i.e., σ_a^2 and σ_b^2) and area frame design effects (i.e., δ_{a1} and δ_{a2}), were obtained from sampling error computations for the 1980 NCS, and the expected difference between telephone and nontelephone crime rates (i.e., $E(\bar{y}_{a1}) - E(\bar{y}_{a2})$) was obtained from estimated victimization rates from the 1980 NCS. The telephone frame design effect (i.e., δ_b) was derived after a review of intraclass correlations within households provided by the U. S. Bureau of the Census. Finally, the design effect for the proportion of persons or households without telephones (i.e., γ) was derived through considerations of cluster sizes and expected levels of within primary area homogeneity for telephone ownership.

Table 2. Values of Error Parameters Used to Estimate Standard Error of Estimated Victimization Rate by Type of Crime

Error Component	Type of Crime				
	Total Personal Crimes	Robbery	Assault	Total Household Crimes	Motor Vehicle Theft
p	0.059	0.059	0.059	0.072	0.072
σ_a^2	0.646	0.057	0.189	1.144	0.068
σ_b^2	0.390	0.017	0.085	0.809	0.051
δ_{a1}	2.134	1.759	1.424	1.418	0.927
δ_{a2}	2.250	1.144	1.791	1.858	1.020
δ_b	1.244	1.009	1.166	1.133	1.005
γ	1.939	1.939	1.939	1.436	1.436
$E[\bar{y}_{a1} - \bar{y}_{a2}]$	–0.629	–0.014	–0.028	–0.084	–0.003

The variance expression (2), the error parameters in Table 2, and the cost components in Table 1 (described more completely in the appendix) provided the basic error and cost models used to examine the optimal allocation between the two frames. The next section reviews the results of those investigations.

5. Sensitivity Analysis

As discussed previously, there is often uncertainty about estimated costs and errors in a survey. For a survey organization developing a dual frame, mixed mode design, there is also uncertainty about the administrative structure most desirable from a cost and error perspective. For example, costs are not routinely reported as part of documentation for a survey. Once the costs are obtained, considerable effort is often required to convert such information to estimates of parameters required in a cost model. As changes to a design are introduced, estimates developed from one design may no longer be accurate. Even experienced personnel may have difficulty speculating about the cost of a single

design feature when sample size or clustering is changed.

In the subsequent discussion, the sensitivity of the dual frame optimal allocation to changes in administrative structure, costs, and errors is explored. Only a single parameter value is manipulated at a time in this investigation. The purpose of single parameter manipulation is to identify parameters for which errors in estimation would have the largest effect on the allocation. A more complex manipulation of parameter values could have been used, changing two or more parameters simultaneously to explore the entire space of parameter values and how the dual frame allocation varies across that space. However, the parameter values were not chosen arbitrarily but represent a point in the space of likely values for an NCS dual frame design. The purpose was not to describe the entire space of parameter values and allocations but to examine how errors in estimation of selected parameters might affect the allocation in a region of parameter values that would be likely to be found in practice.

The sensitivity of the allocation to administrative structure is examined for five types of crime in Section 5.1. Sensitivity to changes in costs and errors are presented for three types of crime (total personal crimes, robbery, and total household crimes) and one administrative structure in Sections 5.2 and 5.3.

5.1. Sensitivity to Administrative Structures

Table 3 and Figures 5 through 9 present the sensitivity of the optimal allocation to changes in administrative structure for five types of crime under a fixed survey budget. In each curve in the figures, the standard error of the dual frame estimator gradually decreases as the proportion of the sample allocated to the telephone frame increases to about 50 to 70 percent of the total sample size. Increasing the allocation to the telephone beyond that level produces dramatic losses of precision. The curves themselves are not smooth because, in the cost models, entire regional offices or telephone facilities are added or removed from the design as sample sizes in the frames change. The changes in sample allocation also produce large cost burdens that reduce the number of sample cases in the full survey.

Table 3. Optimal Proportion of Sample Cases Allocated to the Telephone Frame and Standard Error of the Mean Achieved at the Optimum by Administrative Structure and Type of Crime

	Administrative Structure			
	I	II	III	IV
		a. Total Personal Crimes		
Proportion	0.63	0.65	0.66	0.65
Standard Error	0.00123	0.00121	0.00120	0.00122
		b. Robbery		
Proportion	0.45	0.48	0.39	0.51
Standard Error	0.000254	0.000248	0.000247	0.000245
		c. Assault		
Proportion	0.63	0.65	0.66	0.51
Standard Error	0.000546	0.000535	0.000530	0.000538
		d. Total Household Crimes		
Proportion	0.71	0.74	0.74	0.69
Standard Error	0.00234	0.00228	0.00225	0.00231
		e. Motor Vehicle Theft		
Proportion	0.63	0.66	0.67	0.51
Standard Error	0.000503	0.000490	0.000484	0.000494

