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A BIBLIOGRAPHY OF SELECTED STATISTICAL METHODS AND DEVELOPMENT RELATED TO CENSUS 2000

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OVERVIEW

In an attempt to help facilitate the continuing national conversation on the supplemental use of sampling methods as a part of Census 2000, this report is offered and contains two main parts:

PART I. SELECTED MOMENTS IN THE DEVELOPMENT OF PROBABILITY SAMPLING: Theory & Practice

This part focuses briefly on probability sampling methodology while pointing to selected moments in its development as a serious tool for scientific inquiry.

PART II. AN INDEX & THE LISTING OF AN ANNOTATED BIBLIOGRAPHY

This part provides brief summaries of selected papers which might be of interest to anyone with an interest in beginning a technical background study of the methodology which helps form the foundation of the Census Bureau's planned use of sampling and estimation to improve the count from Census 2000.

This report is a major revision of the earlier issued report (Third Edition: May 1, 2000) under the same title. We are grateful to our colleagues: Hazel Beaton for her expert typing of this report as well as the three earlier drafts, Juanita Rasmann for editing the final draft, Don Malec for calling the 1786 Laplace paper to our attention, and Yves Thibaudeau who read the 1786 Laplace paper (in French) and verified for us that Laplace's estimator can be viewed as similar to capture-recapture or dual system estimation.

PART I
SELECTED MOMENTS IN THE DEVELOPMENT OF PROBABILITY SAMPLING: Theory & Practice

Practically everyday we pick up the newspaper or tune in to a news broadcast and are bombarded with data in the form of numbers, graphs, and tables. We see the results of a study done by the *Gallup Poll.* Forest personnel can tell the number of deer inhabiting a certain land area. Reliable estimates of world grain production can be made before harvest by use of satellite data. *Nielson's Ratings* can tell the approximate number of people who watched television in a given week and the proportion who watched a particular program. Much of this information and more is made possible by an area of statistics referred to as *probability sampling* or simply *sampling.*

Uses of Sampling

Sampling methods are used throughout the world by a variety of individuals, groups, and organizations, as well as by local, state, and national governments. They are used successfully in many fields including agriculture, business, defense, economics, education, energy, environment, finance, health, industry, labor, natural resource management, demographics, and transportation. Some specific applications include taking opinion polls, election polls, and polls for rating TV programs; surveying animal populations (particularly fish, deer, etc.) and farms; taking a sample of buildings; taking air samples to monitor air quality; sampling to monitor traffic activity; sampling to estimate energy consumption; sampling to monitor a nation's economy; taking samples before marketing a new product; taking a sample for auditing or inventory purposes; taking soil samples to measure radioactivity levels; sampling to monitor employment; sampling to monitor education progress; and taking samples of products produced at a manufacturing plant to monitor output quality.

"All scientific observation, whether statistical or not, is based on *sampling*," says Stephan (1948).[(1)] "The earliest examples of sampling procedures are to be found in certain very ordinary human activities. The common practice of taking a small part or portion for tasting or testing to determine the characteristics of the whole precedes recorded history and is one of the roots from which sampling methodology stems..."

Population and Sample

The current approach to sampling assumes a given finite collection of units, called a *population*. It is often the case that certain characteristics of the population are needed but unknown. When examination of each and every unit in the population is undesirable to know a particular population characteristic, a *sample*, i.e., a subset or portion of the population, may be selected to yield satisfactory information regarding the particular population characteristic. The population characteristic is often a quantitative one. In such cases, a *statistic* is computed using information collected from the small and more manageable sample, and its value is used to *estimate* the unknown value of the population characteristic. Although we desire a sample that will provide a "good" estimate of the unknown value of the population characteristic, it is certainly conceivable that the sample information obtained could lead to a very incorrect estimate.

Sampling and Nonsampling Errors

Error is the difference between the known value of the estimator from the sample and the (true but unknown) value of the population characteristic. Error can occur due to sampling reasons and/or nonsampling reasons. *Sampling error* is the error that is caused by measuring only the sampling units instead of all of the population units. *Nonsampling error* is the error that is caused by reasons other than sampling. Examples of nonsampling errors include failure to get responses from all of the sample units, failure of the measuring device to operate properly, and failure to correctly process the sample data.

It is well known that the magnitude of nonsampling errors can far exceed the magnitude of sampling error in a given sample. Unfortunately while much has been written about measuring and controlling sampling error, relatively little is known about the quantification and estimation of the magnitude of nonsampling errors. Current practice seeks to minimize both sampling and nonsampling errors. Small samples where resources are used to implement high quality data collection methods which control and minimize nonsampling errors along with efficient statistical techniques (sampling and estimation) that seek to minimize sampling error is an attractive combination for success.

Probability Sampling

Probability sampling makes use of the laws of probability in the selection of the sample and in the construction of efficient estimators. With *probability sampling*, every population unit has a known positive chance of being selected for the sample. Probability sampling provides a means for saying how good one believes an estimate is relative to all the possible estimates from all of the possible samples. That is, probability allows us to extend results from the sample to the entire population.

A Census or a Sample

When limited resources such as time and costs dictated that a complete census was not possible, sampling has been an alternative. Historically, however, the application of sampling techniques has had its ups and downs, largely owing to common misconceptions about sampling.

The heart of these misconceptions seems to be a belief that if one wants to know something about a given population, it is better to contact the entire population (a census) rather than only a sample of the population. As Kish (1979) [2] has pointed out, censuses, if done correctly, have the potential advantage of providing precise, detailed, and credible information on all population units. On the other hand, samples have the advantage of providing richer, more complex, accurate, inexpensive, and timely information for a sample which can be extended to the entire population.

Indeed the joint judicious use of both sampling and census taking offers the best opportunity for greatest benefit.

Sampling: Its Development

Following are selected major moments in the theoretical and practical development of probability sampling methodology.

1802: P.S. Laplace uses sampling to estimate the population of France as of September 22, 1802. Laplace persuaded the French government to take a sample of the small administrative districts known as communes and to count the total population y in the sample communes on September 22, 1802. From the known total number of registered births (birth registration was required) during the preceding year in these communes x and in the whole country

X, the *ratio estimate* $X\frac{y}{x}$ of the population of France could be calculated. Laplace also derived several theoretical properties of the estimator. Laplace (1786) demonstrated this method earlier in estimating the 1782 population of France.[3] Assuming a closed population (i.e., no births, deaths, nor movement across population boundaries during the preceding year), this ratio estimator is similar to the Petersen estimator. A similar method had been used for estimating the population of England as early as 1662 by John Graunt.[4]

19th Century: There is very limited use of sampling. For government statistical agencies, the generally accepted method of coverage was a complete enumeration. Very limited sampling was done.[5]

1895: A.N. Kiaer calls for sampling based on the "representative method." At the Berne meeting of the International Statistical Institute (ISI), Kiaer (first Director of the Norwegian Central Bureau of Statistics) puts forward the idea that a partial investigation (i.e., a sample) could provide useful information based on what he called the "*representative method*." His representative method aimed to produce a sample which was a miniature of the population and can be described as follows: (1) in social and economic surveys, one could begin by choosing districts, towns, parts of cities, streets, etc., to be followed by systematic, rather than probabilistic, choice of units (houses, families, individuals); (2) there should be substantial sample sizes at all levels of such a selection process; (3) the sample should be spread out in a variety of ways, primarily geographically, but in other ways as well. For example, if a sample had a deficiency of cattle farmers, he would add more of them. [5]

1896: Petersen presents a sampling methodology for estimating the size of a finite population. The Petersen estimator provides the heuristic basis of most estimators of wildlife population size; and from humble beginnings, a very large *capture-recapture* scientific literature has developed. [6]

1897: At a conference of Scandinavian statisticians held in Stockholm, a conference resolution gives guarded support for the representative method being promoted by A.N. Kiaer. [5]

1903: Randomization is proposed for use in sample selection. Lucien March, a French statistician, who, in the discussion to Kiaer's paper at the 1903 Berlin International Statistical Institute meeting, was the first to introduce (with caution) concepts related to the use of probability (i.e., randomization) in the selection of the sample.[5]

1906: Bowley presents a central limit theorem for random sampling. Arthur Lyon Bowley presents a paper which seeks to give an empirical verification to a type of *central limit theorem* for simple random sampling by observing that the distribution of 40 sample means was approximately bell-shaped (i.e., normal).[5]

1912: Bowley uses a systematically chosen sample of houses to study poverty in Reading, England. Bowley often checked the representativeness of his samples by comparing his sample results to known population counts of variables on which these counts were available. For two cases in which he found a discrepancy between his sample and the official statistics, on further checking he discovered that the official statistics were in error.[5]

1925: Based on the work of a commission to study the application of the representative method, the International Statistical Institute's meeting in Rome adopts a resolution which gives acceptance to certain sampling methods both by *random* and *purposive* (non-random) selection.[5]

1926: Bowley provides a theoretical monograph on random and purposive selection. As a major discussant of the resolution adopted on the representative method at the 1925 International Statistical Institute meeting, Bowley provided a theoretical monograph summarizing the known results in random and purposive selection. In addition to several other ideas, the monograph contains a development of stratified sampling with proportional allocation and a theoretical development of purposive selection through correlation between control variables and the variable of interest. This latter development included formulae for the measurement of the precision of the estimate under a purposive sampling design.[5]

1928-1929: Purposive selection does not always work. For example, Corrado Gini and Luigi Galvani describe the selection of a sample from the 1921 Italian Census where the sample was "balanced" on seven important variables and made a purposive selection of 29 out of 214 administrative units in Italy. The resulting sample showed wide discrepancies with the census counts on other variables.[5]