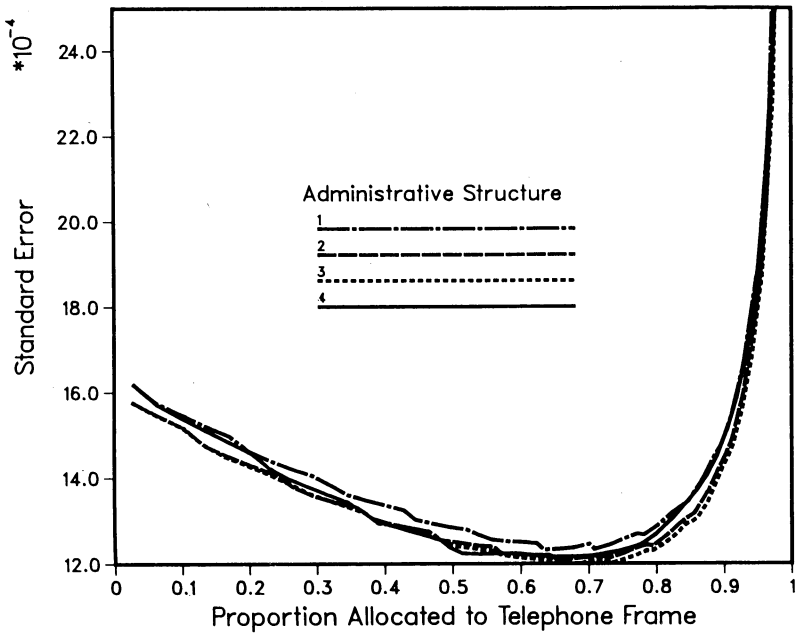

Fig. 5. Standard Error at Alternative Allocations to the Telephone Frame for Total Personal Crimes

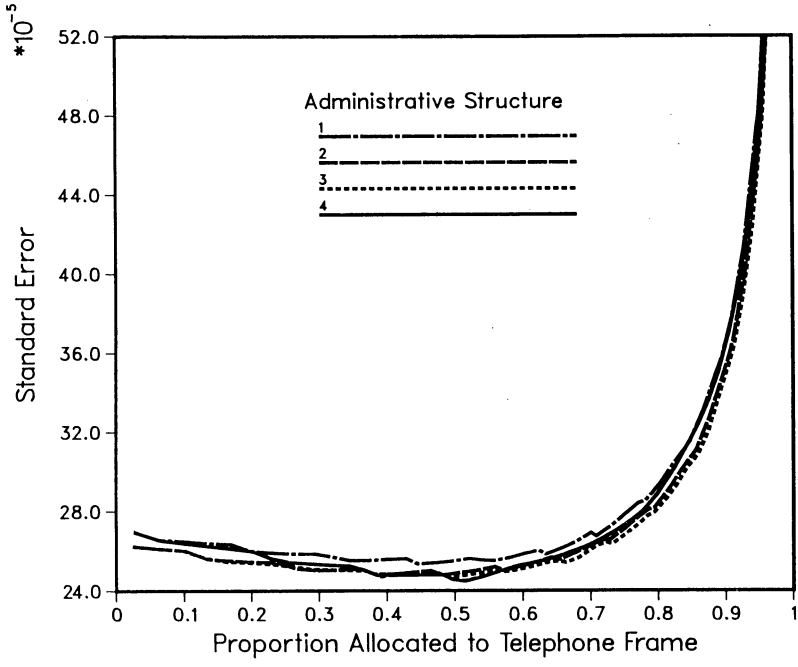

Fig. 6. Standard Error at Alternative Allocations to the Telephone Frame for Robbery

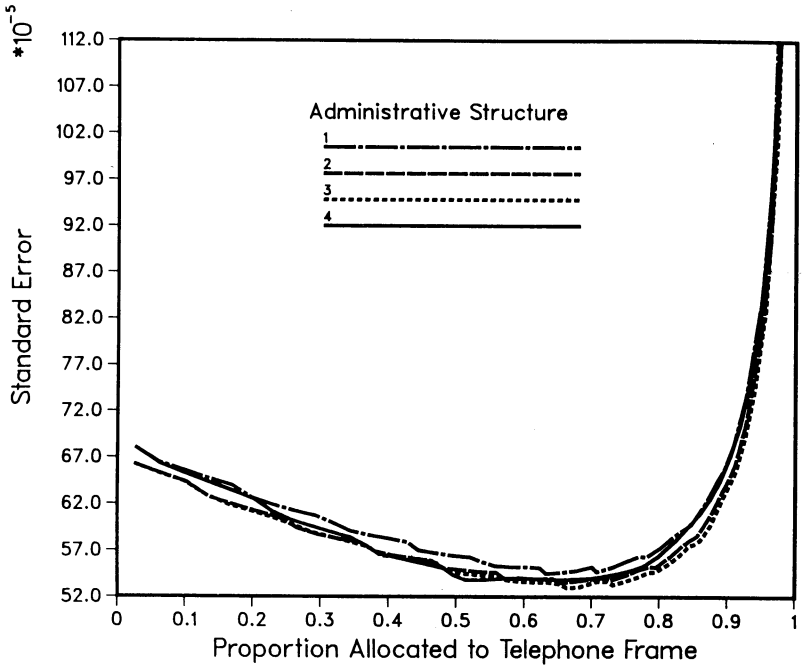

Fig. 7. Standard Error at Alternative Allocations to the Telephone Frame for Assault

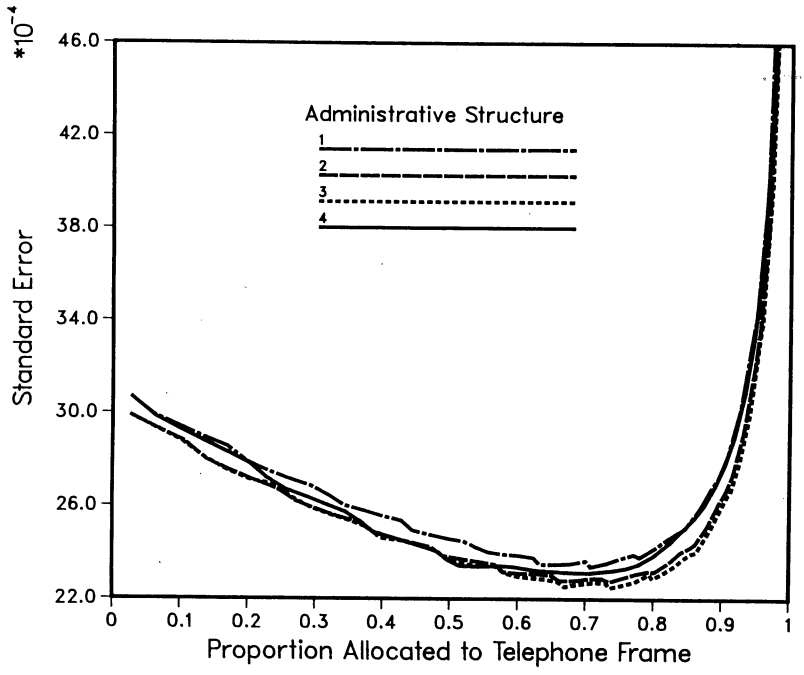

Fig. 8. Standard Error at Alternative Allocations to the Telephone Frame for Total Household Crimes

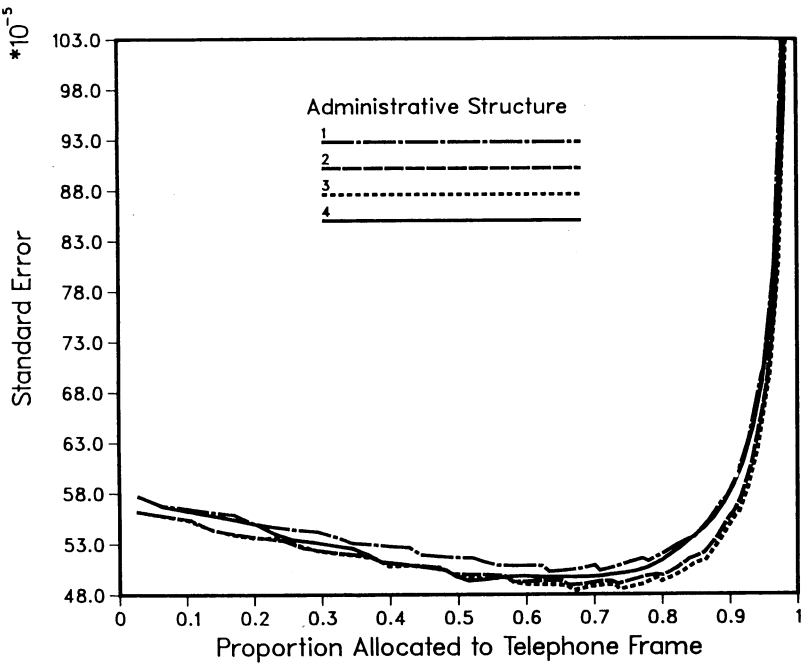

Fig. 9. Standard Error at Alternative Allocations to the Telephone Frame for Motor Vehicle Theft

The figures illustrate that, contrary to expectations, the different administrative structures have little impact on cost efficiencies of the dual frame survey. In Table 3, standard errors at the optimum allocation vary across the four administrative structures by less than five percent for all the statistics examined. This insensitivity to different administrative structures suggests that survey organizations may choose an administrative structure which disrupts the current structure the least and suffer little loss of efficiency in dual frame survey operations compared to utilizing a different structure.

Figures 5 through 9 also demonstrate that, for some statistics (e.g., robbery), the single optimal allocation does not achieve standard errors very much lower than other allocations near the optimum. That is, the standard error curve is relatively flat near the optimum and modest departures from the optimum will not lead to large losses in precision. For several of the statistics, there is little change in the standard error of the dual frame estimator when the proportion allocated to the telephone frame is less than 85 percent. This is a useful result for those planning a transition from a current area frame design to a dual frame design over a period of time. Many of the gains can be achieved at an allocation to the telephone frame lower than optimal.

The multipurpose nature of the NCS complicates the choice of a single allocation to the two frames. Across the five statistics, the optimal allocations vary from 50 to 70 percent telephone, regardless of administrative structure. Different statistics have different optimal allocations, but, in general, for each statistic the standard error is relatively stable in the 50 to 70 percent telephone allocation region. (Given the similarity of standard errors at the optimum allocation across the four administrative structures, the subsequent cost and error sensitivity analyses are presented for only one of the administrative structures examined, structure IV.)