1934: Jersey Neyman's "landmark" paper is published which played a paramount role in promoting theoretical research, methodological developments, and applications of what is now known as *probability sampling*. In this paper, Neyman was able to provide cogent reasons, both theoretically and with practical examples, why randomization gave a much more reasonable solution than purposive selection to the problems that then confronted sampling statisticians. A second major achievement of Neyman's paper is that it provides a theory of point and (confidence) interval estimation under randomization that breaks out of an old train of thought and opens up new areas of research.[5],[7]

1937: W. Edwards Deming invites Neyman to come to Washington, D.C. to give a series of lectures on probability sampling.[5]

1938: U.S. Census Bureau uses national sample to estimate unemployment. In the mid-1930's, the United States was in the grip of the Great Depression, and there was urgent need for current information on the unemployed. But estimates of the number of employed varied by many millions of persons and the next decennial census would not occur until 1940. A *Census of Unemployment* was undertaken as a nationwide voluntary registration of the unemployed and partially unemployed. Lack of confidence in the ability to control the accuracy of the unemployment registration (through the post office) led to the idea of an *enumerative check (sample)*. The Enumerative Check (Sample) involved an enumeration of a sample of the total population, including all households in a 2 percent sample of postal delivery routes... The national registration and the check survey were done in November 1937, preliminary reports began by January 1938, and the final published reports were completed in 1938. The Enumerative Check (Sample) achieved the recognition, in the Census Bureau and elsewhere, that large-scale sample surveys could make substantial contributions, and under appropriate design and control, could produce timely information that was more accurate than complete censuses or national registrations. Many point to this survey as an immediate consequence of Neyman's Washington lectures earlier in 1937 and as the step that gave the Census Bureau the confidence to use sampling in the 1940 Census. The Enumerative Check (Sample) led to the Sample Survey of Unemployment which was started in March 1940 as a monthly activity of the Work Projects Administration (WPA) to measure unemployment. In August 1942, responsibility for the Sample Survey of Unemployment was transferred to the Bureau of the Census, and the sample survey is known worldwide today as the Current Population Survey. A model source of labor market information as well as a wealth of other social and economic data, the Current Population Survey provides what many would consider the leading indicator of our society's well-being -- in the monthly unemployment rate.[8],[9]

1940: Morris Hansen leads the move for implementation of sampling in the 1940 Census of the United States. In an effort to control and limit the extent of efforts to obtain needed information on every person captured in the 1940 Census, sampling was introduced. These changes partly reflected the demand from government and the public for additional information for use in research and policy-making regarding unemployment, occupational shifts, migration, population growth, and so forth. In order to provide this data without requiring it of everyone, a sample of 1 out of 20 people nationwide was selected to answer supplementary questions. Although statistical estimates relating to the supplementary questions were made for the entire population, the population count was the result of summing the individuals captured on all of the collection forms nationwide (without the use of sampling). [5],[10]

1943: Hansen and Hurwitz provide theory for unequal probability selection of sample units. Up to the 1940s, just about all theory and practice was about equal probability of each unit in the population being included in the sample. In their 1943 paper, Hansen and Hurwitz took an important step forward by extending the idea of sampling with unequal inclusion probabilities for units in different strata as put forward by Neyman to differing inclusion probabilities for all units within a stratum. This allowed the development of very complex multi-stage sampling designs that are the backbone of just about all large-scale sample surveys, especially those by governments, done today. With these surveys, large samples with acceptable (not necessarily minimal) levels of variance could be conducted at a reasonable cost.[5],[11]

1949: United Nations Subcommission on Statistical Sampling strongly recommends use of "replicated or interpenetrating samples." Citing Mahalanobis' technique of *replicated* or *interpenetrating samples* applied to jute and rice surveys in India, the United Nations Subcommission on Statistical Sampling strongly recommends use of the technique whose main purpose was (and is) to control and reduce nonsampling errors. One important consequence of the technique is its simplicity in the estimation of sampling variance regardless of the complexity of the form of the estimator.(12)

1952: Horvitz and Thompson present a general theory of sampling with unequal probabilities. This general theory was centered around what has come to be known as the *Horvitz-Thompson estimator* of a population total. In addition to being unbiased, there is no other estimator in a particular class of estimators, which has smaller sampling error than the Horvitz-Thompson estimator.(13)

1953: Two highly cited books (to this day) on probability sampling theory are published. The books which continue to have tremendous influence on the field of probability sampling are:

Cochran, W.G. (1953). *Sampling Techniques*, New York: Wiley and Sons, Inc.

Hansen, M.H., Hurwitz, W.N., and Madow, W.G. (1953). *Sampling Survey Methods and Theory, Vols I and II*, New York: Wiley and Sons, Inc.

1955: Godambe proves that there does not exist a uniformly "best" estimator of the population mean under randomization. In his 1955 paper, V.P. Godambe proved that there is no estimator of the finite population mean which has uniformly minimum variance, within a certain (reasonable) class of estimators. This result caused a reexamination of the *foundations of probability sampling theory* and has led to a serious consideration of the use of *models* in providing more theoretical justifications for many probability sampling techniques. One important focus has been around work initiated by Royall in his 1970 paper.(14)

1968: Small Area Synthetic Estimation is first used based on a national survey. Typically, estimates for a geographic area use only data gathered from the particular area. As the demand for statistics on smaller geographic areas grows, a large enough sample to support precise estimates can become prohibitively expensive. Synthetic estimates, based on the assumption that differences among a population can be characterized mainly by age, race and sex, and not geographic areas, are employed to provide estimates of disability at the state level. This estimation technique is still employed today, however many of the limitations have been determined and documented, in the ensuing decades. This continuous research has resulted in many improved small area estimation techniques, notably the "borrowed strength" estimators.(15),(16)

1970: Under a *model*, Royall shows that the ratio estimator(4) is the "best" estimator of a population total for any sample (random or nonrandom), selected only according to the values of known correlated auxiliary data. With his model, Richard Royall found that by purposively selecting the units associated with the largest values of known auxiliary data, the model sampling error of the ratio estimator was minimized. Though others (e.g., Cochran, Brewer) had earlier used models for benefits, Royall's work generated considerable research around *model-based inference in sampling* as well as the traditional *design-based inference in sampling*. Probability is used to access the goodness of statistical methods. With models, the probability comes with the chosen model; with sampling designs, the probability comes with the randomization used for the sample selection. When models hold, model-based inference is hard to beat. However, randomization through design-based inference offers protection against model failure. Today, many researchers and practitioners make use of both.(17)

1970: The 1970 Census of the United States adds 1.5 million people based on sampling. The 1970 Census was the first census to be conducted in most areas by mail; it was also one that used two sampling efforts to contribute to the official census totals. The problems were (1) that the Census Bureau had found in pretests that occupied units incorrectly reported as vacant were a significant factor in the population undercounts and (2) that, from the 1960 Census, housing unit coverage in the South was considerably worse than in the rest of the United States. The first sampling effort, called the National Vacancy Check, selected for visits and interviews a sample of 13,546 housing units from a list of units that had been classified as vacant. Based on the sample results, approximately 8.5 percent of all the units initially classified as vacant were reclassified as occupied and an estimated 1,068,882 people-0.5 percent of the total 1970 Census count - were added to the count. The second effort, the Postenumeration Post Office Check, was used in 16 southern states. In this check, the U.S. Post Office matched its list of addresses for certain areas (those counted by visits rather than mail) with the addresses from the census. From all addresses on the Post Office list but not on the census list, the Census Bureau selected a sample for visits. On the basis of the sample results, about 484,000 people were added, or 0.8 percent of the entire South and 0.2 percent of the total U.S. population.(18)

1983: The National Health and Nutrition Examination Survey (NHANES) finds high levels of lead in Americans' blood. This national survey provided the first clear-cut evidence that Americans had too much lead in their blood. As a result, Congress, the Environmental Protection Agency, and others phased out the use of lead as a gasoline additive. This survey has been used to continuously monitor the dramatic decline in the blood-lead levels resulting from this action.[19]

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(3) Laplace, P.S. (1786). "Sur Les Naissances, Les Mariages Et Les Morts," In *Histoire de L'Academie Royale des Sciences*, 1783, Paris, 693-702.

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(6) Boswell, M.T., Burnham, K.P., and Patil, G.P. (1988). "Role and Use of Composite Sampling and Capture-Recapture Sampling in Ecological Studies," in (P.R. Krishnaiah and C.R. Rao, Editors) *Handbook to Statistics: Sampling, Vol. 6,* New York: Elsevier Science Publishers B.V., 469-488.

(7) Neyman, J. (1934). "On the Two Different Aspects of the Representative Methods: The Method of Stratified Sampling and the Method of Purposive Selection," *Journal of the Royal Statistical Society, 97,* 558-625.

(8) Hansen, M.H. and Madow, W.G. (1976). "Some Important Events in the Historical Development of Sample Surveys," in (D.B. Owen, Editor) *On the History of Statistics and Probability*, New York: Marcel Dekker, 75-102.

(9) *Current Population Survey: Design and Methodology, Technical Paper 63 (March 2000).* Washington, D.C.: Joint publication of the U.S. Census Bureau and Bureau of Labor Statistics.

(10) Stephan, F.F., Deming, W.E., and Hansen, M.H. (1940). "The Sampling Procedure of the 1940 Population Census," *Journal of the American Statistical Association, 35,* 615-630.

(11) Hansen, M.H. and Hurwitz, W.N. (1943). "On the Theory of Sampling from Finite Populations," *Annals of Mathematical Statistics, 14,* 332-362.