5.2. *Sensitivity to Cost Components*

A range of parameter values was examined in this investigation that includes the possibility that very large errors were made in the designation of cost components presented in the appendix. For both cost and error parameter sensitivity analysis, parameter values were reduced by one-half to obtain the low value of the range and doubled to obtain the high value of the range. Thus, for example, current figures suggest the NCS interview costs for a completed interview with a person average $13.86; a range of $6.93 to $27.72 was used in the sensitivity analysis.

Table 4 presents a summary of the sensitivity analyses for cost related parameters. The first two columns show the range of the single parameter value examined; the next two columns, the optimal allocations corresponding to those values; and the final two columns, the standard error of the dual frame estimator under those values. Each line in the table presents the effect of varying a single parameter, while other parameters not directly dependent on it retain the derived costs, and the estimated error parameters remain fixed in value.

Table 4. Optimal Allocation to Telephone Frame and Standard Error of Victimization Rate for Total Personal Crimes, Robbery, and Total Household Crimes for Alternative Values of Seven Cost Parameters in the Dual Frame, Mixed Mode Design Under Administrative Structure IV

Parameter	Alternative Parameter Values		Optimal Allocation		Standard Error	
	Low Value	High Value	At Low Value	At High Value	At Low Value	At High Value
			Total Personal Crimes			
Per Unit Cost for Area Frame Cases	$6.93	$27.72	0.51	0.76	0.00108	0.00140
Per Unit Cost for Telephone Frame Cases	$3.99	$15.94	0.70	0.48	0.00108	0.00140
Regional Office Cost	$75 742	$302 966	0.68	0.66	0.00114	0.00134
Interviewer Hiring and Training (Area)	$542	$2 166	0.67	0.57	0.00121	0.00122
Interviewer Hiring and Training (Phone)	$125	$500	0.67	0.67	0.00122	0.00122
Interviewer Workload (Area)	267	1 066	0.57	0.67	0.00122	0.00121
Interviewer Workload (Phone)	792	3 166	0.66	0.69	0.00129	0.00116
			Robbery			
Per Unit Cost for Area Frame Cases	$6.93	$27.72	0.42	0.61	0.000212	0.000298
Per Unit Cost for Telephone Frame Cases	$3.99	$15.94	0.59	0.14	0.000227	0.000269
Regional Office Cost	$75 742	$302 966	0.51	0.44	0.000232	0.000273
Interviewer Hiring and Training (Area)	$542	$2 166	0.51	0.50	0.000245	0.000248
Interviewer Hiring and Training (Phone)	$125	$500	0.51	0.52	0.000245	0.000245
Interviewer Workload (Area)	267	1 066	0.50	0.52	0.000248	0.000245
Interviewer Workload (Phone)	792	3 166	0.40	0.51	0.000257	0.000245

(cont.)

Table 4 (cont.) Optimal Allocation to Telephone Frame and Standard Error of Victimization Rate for Total Personal Crimes, Robbery, and Total Household Crimes for Alternative Values of Seven Cost Parameters in the Dual Frame, Mixed Mode Design Under Administrative Structure IV

Parameter	Alternative Parameter Values		Optimal Allocation		Standard Error	
	Low Value	High Value	At Low Value	At High Value	At Low Value	At High Value
			Total Household Crimes			
Per Unit Cost for Area Frame Cases	$14.90	$59.60	0.49	0.76	0.00206	0.00264
Per Unit Cost for Telephone Frame Cases	$8.58	$34.27	0.70	0.47	0.00205	0.00269
Regional Office Cost	$75 742	$302 966	0.69	0.68	0.00217	0.00254
Interviewer Hiring and Training (Area)	$542	$2,166	0.67	0.70	0.00230	0.00234
Interviewer Hiring and Training (Phone)	$125	$500	0.69	0.69	0.00231	0.00232
Interviewer Workload (Area)	124	496	0.70	0.69	0.00233	0.00230
Interviewer Workload (Phone)	368	1 473	0.66	0.69	0.00245	0.00220

In general, the optimal allocation to the two frames is relatively insensitive to changes in the cost parameters investigated. The per unit interviewing costs appear to be the most important single influence on the optimal allocation between frames. Changing these parameter values shifts the optimal allocation by 20 percent or more. The types of crimes examined vary in their sensitivity, with robbery showing the largest effects (under high per unit telephone costs, the optimal allocation is only 14 percent telephone). The distribution of the standard error for robbery across different allocations was fairly flat (see Fig. 6), and large variability in optima does not necessarily imply increased standard errors if somewhat different allocations are chosen. This one result for the robbery rate is atypical of the rest of Table 4. Indeed, the smallest allocations to the telephone tend to be closer to 50 percent, still quite different from the zero percent allocation to the telephone frame currently used in the NCS. It is important to note that although per unit interviewing costs were the single most important cost parameter for the sensitivity analysis, this would not necessarily be true if other parameters took on different values. For example, a survey with a different sample design (in size and number of primary selections) would experience a different relative impact of the number of regional offices and field interviewers. A simpler cost model that included only fixed costs and a per unit interviewing cost, therefore, might be relatively uninformative in such a case.