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(13) Brewer K.R.W. and Hanif, M. (1983). *"Sampling with Unequal Probabilities,"* New York: Springer-Verlag.

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(15) National Center for Health Statistics (1968). "Synthetic State Estimates of Disability," *Public Health Service Publication No. 1759.* U.S. Government Printing Office.

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(19) Annest, J.L., Pirkle, J.L., Makuc, D., Neese, J. W., Bayse, D.D., Kovar, M.G. (1983). "Chronological Trend in Blood Lead Levels between 1976 and 1980," *The New England Journal of Medicine, 308, 23,* 1373-1377.

PART II: AN INDEX & THE LISTING OF AN ANNOTATED BIBLIOGRAPHY

Building on several lists of papers and documents assembled first by Howard Hogan and a bibliography by Steve Fienberg (1992a), published papers on the use of statistical methods (especially sampling) in census taking were obtained, many by members of the Census Bureau's research staff. With few exceptions as noted, almost all entries occur in refereed journals and/or proceedings of professional meetings. The list demonstrates a wealth of scientific research (and discussion) which helps form the foundation for much of the Census Bureau's Census 2000 Plan of providing the most accurate census. The CENSUS 2000 Plan is indeed the result of many decades of effort and development.

There is tremendous overlap of subjects among the listed papers. The following subject index is an attempt to direct the reader to papers that focus mainly on the indicated subject. Each reference is given in terms of the year of publication and the number of the paper within the year. The references for each subject are not exhaustive. In most cases, the description of a given paper's contents comes from the paper's abstract. Any misinterpretation of a paper's contents is unintended. We have attempted to provide summaries which point to each paper's relation to the Census 2000 Plan. As with any listing of papers, no claim is made that this one is free of undercoverage or overcoverage.

SUBJECT INDEX

1896

[1] PETERSEN, C.G.J. (1896). "The Yearly Immigration of Young Plaice into the Limfjord from the German Sea," *Report of The Danish Biological Station to The Ministry of Fisheries, 6,* 1-48.

This paper deals with experiments involved in the counting of plaice (a type of fish) in the Limfjord in 1895 and their migration. The ultimate objective of these experiments was to help control the fish supply in order to get a considerably increased income from this plaice fishery.

One of the experiments in a section of Limfjord known as Thisted-Bredning involved a transplantation of about 82,580 plaice of which 10,900 were marked with a hole in the dorsal fin. Petersen noted that it was reasonable to assume that there were no other plaice in this section of Limfjord. On three different occasions, samples of plaice were caught, and the number marked was noted in each case. Petersen reports, "In October 1895, I saw 28 plaice in Thisted harbor, 6 of which were marked. In December 1895, when many large plaice were caught at Thisted, a thoroughly reliable man estimated 560 of them; 112 of them were marked with one hole in the dorsal fin... Later on in December 1895, another man examined 440 at Thisted, and he informs me that 81 were marred with a hole in the dorsal fin..." In each sample case, "... about every 5^{th} (6/28; 112/560; and 81/440) of those which were caught this year had such a hole, which proves that no other plaice live in that expansion of the Fjord."

Because about every 7^{th} (10,900/82,580) in the transplanted population had been marked, Petersen expected the same proportion for each of the samples; he thought the result was very strange and offered explanations for it. That is, Petersen expected

$$\frac{\textit{Number Marked in Population}}{\textit{Number in Population}} = \frac{\textit{Number Marked in Sample}}{\textit{Number in Sample}}$$

or equivalently

$$\textit{Number in Population} = (\textit{Number in Sample})\ \frac{(\textit{Number Marked in Population})}{(\textit{Number Marked in Sample})}.$$

*(*The importance of this last expression is that it gives an early reference to the concept for the statistical estimation methodology of Census 2000 based on conventional counting and sampling which the Census Bureau refers to as *dual-system estimation,* while it is more commonly referred to as *capture-recapture methodology* with the *Petersen estimator.)*

1924

[1] GEIGER, H. and WERNER, A. (1924). "Die Zahl der von Radium ausgesandten α-Teilchen," *Zeitschrift für, Physik, 21,* 187-203.

This paper applies a capture-recapture method to radium ion particle detection estimation.

1930

[1] LINCOLN, F.C. (1930). "Calculating Waterfowl Abundance on the Basis of Banding Returns," *Circular No. 18 (May 1930),* U.S. Department of Agriculture, Washington, D.C. , 1-4.

It is the intent of this article to suggest what seems to be a reliable method of calculating the annual fluctuations in the abundance of waterfowl. Briefly stated, the solution of the problem (estimation of total number of ducks) as here advanced is to be found in the following postulate: "Given a fairly accurate statement showing the number of wild ducks killed in North America in any one season, then the total number of ducks present on the continent for that season may be estimated by a percentage computation, based upon the relation that the total number of banded ducks killed during their first season as band carriers bears to the total number banded. ...To assume a case: If in one season 5,000 ducks were banded and yielded 600 first-seasons returns, or 12 per cent, and if during that same season the total number of ducks killed and reported by sportsmen was about 5,000,000, then this number would be equivalent to approximately 12 per cent of the waterfowl population for that year, which would be about 42,000,000."

1938

[1] SCHNABEL, Z.E. (1938). "The Estimation of the Total Fish Population of a Lake," *American Mathematical Monthly, 45,* 348-352.

The purpose of this note is to discuss and compare as to fundamental assumptions four different methods which have been developed for the estimation of the fish population of a given lake from a sample census. The paper provides some mathematical theory for capture-recapture estimation and provides extensions to multiple recaptures.

1940

[1] DEMING, W.E. and STEPHAN, F. F. (1940). "On a Least Squares Adjustment of a Sampled Frequency Table When the Expected Marginal Totals Are Known," *Annals of Mathematical Statistics, Vol. 11*, 427-444.

There are situations in sampling wherein the data furnished by the sample must be adjusted for consistency with data obtained from other sources or with deductions from established theory. For example, in the 1940 Census of population, a problem of adjustment arises from the fact that although there will be a complete count of certain characteristics for the individuals in the population, considerations of efficiency will limit to a sample many of the cross-tabulations of these characteristics. The tabulations of the sample will be used to estimate the result that would have been obtained from cross-tabulations of the entire population.

In estimating any cell frequency of the universe in a two-way layout, three possibilities present themselves. In this paper, the authors present a rapid method of adjustment, which in effect combines all three possibilities. The method is extended to varying degrees of cross-tabulations in three dimensions.

1941

[1] TRACEY, W.R. (1941). "Fertility of the Population of Canada," Reprinted from *Seventh Census of Canada, 1931, (Vol. 2),* Census Monograph No. 3. Ottawa: Cloutier.

This paper provides an early application of the dual systems approach to census data.

1944

[1] BLEGVAD, H. (1944). "The Danish Biological Station through 50 Years 1889–1939," *Report of The Danish Biological Station to The Ministry of Agriculture and Fisheries, 45,* Copenhagen: C.A. Reitzels, 1-69.

In 1939 the Danish Biological Station had existed for 50 years. The history and the work of the Station during these years may be said to be the mirror of the history of the Danish fishery throughout the same period. The paper provides summaries of the important work of the Station, including that by C.G.J. Petersen, the Station's first director.

1947

[1] PRICE, D.O. (1947). "A Check on Underenumeration in the 1940 Census," *American Sociological Review, Vol. XII,* 44-49.

This paper presents a study of the variations between Selective Service and census figures on a state basis which gave no clue to the factors associated with underenumeration except migration between the time of the census and the Selective Service Registration. Data are presented that 452,866 (2.81 percent of the census count) more men nationwide registered for the Selective Service than were counted in the 1940 Census. Also, 228,714 (14.88 percent of the census count) more African-American males nationwide registered for the Selective Service than were counted in the 1940 Census.

1949

[1] CHANDRA SEKAR, C.C. and DEMING, W.E. (1949). "On a Method of Estimating Birth and Death Rates and the Extent of Registration," *Journal of the American Statistical Association, Vol. 44*, 101-115.

A mathematical theory is presented which, when applied to a comparison of the registrar's list of births and deaths with a list obtained in a house-to-house canvas, gives an estimate of the total number of events over an area in a specified period; also the extent of registration. In the development of the theory, allowance is made for the fact that the chance of an event being missed on one list (registrar's list or the house-to-house canvas) may not be independent of its chance of being missed on the other list. Where there is likely to be lack of independence, a test is suggested and a method introduced to reduce the effect of dependence. This is done by subdividing the data into small homogeneous groups, such as might be formed by small areas, sex and age classes, domiciliary and institutional births; then by estimating the number of events in these groups separately and summing them for a total. The standard errors of the estimates are given.

[2] SHAPIRO, S. (1949). "Estimating Birth Registration Completeness," *Journal of the American Statistical Association, 45*, 261-264.

A nationwide test on the completeness of birth registration was carried out in 1940 in connection with the 1940 Census.

The present paper discusses the comparison, based on this data, of two methods of obtaining percent completeness of birth registration by states: 1) by relating a matched set of records for the state as a whole to the total group of matched and unmatched records combined; and 2) by a cumulative technique suggested by Chandra Sekar and Deming (1949). Differences in the results by the two methods were minor except in those areas having a comparatively high degree of under-registration.

1951

[1] CHAPMAN, D.G. (1951). "Some Properties of the Hypergeometric Distribution with Applications to Zoological Sample Censuses," in the *University of California Publications in Statistics, Vol. I, 1949-1953,* (Eds. G.M. Kuznets, E.L. Lehmann, M.M. Loève, J. Neyman, O. Struve, and J. Yerushalmy*).* London: Cambridge, 131-159.

In this paper, certain aspects of the problem of sampling without replacement from a finite population are treated; such sampling involves the use of the hypergeometric distribution. The results are applied to a problem that arises in many zoological studies, viz., the determination of the total size of the population under consideration. In such studies, it is necessary to estimate and to compare population sizes in order to formulate plans, or to evaluate the results, for either extermination or conservation programs.

Since a total census is usually impractical, some sampling approach to the problem must be undertaken. The practical considerations which usually exist in such a sample census are kept in mind throughout this paper.

[2] MANTEL, N. (1951). "Evaluation of a Class of Diagnostic Tests," *Biometrics, 7*, 240-246.

Medical diagnostic tests constitute a class of diagnostic tests which, under certain control conditions, yield no false positives. How good any one such diagnostic test is, is measured by the probability that an infected person will be found positive by a single application of the test. If we assume that this probability is the same for all infected individuals, we may term this probability the *efficiency* of the diagnostic test. Also, in addition to estimating the efficiency of the test, we may be required to estimate the *prevalence* of the infection in the population for which our group is considered to be a representative sample. These problems, estimation of efficiency and prevalence, are considered and solutions provided. The solutions assume that examination efficiency is the same for all infected individuals. When there is unequal examination efficiency among the infected individuals, i.e., heterogeneity, reference to a partial solution is noted.

1953

[1] HANSEN, M.H., HURWITZ, W.N., and MADOW, W.G. (1953). *Sample Survey Methods and Theory, Vols. I and II.* New York: John Wiley and Sons, Inc.

Volume I, in a sense, is a report on the applied sampling work in the United States Bureau of the Census. Volume II contains the fundamental theory on which sampling methods are based, together with derivations of the formulas and proofs of statements made in Volume I.

1954

[1] SHAPIRO, S. (1954). "Recent Testing of Birth Registration Completeness in the United States," *Population Studies, 8,* 3-21.

This article is a sequel to "Development of Birth Registration and Birth Statistics in the United States," which appeared in the June 1950 issue of the Journal. The earlier article contained a description of the first nationwide test of birth registration completeness in the United States, which was conducted in conjunction with the 1940 Census. Plans for carrying out a similar test in 1950 were mentioned. The present article discusses briefly the factors affecting the methodology of this test, presents some of the results, and considers the comparability of the 1940 and 1950 test figures. The final section of the paper consists of observations on the subject of testing birth registration completeness based on the experience gained.

1955

[1] COALE, A.J. (1955). "The Population of the United States in 1950 Classified by Age, Sex, and Color–A Revision of Census Figures," *Journal of the American Statistical Association, Vol. 50,* 16-54.

This article is addressed to errors of omission and mistaken inclusion in the 1950 Census, and to the erroneous classification of persons according to their age, sex, and color.

1958

[1] CHRISTENSEN, H.T. (1958). "The Method of Record Linkage Applied to Family Data," *Marriage and Family Living, 20,* 38-43.

This report is to deal with "record linkage," a relatively new approach in research, accompanied by illustrations of its applications to a few specific problems in the area of family phenomena. Briefly stated, record linkage consists of using documentary sources--in contrast to data obtained by questionnaires, interviews, or direct observation--and of cross-checking and matching these records against each other.

[2] DARROCH, J.N. (1958). "The Multiple-recapture Census I: Estimation of a Closed Population," *Biometrika, 45*, 343-359.

The present paper treats the multiple-recapture census for which the population is closed both to augmentation from outside and departure from inside and the number of samples *s* is fixed.

1959

[1] DARROCH, J.N. (1959). "The Multiple-recapture Census II. Estimation When There is Immigration or Death," *Biometrika, No. 46*, 336-351.

This paper treats the multiple-recapture census for which the population is not closed. The aims of this paper are to provide exact, fully stochastic models for the observed frequencies of individuals, to show how simply these frequencies naturally group themselves, and to obtain estimates of the unknown parameters. When there is immigration only or death only, the estimates are shown to be asymptotically efficient and their variances are found. In addition, a method of performing tests on the values of the parameters is given. When both immigration and death are operating, on the other hand, the complexity of the probability density prevents us from going further than obtaining the estimates and merely indicating how their variances can be found.

[2] SEN, P.K. (1959). "On the Estimation of the Population Size by Capture-Recapture Methods," *Calcutta Statistical Association, Bulletin 9*, 93-110.

In this paper, the author investigates the asymptotic convergence of the variances of the estimates (relating to the capture-recapture method) to the 'information limit' in both the cases of the second sample being drawn with and without replacement.

[3] DEMING, W.E. and GLASSER, G.J. (1959). "On the Problem of Matching Lists by Samples," *Journal of the American Statistical Association, Vol. 54,* 403-415.

This paper presents theory for estimation of the proportions of names common to two or more lists of names, through use of samples drawn from the lists. The theory covers the probability distributions, expected values, variances, and the third and fourth moments of the estimates of the proportions duplicated, testing a hypothesis with respect to a proportion, optimum allocation of the samples, the effect of duplicates within a list, and possible gains from stratification. Examples illustrate some of the theory.

1961

[1] DARROCH, J.N. (1961). "The Two-Sample Capture-Recapture Census When Tagging and Sampling Are Stratified," *Biometrika, 48,* 241-260.

The author starts by recalling the capture-recapture argument used for the simplest type of experiment with only two samples and negligible death and emigration rates. Let *a* animals be taken from a population, marked and put back into it. After allowing time for these *a* individuals to 'mix' with the others, let a second sample be taken and suppose that it comprises b unmarked individuals and c marked ones. Then, if it is assumed that *every individual has the same probability p of being a member of the second sample*, p is estimated by $\tilde{p} = c/a$ and, if n is the number of unmarked individuals in the population at the time of the second sample, n is estimated by $b/\tilde{p} = ab/c$. We shall denote this estimate by $\tilde{n}_p$ and refer to it as the Petersen estimate, although this name is usually given to $\tilde{n}_p + a = a(b+c)/c$, the estimate of total population size. In practice, the assumption in italics can be violated in many ways which may be summarized as follows. (i) Animals can differ in their inherent catchability. (ii) The catchability of an animal may change after being captured and marked. (iii) The probability p can vary geographically over the region occupied by the population, partly because the animals are more catchable in one locality than another and also because the effort expended in catching them is not uniform over the region. Stratification at the selection of the first sample and again at the selection of the second sample is used to help provide estimation methodology when the assumption fails.

[2] HANSEN, M.H., HURWITZ, W.N., and BERSHAD, M.A. (1961). "Measurement Errors in Censuses and Surveys," *Bulletin of International Statistical Institute 38, Part 2,* 359-374.

In a census or a sample survey, we may obtain observations through personal inquiry, direct questionnaire, or other methods, of the age, income, buying performance, attitude on a particular question, acreage, or other characteristic of a person, household, farm, business, area, or other unit. The set of measurements or observations recorded in the collection operation ordinarily are examined for internal consistency and acceptability, certain 'corrections' may be made, and some of the entries may be coded to identify them in a classification system. The results are then summarized into totals, averages, correlations, or other statistical measures. Taken together the collection and processing operations constitute the measurement process and are the source of any measurement errors. The authors present an expression of total variance including response variance, sampling variance, and a covariance term. An analysis of response variance is given as well as methods for the estimation of response variance.

1962

[1] DAVIDSON, L. (1962). "Retrieval of Misspelled Names in an Airline Passenger Record System," *Communications of the Association of Computer Machinery, 5,* 169-171.

This paper discusses the limited problem of recognition and retrieval of a given misspelled name from among a roster of several hundred names, such as the reservation inventory for a given flight of a large jet airliner. A program has been developed and operated on the Telefile (a stored-program core and drum memory solid-state computer) which will retrieve passengers' records successfully, despite significant misspellings either at original entry time or at retrieval time. The procedure involves an automatic scoring technique which matches the names in a condensed form. Only those few names most closely resembling the requested name, with their phone numbers annexed, are presented for the agent's final manual selection. The program has successfully isolated and retrieved names which were subjected to a number of unusual (as well as usual) misspellings.

1963

[1] CHAKRABORTY, P.N. (1963). "On a Method of Estimating Birth and Death Rates from Several Agencies," *Calcutta Statistical Association Bulletin, 12,* 106-112.

The paper aims at presenting a method of estimation of population size in the general case of k different listings of units over a large area from k different sources. It is shown that this estimate, which is a generalization of that of Chandrasekar and Deming (1949), is consistent. An expression for the large sample standard error of this estimate is given for $k=3$. It is further shown that this estimate is asymptotically equivalent to the maximum likelihood estimate for $k=2$. Finally, the results of a sampling experiment are presented to show the practical usefulness of the estimate.

[2] COALE, A.J. and ZELNIK, M. (1963). *New Estimates of Fertility and Population in the United States*, Princeton, N.J.: Princeton University Press.

The inaccuracy of census enumerations has meant that conclusions are based on census data, including per capita rates such as death rates, that have been erroneous, and to an unknown degree. In some instances, the size of the error involved is small and of only minor significance; in other instances, the error may be much larger and may have led to seriously defective conclusions. This book is an attempt to fill these gaps in United States demographic data by providing estimates of annual births and birth rates for the white population of the United States back to the 1850's, and by providing estimates of census enumeration errors, by age and sex, for the native white and total white populations enumerated in the decennial censuses from 1880 to 1950.