5.3. *Sensitivity to Error Components*

Table 5 demonstrates the sensitivity of the dual frame allocation to changes in error parameter values. Recent changes in the U.S. telephone system may affect the proportion of households having a telephone, and noncoverage rates of 3 and 12 percent were examined to measure possible effects on the optimal allocation between the two frames.[2] With the higher rate of telephone noncover-

[2] This single parameter sensitivity analysis left untouched the estimated difference between telephone and nontelephone population values on the statistics (noncoverage bias for the telephone frame). It is likely that the magnitude of this difference is negatively correlated with the noncoverage rate, but we have no empirical data on the relationship.

Table 5. Optimal Allocation to Telephone Frame and Standard Error of Victimization Rate for Total Personal Crimes, Robbery, and Total Household Crimes at Alternative Values of Four Error Parameters in the Dual Frame, Mixed Mode Design Under Administrative Structure IV

Parameter	Alternative Parameter Values		Optimal Allocation		Standard Error	
	Low Value	High Value	At Low Value	At High Value	At Low Value	At High Value
			Total Personal Crimes			
Proportion Nontelephone	0.030	0.12	0.78	0.51	0.00109	0.00144
Intracluster Correlation for Nontelephone Population (Area Frame)	0.010	0.042	0.71	0.51	0.00116	0.00130
Intracluster Correlation for Phone Population (Area Frame)	0.00071	0.0028	0.51	0.71	0.00117	0.00125
Intracluster Correlation for Phone Population (Phone Frame)	0.00083	0.0033	0.65	0.65	0.00118	0.00128
Design Effect for Proportion Nontelephone	1.39	2.58	0.65	0.65	0.00122	0.00122
			Robbery			
Proportion Nontelephone	0.030	0.12	0.51	0.26	0.000215	0.000314
Intracluster Correlation for Nontelephone Population (Area Frame)	0.0070	0.028	0.51	0.51	0.000234	0.000266
Intracluster Correlation for Phone Population (Area Frame)	0.000081	0.00033	0.51	0.51	0.000243	0.000248
Intracluster Correlation for Phone Population (Phone Frame)	0.000029	0.00012	0.51	0.51	0.000245	0.000245
Design Effect for Proportion Nontelephone	1.39	2.58	0.51	0.51	0.000245	0.000245
			Total Household Crimes			
Proportion Nontelephone	0.036	0.14	0.78	0.51	0.00214	0.00257
Intracluster Correlation for Nontelephone Population (Area Frame)	0.0069	0.027	0.71	0.63	0.00226	0.00241
Intracluster Correlation for Phone Population (Area Frame)	0.0011	0.0042	0.51	0.71	0.00225	0.00236
Intracluster Correlation for Phone Population (Phone Frame)	0.0010	0.0040	0.69	0.69	0.00228	0.00239
Design Effect for Proportion Nontelephone	1.18	1.73	0.69	0.69	0.00231	0.00231

age, the optimal allocations move in the direction of increased area sampling. Total personal crimes and total household crimes then would have optima at 51 percent telephone, in contrast to 65 to 70 percent telephone under the current noncoverage rate. Similarly, the optimal allocation for robbery moves to 26 percent telephone from 51 percent under the standard parameter set. When the noncoverage rate is set at 3 percent, the optimal allocation rises to 78 percent telephone for total personal or household crimes, and remains at 51 percent for robbery rates.

Three different intracluster homogeneities were examined to determine whether or not the magnitude of the design effects for each frame affects the allocation. The telephone frame intracluster homogeneity appears to have little impact on the optimal allocation or the standard errors, a result of the relatively small cluster sizes used in the telephone sample design. The intracluster correlations for the telephone and nontelephone households in the area frame do affect results for total personal and total household crimes, moving their optimal allocations by 20 percentage points from 50 to 70 percent telephone. The actual changes in the standard errors obtained at the optimal allocation, however, are not large, generally within a 10 percent range.

The last error component varied was the design effect of the estimated proportion of units without telephones. The optimal allocations appear to be insensitive to changes in the values of this parameter across the range of values used.

6. Discussion

The figures and tables of Section 5 suggest that large gains in sampling precision are possible for some types of crime statistics in a dual frame survey design. On the other hand, the magnitude of other sources of error (e.g., response variance, response and nonresponse bias) and their effects on the allocation have not been addressed. Ideally these nonsampling errors would be added to the error models used in determining the optimal allocations. Unfortunately, few of these errors are measurable and even fewer are routinely measured and presented with survey estimates themselves. For example, with respect to bias, there is little empirical evidence of systematic differences in point estimates obtained by personal visit or telephone interviews, suggesting that few large differences between the frames exist with respect to bias. There are arguments, but little evidence at present, that interviewer variance is lower in centralized telephone surveys (Groves and Magilavy (1983)). There is no evidence of differences in simple response variance. In short, it is likely that biases and nonsampling variances in the two modes might not work exclusively to the disadvantage of the telephone mode. If that is the case, the conclusions obtained by focusing on sampling variance alone, that large gains in efficiency are possible using a dual frame design, may be repeated when a full mean square error model is used to study the allocation problem.