[3] COCHRAN, W.G. (1963). *Sampling Techniques (Second Edition)*, New York: Wiley and Sons. [Third Edition (1977)].

This book presents a comprehensive account of sampling theory as it has been developed for use in sample surveys, with illustrations to show how the theory is applied in practice.

1964

[1] BOGUE, D.J., MISRA, B.D., and DANDEKAR, D.P. (1964). "A New Estimate of the Negro Population and Negro Vital Rates in the United States, 1930-60," *Demography, Vol. I*, 339-358.

It is suspected that the African-American population of the United States has been underenumerated by a sizable percentage at all the censuses since 1790, and the registration of births and deaths is thought to have been very incomplete, especially before 1950. As a result, American demographers have tended to regard population statistics for African-Americans as so inadequate as to be untrustworthy for refined analysis.

The present research takes advantage of certain facts (rise in level of educational attainment and improved coverage of the African-American population in the 1960 Census) to attempt to construct a set of estimates of what the count of African-Americans, by age and sex, would have been at each census since 1930 had there been only an insignificant error in reporting.

In the estimation presented in this paper, the authors have avoided making use of previous assumptions about underregistration of births and correctness of age statement at the childhood ages. The authors assumed that the most reliable data available for the African-American population are (a) the total census count without reference to age and (b) the registration data for deaths by age. The authors have made their estimates in two major stages. First, they have made them with respect to the 1960 Census after adjusting the 1960 Census for obvious errors at particular ages. Then, by estimating the absolute level of error in the 1960 Census that might apply uniformly to all ages, they have adjusted the estimates for earlier censuses to an absolute basis.

[2] DAS GUPTA, P. (1964). "On the Estimation of the Total Number of Events and of the Probabilities of Detecting an Event from Information Supplied by Several Agencies," *Calcutta Statistical Association Bulletin, 13*, 89-100.

This paper aims at generalizing and filling the gaps of Chandrasekar and Deming (1949), and Chakraborty (1963) by (i) finding out optimum estimates for the total number of population units N and for the probabilities (p_i) of the k listings detecting an event, (ii) working out the variances of these optimum estimates, (iii) working out the variances of Chakraborty's estimates, and finally, (iv) showing that the efficiency of the Chakraborty's estimates compared to the estimates presented here is always less than unity. In the last section, a model sampling experiment has been presented to illustrate some of these findings.

[3] TAEUBER, C. and HANSEN, M.H. (1964). "A Preliminary Evaluation of the 1960 Censuses of Population and Housing," *Demography, Vol. 1, No. 1,* 1-14.

The purpose of this paper is to summarize the findings to date of the work on the evaluation of the quality of the 1960 Census of Population and Housing.

1965

[1] JOLLY, G.M. (1965). "Explicit Estimates from Capture-recapture Data with Both Death and Immigration – Stochastic Models," *Biometrika, 52,* 225-247.

The first purpose of the paper is to derive a general probability distribution designed to fit the majority of capture-recapture problems involving a 'single' population. The second purpose of the paper is to show that extremely simple estimates of the population parameters exist for a homogeneous population subject to both death and immigration.

[2] PERKINS, W.M. and JONES, C.D. (1965). "Matching for Census Coverage Checks," *Proceedings of the Social Statistics Section, American Statistical Association*, 122-139.

In the paper, the authors discuss the requirements of coverage evaluation that are particularly critical to the matching. Of the requirements, undoubtedly the most important is the fact that coverage evaluation matching focuses on *unmatched* rather than *matched* cases.

[3] POLLACK, E.S. (1965). "Use of Census Matching for Study of Psychiatric Admission Rates," *Proceedings of the Social Statistics Section, American Statistical Association*, 107-115.

Studies or analyses designed to measure the rate of occurrence of a particular event in specific population groups are extremely common. In most of those concerned with illness or mortality, the numerators are obtained from interviews, vital records, or hospital or agency case records and are related to published population data. The assumptions implicit in such a procedure are: (1) that each individual counted in the numerator has been enumerated in the population and (2) that each individual is classified identically in both numerator and population denominator with respect to the characteristics under study.

An alternative procedure involves identifying the individuals to whom the event of interest has occurred and locating for each of these persons the Census document used for tabulating population data. If this procedure is successful in locating the census records for all of the persons in the study, both of the above assumptions will be fulfilled. It is the purpose of this paper (1) to describe a study using this procedure, (2) to present data indicating the relative success of the census matching procedure for various groups and (3) to discuss the implications of failure to find matching census schedules for the analysis of rates.

[4] SEBER, G.A.F. (1965). "A Note on the Multiple-recapture Census," *Biometrika, 52,* 249-259.

Various capture-tag-recapture models have been developed to estimate these population parameters (e.g., size, death rate, birth rate) with a minimum number of assumptions on the underlying population. One such method, the multiple-recapture census, has been the topic of many papers and is described briefly as follows. The experimenter takes a sequence of random samples a_1, a_2, ..., a_s, say. The members of each sample a_i are tagged and returned to the population before taking the next sample. Thus the members of a_2, a_3, ..., a_s can be classified according to when, if at all, they have been captured before. Although several models have been developed from different basic assumptions, three papers in particular by Darroch (1958, 1959) and Jolly (1965) give the most general treatment of this method in the form of exact, fully stochastic models which lend themselves readily to the method of maximum-likelihood estimation. This paper considers this general population with both immigration and death and sets up a model which differs slightly from that of Darroch and Jolly in that certain parameters are treated as unknown constants rather than random variables.

1966

[1] MARKS, E.S. and WAKSBERG, J. (1966). "Evaluation of Coverage in the 1960 Census of Population Through Case-by-Case Checking," *Proceedings of the Social Statistics Section, American Statistical Association*, 62-70. ("Discussion," Mauldin Parker, 89-90.)

There are essentially two methods of evaluating census data. One is by case-by-case analysis of a sample of census returns, using whatever means are available to uncover errors in the census. The other is by analysis of the statistics themselves, comparing them with other related information (on births, deaths, previous census counts, etc.) and examining problems of internal consistency.

This report describes the use of these methods in evaluating the coverage of the 1960 Census and provides alternative estimates of undercounts. This paper is restricted to the results of the case-by-case studies of the 1960 coverage. This includes reinterviews and matching the census against sample selected from various independent lists.

[2] SIEGEL, J.S. and ZELNIK, M. (1966). "An Evaluation of Coverage in the 1960 Census of Population by Techniques of Demographic Analysis and by Composite Methods," *Proceedings of the Social Statistics Section: American Statistical Association*, 71-85. "Discussion," Joseph Steinberg, 86-88.

This paper presents (1) the results of studies using methods of Demographic Analysis to evaluate the 1960 Census counts, and (2) several sets of composite estimates which combine (a) the results derived by various analytic techniques or (b) the results derived by analytic techniques and the case-by-case checking techniques involving reinterviews and matching against independent lists discussed in the companion paper by Marks and Waksberg. Because of the close relation between coverage of the total population and the accuracy of the date by age, sex, and color, the authors are concerned here both with overall underenumeration and with net undercounts (or overcounts) by age, sex, and color.

1967

[1] DEMING, W.E. and KEYFITZ, N. (1967). "Theory of Surveys to Estimate Total Population," In *Proceedings of the World Population Conference,* Belgrade, 1965 (Vol. 3). New York: United Nations, 141-144.

The purpose of this paper is to discuss some of the statistical problems encountered in estimating by sampling the total number of a population, without benefit of a previous census, and to present a device for this purpose which may have other uses as well. The authors consider two kinds of situations: (a) the population is fixed, each person being nominally attached in some recognizable manner to a fixed location, such as a dwelling unit; (b) the population is mobile – here today, somewhere else tomorrow. Some theory for the moving population is introduced.

1968

[1] CROXFORD, A.A. (1968). "Record Linkage in Education," in *Record Linkage in Medicine* (Ed. E.D. Acheson). London: E. and S. Livingstone, 351-358.

This paper is concerned with the official statistics of students in the various fields of education which are available after finishing compulsory schooling, as produced by the Department of Education and Science (formerly the Ministry of Education). Until now, record linkage has played little part in the production of these statistics and as a consequence certain areas of investigation which are becoming of increasing importance to educational planners have been almost entirely unexplored. The second part of this paper explains how record linkage is expected to make good these deficiencies while the first part explains what these deficiencies are and how they have been inevitable under their traditional method of collection.

[2] JABINE, T.B. and BERSHAD, M.A. (1968). "Some Comments on the Chandrasekar and Deming Technique for the Measurement of Population Change," Paper presented at *CENTO Symposium on Demographic Statistics,* Karachi, Pakistan.

Chandrasekar and Deming (1949) provided an estimation of the population size when a unit being observed by the first method is independent of it being observed by the second method. (A less stringent assumption is that there is zero correlation in the usual 2×2 table for the dual system estimation model.) Chandrasekar and Deming observed that it may be possible to reduce the bias resulting from lack of independence by classifying the units into homogeneous groups on the basis of age, sex, and other appropriate characteristics and making the usual estimate of size separately for each group. This will be effective if the correlation for the contingency table for each grouping or stratum is near zero but the correlation for the contingency table for all strata combined is not zero. The present paper considers correlation and the bias of the usual estimate, as well as other sources of bias of the usual estimate. It provides recommendations concerning the use of the method introduced by Chandrasekar and Deming.

[3] SIEGEL, J.S. (1968). "Completeness of Coverage of the Nonwhite Population in the 1960 Census and Current Estimates, and Some Implications," pp.13-54 in D.M. Heer (Ed.*), Social Statistics and the City: Report of a Conference Held in Washington, D.C., June 22-23, 1967. Cambridge, Mass.:* Joint Center for Urban Studies of the Massachusetts Institute of Technology and Harvard University.

It is widely believed that the census counts for African-Americans are quite defective, and the evidence supports this belief. The magnitude of the errors in the census counts is less well known, and it is a principal subject of concern in this paper. This paper largely concerns itself with (1) the extent of the undercoverage of the nonwhite population in total and by age and sex in the 1960 Census, (2) the basis of these findings, (3) some demographic factors affecting the change in coverage between 1950 and 1960 and between 1960 and 1970, (4) the extent of understatement of the Census Bureau's current estimates, including those in the Current Population Survey, and (5) the implications of the findings for some of the demographic characteristics of the nonwhite population. This paper shows that in many respects the counts and estimates of national population by age, sex, and color do not seriously distort the picture of the demographic situation in the United States as a whole. The authors conjecture that the same can not be said for smaller geographic areas within the country.

[4] SRINIVASAN, K. and MUTHIAH, A. (1968). "Problems of Matching of Births Identified from Two Independent Sources," *The Journal of Family Welfare, 14,* 13-22.

The aim of this article is to highlight the importance of the problem of selection of characteristics and criteria to be used in matching and their influence on the estimates from dual-system estimation.

[5] WITTES, J.T. and SIDEL, V.W. (1968). "A Generalization of the Simple Capture-recapture Model with Applications to Epidemiological Research," *Journal of Chronic Diseases, 21,* 287-301.

A method has been described to estimate the efficiency of each notification source and the total population when two or more independent sources are used for reporting the occurrence of events. The method depends on the independence of the sources and, for the special case of two sources, reduces to the simple capture-recapture model.

1969

[1] FELLIGI, I.P. and SUNTER, A.B. (1969). "A Theory for Record Linkage," *Journal of the American Statistical Association, 64,* 1183-1210.

A mathematical model is developed to provide a theoretical framework for a computer-oriented solution to the problem of recognizing those records in two files which represent identical persons, objects, or events (said to be matched). A comparison is to be made between the recorded characteristics and values in two records (one from each file) and a decision made as to whether or not the members of the comparison-pair represent the same person or event, or whether there is insufficient evidence to justify either of these decisions at stipulated levels of error. Criteria for an optimal linkage rule are given. A theorem describing the construction and properties of the optimal linkage rule and two corollaries to the theorem which make it a practical working tool are given.

[2] LEWIS, C.E. and HASSANEIN, K.M. (1969). "The Relative Effectiveness of Different Approaches to the Surveillance of Infection among Hospitalized Patients," *Medical Care, 7,* 379-384.

A method for estimating the effectiveness of systems designed to monitor the occurrence of events within a population is described. Specific application of this model to the analysis of a control program for the surveillance of infectious disease in a university hospital is presented. A reporting system with three sources - physicians, nurses, and bacteriology laboratory - was instituted. The effectiveness of the system ranged from 61 to 85 percent over a period of 12 months. There was considerable variation among the three sources in terms of their relative effectiveness in identification of patients with infections. Under the circumstances described, the most effective two-source reporting system would have been the physicians' discharge reports and bacteriology laboratory records.

[3] MEHTA, D.C. (1969). "Sample Registration in Gujarat, India," *Demography, Vol. 6, No. 4,* 403-411.

Since October, 1965, births and deaths in rural Gujarat State, India, have been recorded under two independent systems in a random sample of units. First, a part-time local "registrar" is appointed in each sample unit (village or segment thereof) who: prepares a house list; conducts a baseline survey showing the individuals in each household; and maintains a list of the vital events reported by informants whom he contacts fortnightly. Second, a staff member at the rural health center is assigned part-time supervisory and survey duties: to check the initial listings of the registrar; thereafter, to inspect the registrar's records at least quarterly; and to conduct a household survey each six months, updating the household register and recording births and deaths independently. The registrar's list is sent to the district office immediately before the survey, where it is matched with the survey list forwarded by the local supervisor. A list of unmatched events is returned to the supervisor who with the registrar revisits households to resolve the discrepancies. Under registration is estimated to be 13 to 20 percent by the registrar method, 8 to 17 percent by the survey method. The birth rate is estimated to be about 14 and the death rate about 19.

1970

[1] HANSEN, M.H. and WAKSBERG, J. (1970). "Research on Non-Sampling Errors in Censuses and Surveys," *Review of the International Statistical Institute 38, No. 3,* 317-332.

Considerable progress has been made in the art and science of taking censuses and sample surveys, but many problems still remain that deserve extensive further research attention. With a focus on measurement methods and errors, the authors argue for support of a strong research and consultation program in census and sample survey methods.

[2] SIEGEL, J.S. (1970). "Coverage of Population in the 1970 Census: Preliminary Findings and Research Plans," *Proceedings of the Social Statistics Section, American Statistical Association,* 64-69.

In view of the limitations of the reenumerative and record-checking procedures (i.e., case-by-case matching studies) in establishing the level of underenumeration in the censuses of 1960 and 1950, it has been decided to employ *demographic analysis* as the principal basis for estimating the level of under-enumeration in the 1970 Census. Some case-by-case matching studies will also be conducted and these will be employed in conjunction with the studies using demographic analysis in making the final evaluation. This paper describes both methodologies.

1971

[1] NATIONAL ACADEMY OF SCIENCES (1971). *America's Uncounted People,* Washington, D.C.

This report is primarily concerned with one major segment of the vast social data-gathering activities of the federal government—the population census—and with one specific census problem—the failure to enumerate an estimated 3 percent of the nation's population in recent decennial censuses. A program of continuing research for better understanding of under-enumeration is recommended including: ethnographic research, longitudinal studies, casual interview studies, record-matching experiments, registration systems, and demographic accounting.

1972

[1] FIENBERG, S.E. (1972). "The Multiple Recapture Census for Closed Populations and Incomplete 2^k Contingency Tables," *Biometrika, Vol. 59, No. 3,* 591-603.

The multiple recapture census for closed populations is reconsidered, assuming an underlying multinomial sample model. The resulting data can be put in the form of an incomplete 2^k contingency table, with one missing cell, that displays the full multiple recapture history of all individuals in the population. Log linear models are fitted to this incomplete contingency table, and the simplest plausible model that fits the observed cells is projected to cover the missing cell, thus yielding an estimate of the population size. Asymptotic variances for the estimate of the population size are considered, and the techniques are illustrated on a population of children possessing a common congenital anomaly.

[2] GOODMAN, L.A. (1972). "A General Model for the Analysis of Surveys," *American Journal of Sociology, 77*, 1035-86.

This article shows how the combined use of direct estimation methods and indirect testing procedures, which was advocated by Goodman (1970, 1971*a*) can be applied in survey analysis. The methods presented in the present article can also help the survey analyst to determine whether his survey data support or negate a given hypothesized causal system; and in some cases these methods can be used to determine alternative causal systems that provide better descriptions of the phenomena under investigation. Included in the article are some new results on how the relationship between two given dichotomous variables is affected by the introduction of additional variables.

[3] JELINSKI, Z. and MORANDA, P.B. (1972). "Software Reliability Research," in *Statistical Computer Performance Evaluation,* (Ed. W. Freiberger). New York: Academic Press, 465-484.

A software reliability study was initiated to conduct research into the nature of the software reliability problem including definitions, contributing factors and means for control. Discrepancy reports which originated during the development of two large-scale real-time systems form two separate primary data sources for the reliability study. A mathematical model was developed to describe the time pattern of the occurrence of discrepancies (errors).

This model has been employed to estimate the initial (or residual) error content in a software package as well as to estimate the time between discrepancies at any phase of its development. Means of predicting mission success on the basis of errors which occur during testing are described.

[4] SANATHANAN, L. (1972a). "Estimating the Size of a Multinominal Population," *Annals of Mathematical Statistics, 43,* 142-152.

This paper deals with the problem of estimating the number of trials of a multinomial distribution, from an incomplete observation of cell totals, under constraints on the cell probabilities.

[5] SANATHANAN, L. (1972b). "Models and Estimation Methods in Visual Scanning Experiments," *Technometrics, 14*, 813-829.

This paper deals with a problem that often arises in visual scanning experiments in particle physics, viz. that of estimating the number of undetected particles from the scanning record. This problem is formulated here as one in estimating the size of a multinomial population from an incomplete observation of the cell totals under constraints on the cell probabilities. These constraints differ according to the assumptions made about the scanners and the particles, thus giving rise to different probability models. Several models are considered here – existing ones as well as a new generalized model. Estimation procedures corresponding to these models are discussed. A discussion of the applicability of the techniques presented here to other areas is also included.

1973

[1] COALE, A.J. and RIVES, Jr., N.W. (1973). "A Statistical Reconstruction of the Black Population of the United States 1880-1970: Estimates of True Numbers by Age and Sex, Birth Rates, and Total Fertility," *Population Index, Vol. 39, No.1*, 3-36.

The black population of the Untied States experienced negligible international migration after the first years of the nineteenth century. By 1880, apparently such an approach to stability had occurred, as is evident in the similarity in general form of the age distributions of 1850, 1860, and 1880 (Farley, 1965). The absence of international migration makes the mechanics of the growth and age structure of closed populations applicable. This paper describes new procedures, based on this characteristic, that the authors have used to reconstruct the black population, distributed by age and sex, from 1880 to 1970.

[2] HOLST, L. (1973). "Some Limit Theorems with Applications in Sampling Theory," *Annals of Statistics, 1*, 644-658.