From the concern of sampling precision alone, it is likely that the joint use of telephone and personal interview surveys may offer advantages to U.S. household surveys in a period of rising costs of conducting interview surveys. The analysis has shown optimal allocations of 50 to 70 percent telephone in a dual frame design for the U.S. National Crime Survey, allocations which reflect the cost and sampling error advantages of telephone surveys. These results appear to favor the dual frame design over the single frame approach currently used, a design which, at present, uses telephone interviewing extensively for households being interviewed in waves subsequent to first contact. Table 6 summarizes

the potential gains of the dual frame approach by presenting the percentage reduction in sampling variance that a dual frame design could offer when compared to a single frame design with the same total cost.[3] The gains are those that occur when sampling variances of an area frame design are compared to those of a dual frame design at optimal allocation.

Table 6. Percent Gain in Precision (or Percent Cost Saving) for the Four Dual Frame, Mixed Mode Administrative Structures Relative to a Single Frame Design by Five Types of Crimes

Victimization Rate	Single Area Frame Standard Error	Percent Gain in Variance for Fixed Cost/Percent Reduction in Cost for Fixed Variance			
		I	II	III	IV
Total Personal Crimes	0.00149	31.9	34.1	35.1	33.0
Robbery	0.000238	–13.9	–8.6	–7.7	–6.0
Assault	0.000648	29.0	31.8	33.1	31.1
Total Household Crimes	0.00279	29.7	33.2	35.0	31.4
Motor Vehicle Theft	0.000562	19.9	24.0	25.8	22.7

All types of victimization rate estimates, except robbery, could achieve gains in sampling variance of 20 to 30 percent under an optimally allocated dual frame design. Robbery, however, could actually achieve a higher sampling variance under the dual frame. Alternatively, these gains in efficiency may be expressed as sample size reductions of 20 to 30 percent which could be achieved with no loss of precision for four of the five variables.

The anomalous results for robbery reflect a high element variance in the nontelephone population for this type of crime (see Table 2). Although the standard error of the robbery victimization rate is relatively invariant in the range of 0 to 40 percent allocation to the telephone frame, there may be other types of crimes in the NCS whose standard errors will increase under dual frame allocations that are optimal for some other variables. As in all multipurpose allocation problems, some assignment of importance to various estimates must be given by the survey designer before a choice of an overall allocation can be made. No single design will be optimal for all statistics of interest, but the dual frame design appears to hold promise for many.

7. Appendix. Cost Components and Estimates for Four Administrative Structures

The cost models developed for the four administrative structures examined in this investigation have a component for administrative overhead for both frames; separate components for personal visit and telephone administrative facilities costs, hiring and training costs, and per unit interviewing costs; and a mixed component for transferring cases from telephone to personal visit modes. Table A1 presents the cost models in complete detail.

The data used to derive cost estimates were obtained from several sources. For telephone interviewing, experiences at the Survey Research Center were used to estimate costs of conducting interviews at the U.S. Bureau of

[3] The standard error for a single frame design was computed using design effects currently achieved by the single frame NCS design.

Table A.1. Components for Cost Models for Estimated Household Level Costs to Produce Annual Estimates for the National Crime Survey

Cost Component	Administrative Structure			
	I	II	III	IV
Overhead	$(0.18)C$	$(0.18)C$	$(0.18)C$	$(0.18)C$
Regional Office	$(\$122,083)*$ $INT[(m_A/32)+1]$	$(\$122,083)*$ $INT[(m_A/32)+1]$	$(\$122,083)*$ $INT[m_A/32+1]$	$(\$151,483)*$ $INT\{MAX[m_A/32, (m_B\bar{N}_B/W_B)/50, (m_A\bar{N}_A+m_B\bar{N}_B)/(25W_B+16\bar{N}_A)]+1\}$
Hiring and Training, Personal Interviewers	$(\$320.94)*$ $INT[MAX(m_A\bar{N}_A/W_A, m_B\bar{N}_B/W_B)]$	$(\$320.94)*$ $INT[(m_A\bar{N}_A/W_A)+1]$	$(\$320.94)*$ $INT[(m_A\bar{N}_A/W_A)+1]$	$(\$320.94)*$ $INT[(m_A\bar{N}_A/W_A)+1]$
Supplementary Training, Personal Interviewers in Centralized Telephone Interviewer Techniques	...[1]	...	...	$(\$41.25)*$ $INT\{[(0.1)m_A\bar{N}_A/W_A]+1\}$
Centralized Telephone Interviewing Facility	...	$\$58,800+(\$13,710)*$ $\{[INT((m_B\bar{N}_B/W_B)+1)-50]/10+1\}$	$(\$58,800)*$ $INT[(m_B\bar{N}_B/W_B)/50+1]$	...
Hiring and Training, Telephone Interviewers	...	$(\$92.40)*$ $INT[(m_B\bar{N}_B/W_B)+1]$	$(\$82.50)*$ $INT[(m_B\bar{N}_B/W_B)+1]$	$(\$82.50)*$ $INT\{[m_B\bar{N}_B-(0.6)W_B[(0.1)m_A\bar{N}_A/W_A+1]]/W_B+1\}$
Cases Transferred from Personal Visit to Telephone Interviewing Mode	$(0.5)(\$24.53)(0.05)m_B\bar{N}_B$	$[\$10+(0.5)(\$24.53)]*(0.05)m_B\bar{N}_B$	$[(\$10+(0.5)(\$24.53)]*(0.05)m_B\bar{N}_B$	$(0.5)(\$24.53)(0.05)m_B\bar{N}_B$
Remaining Per Unit Costs for Personal Interviewing	$(\$24.53)m_A\bar{N}_A$	$(\$24.53)m_A\bar{N}_A$	$(\$24.53)m_A\bar{N}_A$	$(\$24.53)m_A\bar{N}_A$
Remaining Per Unit Costs for Telephone Interviewing	$(\$18.15)m_B\bar{N}_B$	$(\$15.12)m_B\bar{N}_B$	$(\$14.52)m_B\bar{N}_B$	$(\$13.68)m_B\bar{N}_B$

[1]Not Applicable
Note: The function INT [x] denotes the integer portion of the argument [x]. The function '*' denotes product.

the Census. For personal visit interviewing, the U.S. Bureau of the Census provided detailed cost estimates for ongoing operation of the NCS in 1980. (Thus, the costs presented here are for the rotating panel design as currently employed by the NCS, including the use of telephone interviews in later waves of interviewing.) Cost estimates contained in this paper are based on those data but are not official estimates approved by the Bureau.

A number of assumptions were made to derive the estimated costs in the models. It is assumed that a steady-state or ongoing dual frame survey is being modeled; start-up or phase-in costs are not considered. The area frame survey uses the same interviewing procedures as currently applied to the NCS, including telephone interviews from interviewer homes for previously interviewed households. All values are based on the costs needed to produce annual victimization rate estimates. Although costs and other data from 1980 were used, it is assumed that the relative values of costs will apply to a future dual frame design. The 1980 NCS design used 12 regional offices to supervise an average of 32 primary areas each; this average was used in the cost models. From Survey Research Center experience it has been recognized that a telephone facility with approximately 50 interviewers, a maximum of 25 on a shift, could be adequately supervised by a single facility manager and three or four shift supervisors; facilities with a base of 25 stations or carrels were used in two cost models. For structure II, modules of 10 carrels were added to a base facility of 25 carrels as the sample allocation to the telephone frame increased. A regional office or telephone facility is added in entire units and not in increments; cost models contain an integer function to determine when a new facility is needed. Finally, it is assumed that the average cluster sizes in the area and telephone frames are fixed across all allocations (i.e., a change in allocation and corresponding sample size for each frame does not change the average cluster size).

The cost components are described by mode and function. For each component the survey activities covered, the costs and units for the costs, and the determination of the number of units is described.

7.1. *Overhead*

The overhead costs include charges in both frames for space, administrative support, engineering, data processing of keyed data, report preparation and publication, and sample selection. These costs are generally computed as an application of a fixed percentage to some function of total direct interviewing costs and, as such, are not fixed costs that will be unchanged as the sample size increases. For each model, the overhead cost is computed as 18 percent of the total survey budget (C).

7.2. *Area Frame Costs*

Regional Offices. Regional offices process sample cases, supervise interviewers, and edit and keypunch completed interviews. Separate charges are incurred for regional office space and administrative support. Each regional office costs \$122 083 per year. A regional office is added or deleted whenever another set of 32 primary areas is added or deleted, where the number of primary areas (m_A) is determined from the allocation. For structure IV, the number of regional offices is also a function of the number of telephone facilities, determined by average telephone interviewer workload (W_B) and an expected facility size of 50 interviewers. In addition, since both personal visit and telephone interviews are administered from the same regional offices, the cost of structure IV regional offices is higher than for the other structures. However, it is assumed that many of the administrative functions performed separately in regional

offices and telephone facilities can be combined to reduce the overall facility costs for structure IV.

Hiring and Training. The costs of recruiting, hiring, and training include material, time, travel, and per diem for interviewers and supervisors. The average cost per interviewer per year for this training is \$320.94; this is not the cost for training each interviewer but only the average cost per interviewer employed. The number of interviewers needed to conduct the NCS is determined as a function of sample size ($m_A\bar{N}_A$) and average personal visit interviewer workload (W_A).

Interviewing. Interviewing costs include travel, interview time, field editing, general case processing, and other activities associated with obtaining a completed interview at each sample address. As Sirken and Casady (1983) discuss, one of the major concerns with a dual frame design and telephone interviewing in general is a higher nonresponse rate typically observed in telephone interviewing than in comparable personal visit surveys. The per completed interview costs implicitly take into account for the costs of failing to obtain interviews with some households (i.e., nonresponse). The nonresponse rate for personal visit interviews in the current NCS is approximately five percent. The interviewing cost is \$24.53 per completed household interview and is applied to the total number of personal visit interviews ($m_A\bar{N}_A$).

7.3. *Telephone Frame Costs*

Centralized Facilities. Costs of a centralized facility include administration, supervision, keypunching, and space charges. A pencil-and-paper mode of administration (not Computer Assisted Telephone Interviewing) is assumed. The facility is, based on SRC experience, estimated to cost \$58 800 per year to operate for the NCS. Only structures II and III have centralized facilities, and structure II expands the single facility by increments of 10 carrels costing \$13 710 each per year.