As Fienberg (1992) notes, Section 7 of this paper applies results on successive sampling to derive asymptotic distributions of the usual Petersen estimator when there are heterogeneous capture probabilities or the effects of matching.

[3] SANATHANAN, L. (1973). "A Comparison of Some Models in Visual Scanning Experiments," *Technometrics, 15*, 67-78.

In a previous paper by the author (1971) several models were presented in the context of a problem that often arises in visual scanning experiments in particle physics, that of estimating the number of undetected particles from the scanning record. A comparison of those models is given here, with respect to their adequacy in specific situations.

1974

[1] ERICKSEN, E. (1974). "A Regression Method for Estimating Population Changes of Local Areas," *Journal of the American Statistical Association, Vol. 68, No. 348*, 867-875.

A regression method is presented in which current sample data and symptomatic information are combined to estimate postcensal populations for local areas. This procedure was tested for counties and states using 1970 Census data, and the resulting estimates were found to be more accurate than estimates computed by standard demographic procedures for the same period. The ratio-correlation estimates were the most accurate series of standard estimates. When this series was added to the set of symptomatic information used in the regression method, further increases in accuracy were obtained.

[2] FAY, R.E. (1974). "Statistical Considerations in Estimating the Current Population of the United States," Ph.D. Dissertation, Department of Statistics, University of Chicago, Chicago, Illinois.

On April 26, 1973, the *New York Times* (Kovack, 1973) reported an estimate by the United

States Bureau of the Census of the number of Americans missed by the 1970 Census of Population. The estimate was that 5.3 million persons were overlooked, approximately 2.6 percent of the total count of 203,235,000 persons. The *Times* further noted that "the 5.3 million estimate of the number of persons missed in the count is not a fixed figure but what the bureau calls 'the best estimate' within a range of error that extends from 4.8 to 5.8 million people." The purpose of this study is to use statistical methods to assess the uncertainty in this estimate of 5.3 million.

[3] MARKS, E.S. (1974). "Methods of Evaluating Population and Housing Census Results," *Handbook of Population and Housing Census Methods, Part V,* United Nations, New York.

In any census, errors can occur at the time of enumeration and during the processing of the raw data. If sampling is employed, there will also be sampling errors. The possibility of error at either stage can be greatly reduced by the application of sound principles of census taking and of sampling. Some obvious enumeration errors can be detected and partially corrected during processing as can most processing errors. Many enumeration errors, however, cannot be detected at this stage; and complete correction for errors that are detected (e.g., omitted ages) may not be feasible. It is generally assumed, therefore, that the bulk of the non-sampling errors in the results originates during enumeration. Accordingly, this part of the *Handbook* is devoted to the types and causes of enumeration errors and the evaluation of the accuracy of census results, with particular emphasis on the *ad hoc* post-enumeration sample field survey as a method of evaluation.

[4] MARKS, E.S., SELTZER, W., and KROTKI, K.J. (1974). *Population Growth Estimation*: *A Handbook of Vital Statistics Measurement,* New York: Population Council.

Essentially, the population growth estimation (PGE) approach as used in the measurement or evaluation of vital statistics has three distinct features: the collection of reports of vital events by two quasi-independent data gathering procedures; the case-by-case matching of the reports in the two systems to determine which events are reported by both systems, and the preparation of an estimate of the number of events adjusted for omissions, or an estimate of the relative completeness of either system, on the basis of the match rates obtained. All three factors must be present for the study to be classified as one using the PGE approach.

The purpose of this handbook is to provide: an explanation of what the PGE technique is, some information on experiences around the world in its use, guidance on the general planning and the detailed design of a PGE study, including questions of cost, examples of procedures that may serve as models (even though imperfect ones) for the preparation of actual procedures, and a methodology for dealing with the inevitable weaknesses in the procedures used and in the estimates prepared.

[5] SCOTT, C. (1974). "The Dual Record (PGE) System for Vital Rate Measurement: Some Suggestions for Further Development," Vol. 2, *International Population Conference,* Liege, Belgium, 1973. International Union for the Scientific Study of Population, 407-416.

The dual record, or dual source, system of vital rate measurement has developed into a well-recognized technique. This system, often termed the "PGE" after the original application in the Population Growth Estimation project in Pakistan, is achieving a measure of standardization. There is some resistance to use of the PGE system, and this paper is an attempt to sketch an approach to the further development of the system by taking a critical look at the system's weak points including its complexity and sources of bias.

[6] SIEGEL, J. (1974). "Estimates of Coverage of the Population by Sex, Race, and Age in the 1970 Census," *Demography, Vol. 11*, 1-23.

This paper represents another installment in the Census Bureau's continuing effort to publish information regarding the quality of census data, and particularly about the completeness of coverage of the population in the decennial censuses.

[7] WITTES, J.T. (1974). "Applications of a Multinomial Capture-recapture Model to Epidemiological Data," *Journal of the American Statistical Association, 69*, 93-97.

A multinomial multiple recapture model is used to estimate the size of a population ascertained by merging incomplete lists, or samples, of population members. Methods for estimating the efficiencies of each list, and for establishing the basic criteria for selecting lists are presented. The model assumes the lists are independent samplings; a technique for dealing with dependent lists is discussed. An example illustrates the methods.

[8] WITTES, J.T., COLTON, T., and SIDEL, V.W. (1974). "Capture-recapture Methods for Assessing the Completeness of Case Ascertainment When Using Multiple Information Sources," *Journal of Chronic Diseases, 27*, 25-36.

In this paper, the authors consider the problem of estimating the total size of a target population from which a study sample has been obtained by merging names from several routinely collected lists. Corrections to previous work are presented, and discussions about results when assumptions fail are provided.

1975

[1] BISHOP, Y.M.M., FIENBERG, S.E., and HOLLAND, P.W. (1975). *Discrete Multivariate Analysis*: *Theory and Practice,* Chapter 6, "Estimating the Size of a Closed Population," 229-254. Cambridge, MA.: MIT Press.

This chapter deals with a special application: If, as sometimes happens, we have several samplings or censuses, we may wish to estimate a total count. For example, we may have several lists of voluntary organizations from the telephone book, newspaper articles, and other sources. Although each list may be incomplete, from the several lists we want to estimate the total number of voluntary organizations (including those on *none* of the lists). This chapter offers ways to solve such multiple-census problems by treating the data sets as incomplete multidimensional tables. The method is one generalization of the capture-recapture method of estimation used in wildlife and other sampling operations.

[2] BLUMENTHAL, S. and MARCUS, R. (1975). "Estimating Population Size with Exponential Failure," *Journal of the American Statistical Association, 70,* 913-922.

Assume J observations obtained by truncated sampling of a population of N items which fall independently according to the exponential are unknown. Estimates of N are developed and compared. These are conditional and unconditional maximum likelihood estimates, and a class of Bayes model estimates. On the basis of second-order asymptotic properties, one of the Bayes estimates is singled out as most desirable.

[3] GREENFIELD, C.C. (1975). "On the Estimation of a Missing Cell in a 2×2 Contingency Table," *Journal of the Royal Statistical Society, Series A, 138,* 51-61.

An additional assumption to that of independence in estimating a missing cell from a 2×2 contingency table is proposed. This is applicable where dual systems of data collection have been employed. It is suggested that, particularly where human populations are the source of data, the assumption of independence might reasonably be regarded as providing a lower limit and the additional assumption an upper limit to the value of the missing cell. A practical example is given.

1976

[1] CARVER, J.S. (Ed.) (1976). *"Systems of Demographic Measurement, The Dual Record System Systems." Bibliography on the Dual Record System,* International Program of Laboratories for Population Statistics, The Department of Biostatistics, The University of North Carolina at Chapel Hill, Chapel Hill, North Carolina.

The *dual record system* is one of several measurement techniques used to produce up-to-date information on population change to supplement data obtained from vital registration and the traditional population census. The system involves the collection of two independent records on each vital event occurring in the same population. These two records are matched on a case-by-case basis, and, with the use of the Chandrasekaran-Deming technique, the match rates are utilized to estimate the number of events missed by both methods and to obtain an estimate of the total number of births and deaths. The dual record system had two relatively independent origins: (1) civil registration completeness studies made in Canada, the United States, and the Soviet Union, and (2) experiments in demographic estimation in the developing countries, first in Asia and more recently in Africa and Latin America. The most comprehensive coverage of dual record research is found in Marks, Seltzer, and Krotki (1974). A considerable volume of other literature and documentation on this subject is widely scattered through a variety of sources. This bibliography is an attempt to make these diverse materials better known and more readily available. This bibliography is restricted in coverage to research in developing countries.

[2] EFRON, B. and THISTED, R.A. (1976). "Estimating the Number of Unseen Species: How Many Words Did Shakespeare Know?," *Biometrika, 63,* 435-447.

Shakespeare wrote 31534 different words, of which 14376 appeared only once, 4343 twice, etc. The question considered is how many words he knew but did not use. A parametric empirical Bayes model due to Fisher and a nonparametric model due to Good and Toulmin are examined.

The latter theory is augmented using linear programming methods. We conclude that the models are equivalent to supposing that Shakespeare knew at least 35000 more words.

[3] GREENFIELD, C.C. (1976). "A Revised Procedure for Dual Record Systems in Estimating Vital Events," *Journal of the Royal Statistical Society, Series A, 139,* 389-401.

Dual record systems for estimating vital events have typically been designed with the intention of correcting their results for bias using an assumption of independence. The operational significance of this assumption and that of other correcting techniques is examined.