Hiring and Training. The costs of recruiting, hiring, and mass training sessions (i.e., materials, trainer and trainee time, and practice interviews, but no travel or per diem charges) are included in hiring and training costs. The average cost per telephone interviewer (not per trainee) per year is \$92.40. The number of interviewers is calculated from the sample size ($m_B\bar{N}_B$) and the average telephone interviewer workload (W_B).

Supplementary Training. Supplementary training of personal visit interviewers in telephone interviewing techniques is needed for structure I. It is estimated to cost \$41.20 per interviewer (not per trainee) per year.

Interviewing. Interviewing costs include the costs of dialing sample numbers, interviewing (including telephone charges), and data entry of completed interviews. As for the personal visit remaining per completed interview costs, the telephone remaining per completed interview costs implicitly take into account for the costs of nonresponding units and increasing the sample size to adjust for them. The nonresponse rate was set at 20 percent for the telephone interviewing component of the design. The cost varies by structure because of such factors as increased telephone charges for interviewing in interviewer homes and decreased telephone charges for centralized facilities located at geographically dispersed sites across the country. Total interviewing costs depend on the telephone frame sample size ($m_B\bar{N}_B$).

7.4. *Mixed Costs*

Transfers. The transfer costs include the costs of processing and completing personal visit interviews that have already been contacted by telephone. It is assumed that five percent of the cases will request this transfer, an additional interviewing cost of one-half the

personal visit interviewing cost is incurred, and, for structures II and III, an added \$10 charge is applied for the administrative activity associated with reassigning a telephone interview to a personal visit interview. The number of transfers depends on the telephone frame sample size ($m_B\bar{N}_B$).

7.5. Other Parameters

Table A2 presents values for other non-cost parameters which appear in the cost models. The personal visit interviewer workloads are the average number of completed household or person interviews for a personal visit interviewer in the 1980 NCS. The telephone interview workloads are estimates based on Survey Research Center experience for interviews of the same length. The area frame cluster sizes were derived from 1980 NCS primary area sizes. The telephone frame cluster sizes were derived from a consideration of optimal cluster size for a survey with the same relationship of cluster to interviewing costs and the same intracluster correlation.

Table A2. Average Workload (W_A, W_B) and Average Cluster Size ($\bar{N}_A$, $\bar{N}_B$) Used in Cost Models to Produce Annual NCS Estimates by Administrative Structure and Type of Crime

Workload/Cluster Size	Administrative Structure I	Administrative Structure II, III, IV
a. Total Personal Crimes, Robbery, and Assault		
W_A	230	690
W_B	460	1837
$\bar{N}_A$	940	940
$\bar{N}_B$	37	37
b. Total Household Crimes and Motor Vehicle Theft		
W_A	107	321
W_B	214	854
$\bar{N}_A$	437	437
$\bar{N}_B$	17	17

8. References

Cannell, C., Groves, R., Magilavy, L., Mathiowetz, N., and Miller, P. (forthcoming): An Experimental Comparison of Telephone and Personal Health Surveys. Vital and Health Statistics, National Center for Health Statistics, Washington, D.C.

Casady, R., Snowden, C. and Sirken, M. (1981): A Study of Dual Frame Estimators for the National Health Interview Survey. American Statistical Association, Proceedings of the Section on Survey Research Methods, pp. 444–447.

Groves, R. and Kahn, R. (1979): Surveys by Telephone: A National Comparison with Personal Interviews. New York: Academic Press, Inc.

Groves, R. and Magilavy, L. (1983): Investigations of the Magnitude and the Sources of Interviewer Effects in Telephone Surveys. Paper presented at the biennial meetings of the International Statistical Intstitute, Madrid.

Hartley, H. O. (1962): Multiple Frame Surveys. American Statistical Association, Proceedings of the Social Statistics Section, pp. 203–206.

Hartley, H. O. (1974): Multiple Frame Methodology and Selected Applications. Sankhya, Series C, 36(3), pp. 99–118.

Kish, L. (1965): Survey Sampling. New York: Wiley and Sons, Inc.

Lund, R. E. (1968): Estimates in Multiple Frame Surveys. American Statistical Association, Proceedings of the Social Statistics Section, pp. 282–288.

McGowan, H. (1982): Telephone Ownership in the National Crime Survey. Unpublished report, U. S. Bureau of the Census.

Sirken, M. and Casady, R. (1983): Nonresponse in Dual Frame Surveys Based on Area/List and Telephone Frames. American Statistical Association, Proceedings of the Section on Survey Research Methods, pp. 151–153.

Steinberg, J. (1965): A Multiple Frame Survey for Rare Populations. American Statistical Association, Proceedings of the Social Statistics Section, pp. 262–266.

Thornberry, O. and Massey, J. (1983): Coverage and Response in Random Digit Dialed National Surveys. American Statistical Association, Proceedings of the Section on Survey Research Methods, pp. 654–659.

U. S. Bureau of the Census (1978): The Current Population Survey; Design and Methodology, by R. H. Hanson. Technical Report No. 40, U. S. Government Printing Office, Washington, D. C.

Waksberg, J. (1978): Sampling Methods for Random Digit Dialing. Journal of the American Statistical Association, 73:361, pp. 40–46.

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