[4] GREENFIELD, C.C. and TAM, S.M. (1976). "A Simple Approximation for the Upper Limit to the Value of a Missing Cell in a 2×2 Contingency Table," *Journal of the Royal Statistical Society, Series A, 139,* 96-103.

A simple approximation for the upper limit to the value of a missing cell in a 2× 2 contingency table is presented. This is applicable where dual-systems of data collection have been employed, under specified assumptions. A table of correction factors for the approximation is given and some empirical results for the case where one of the assumptions does not apply.

[5] PASSEL, J.S. (1976). "Provisional Evaluation of the 1970 Census Count of American Indians," *Demography, Vol. 13, No. 3,* 397-409.

Estimates of the American Indian population under 20 years of age on April 1, 1970, based on birth and death statistics for a 20-year period, show a possible net undercount of 6.9 percent for this age group in the 1970 Census. However, for some particular ages the estimates indicate net overcounts in the census. Likewise, the net increase of the entire American Indian population as measured by the difference between the 1960 and 1970 Censuses is 67,000 greater than the natural increase for the decade. Detailed analysis of cohort data with respect to the possible causes of the differences between the estimates and the census figures indicate that a portion of the estimated net overcounts can be attributed to classification, as well as coverage, problems. The estimated net overcounts offer support for the hypothesis that many individuals who were registered as white at birth and who were counted as white in the 1960 Census shifted their racial self-identification from white to American Indian during the 1960s.

1977

[1] EL-KHORAZATY, M.N. and SEN, P.K. (1977). "The Capture-mark-recapture Strategy as a Method for Estimating the Number of Events in a Human Population with Data from Dependent Sources," Department of Biostatistics, University of North Carolina at Chapel Hill. Chapel Hill, North Carolina.

This paper discusses the application of the capture-mark-recapture technique to estimate the total number of events in a human population when data are available from two or three sources of information. The capture-mark-recapture stochastic models, developed by Seber and Jolly are generalized to human populations, assuming dependence among the sources (source correlation), a real fact in most cases. Numerical examples from different fields show that the estimated numbers of events, based on the dependent model-likelihood functions, are sensitive to such dependence.

[2] EL-KHORAZATY, M.N., IMREY, P.B., KOCH, G.G., and WELLS, H.B. (1977). " Estimating the Total Number of Events with Data from Multiple-record Systems: a Review of Methodological Strategies," *International Statistical Review*, *45*, 129-157.

Two techniques for estimating a total number of events are reviewed in this paper. Through multiple recording of the same event (individual or animal), the multiple - record system (MRS) technique (used mainly for human populations) and the capture - mark - recapture (CMR) technique (used mainly for animal populations) attempt to adjust for the incomplete coverage of single systems. The dual-record system (DRS) technique, as a special case of the MRS, has been used rather widely to adjust for omissions in the recording of vital events. Estimation procedures developed for the MRS and CMR have certain limitations because of their inherent assumptions and these may seriously affect the estimates obtained. The use of a log-linear model analysis for incomplete contingency tables, arising from MRS-CMR data, as a methodological strategy for estimating the total number of events, allows choosing an estimation procedure realistically adapted to the properties of actual recording sources of information. Moreover, the incorporation of *source correlation* and/or *event correlation* into the estimation procedure can provide insight into the effects of such factors and the strengths and weaknesses of the statistical information systems which have been implemented. On the other hand, application of the theory already developed for the CMR technique to human populations, in the presence of source correlation, yields more refined estimates of the population size. Comparisons of the MRS and CMR in terms of their assumptions and modes of application are given in order to clarify their similarities and differences.

[3] RAJ, D. (1977). "On Estimating the Number of Vital Events in Demographic Surveys," *Journal of the American Statistical Association*, *72*, 377-381.

An examination is made of the effectiveness of the Chandrasekar-Deming technique for estimating the number of vital events using both the registration (continuous recording) of events and a periodic retrospective survey. It is shown that, under a general mode for response errors, the technique may produce estimates that are considerably biased downwards. A comparison is made with a number of other estimators. The possibility of improving results through double sampling is explored.

[4] YUSKAVAGE, R., HIRSCHBERG, D., and SCHEUREN, F. (1977). "The Impact on Personal and Family Income of Adjusting the Current Population Survey for Undercoverage," *Proceedings of the Social Statistics Section, American Statistical Association*, 70-80.

This paper presents the results of adjusting the Current Population Survey (CPS) for undercoverage, with attention focused on the impact of alternative adjustment procedures on the distribution of personal and family income. In addition, the impact on selected population characteristics and labor force estimates are reviewed.

[1] BURNHAM, K.P. and OVERTON, W.S. (1978). "Estimation of the Size of a Closed Population When Capture Probabilities Vary among Animals," *Biometrika, 65, 3*, 625-633. (Correction (1981) *68, 1*, 345.)

A model which allows capture probabilities to vary by individuals is introduced for multiple recapture studies on closed populations. The set of individual capture probabilities is modeled as a random sample from an arbitrary probability distribution over the unit interval. The authors show that the capture frequencies are a sufficient statistic. A nonparametric estimator of population size is developed based on the generalized jackknife; this estimator is found to be a linear combination of the capture frequencies. Finally, tests of underlying assumptions are presented.

[2] GOLDBERG, J.D. and WITTES, J.T. (1978). "The Estimation of False Negatives in Medical Screening," *Biometrics, 34*, 77-86.

In a medical screening program for early detection of disease, one or more screening modes are administered to an apparently healthy population. Knowledge of the true disease status for all screened individuals would allow estimation of the false negative and false positive rates for each mode of detection and for the program as a whole.
This paper develops capture-recapture methods applicable to programs when follow-up of individuals negative on screening is not performed or is incomplete. The methods require at least two independent modes of detection. Data from a breast cancer screening program illustrate the procedures. The results of four screening examinations at approximately one-year intervals and the long-term follow-up of all screened individuals support the usefulness of these methods in the evaluation of a screening program.

[3] GONZALEZ, M.E. and HOZA, C. (1978). "Small-Area Estimation with Application to Unemployment and Housing Estimates," *Journal of the American Statistical Association, Vol. 73, Number 361*, 7-15.

The purpose of this study is to investigate methodologies for constructing intercensal estimates of various characteristics of the population for small areas. The proposed methodology is illustrated mainly in the context of unemployment estimates, with one section utilizing dilapidated housing estimates. Alternative synthetic estimates of unemployment based on the 1970 Census 20-percent sample are investigated and their relative error is analyzed. The reliability of the synthetic estimates is discussed in the context of dilapidated housing estimates. Two types of regression models are studied, and the improvements obtained by excluding outliers from the regression are discussed.

[4] GOSSELIN, J.F. and BRACKSTONE, G.J. (1978). "The Measurement of Population Undercoverage in the 1976 Canadian Census Using the Reverse Record Check Method," *Proceedings of the Social Statistics Section, American Statistical Association,* 230-235.

The purpose of this paper is to present a description of the methodology of the 1976 Reverse Record Check as well as some of the results of the study. The Reverse Record Check was designed to measure the incidence of undercoverage in the 1976 Canadian Census of Population and Housing. Section 2 gives some background information on the Canadian Census of Population and Housing. Section 3 deals with the construction of the frame and sample selection, while

Section 4 describes the main Reverse Record Check operations. Finally, Section 5 gives an outline of the results.

[5] KROTKI, K.J. (Ed.) (1978). *Developments in Dual-system Estimation of Population Size and Growth.* Edmonton: University of Alberta Press. (pp. 260)

This book explores the collection of vital statistics and the estimation of population size by two independent systems, and comparing the results on a name-by-name basis. This book discusses a number of theoretical issues related to dual-systems of data collection, practical problems that arise in carrying out such systems, reports in detail on selected surveys (particularly in Africa where vital statistics systems are notably weak), and summarizes actual surveys as well as the state of the art.

[6] LANCASTER, C. and SCHEUREN, F. (1978). "Counting the Uncountable Illegals: Some Initial Statistical Speculations Employing Capture-recapture Techniques," *Proceedings of the Social Statistics Section, 1977: Part I., American Statistical Association*, 530-535.

This paper provides some initial statistical speculations on the number of illegal aliens residing in the United States. The results come from the 1973 CPS-IRS-SSA Exact Match Study which was conducted by the Census Bureau and the Social Security Administration, assisted by the Internal Revenue Service. Direct estimates are presented only for the age group 18 to 44 years old as of April 1973; however, there are some discussions of ways, using other sources, that one can extend these figures to all age groups and project them forward in time.

[7] NATIONAL RESEARCH COUNCIL (1978). *Counting the People in 1980: An Appraisal of Census Plans*, Washington, D.C.: National Academy Press.

This report documents the work, findings, and recommendations of the 14-member Panel on Decennial Census Plans which was established in December 1977. The Panel was given four charges: (1) to examine decennial census improvement plans, (2) to review proposed procedures for handling contested counts, (3) to investigate the feasibility of adjusting census counts, and subsequent population estimates, for underenumeration, and assess the implications of such procedures, and (4) to consider plans to evaluate the 1980 Census and recommend steps to improve planning for subsequent censuses. In order that Panel recommendations might influence the 1980 Census, the evaluation was to be completed in six months.

[8] OTIS, D.L., BURNHAM, K.P., WHITE, G.C., and ANDERSON, D.R. (1978). "Statistical Inference from Capture Data on Closed Animal Populations," *Wildlife Monographs, 62,* Washington, D.C.: Wildlife Society.

This publication treats inference procedures for certain types of capture data on closed (i.e., the population size is constant over the period of investigation) animal populations. The objectives of this publication are twofold:

(1) to give a thorough treatment of the estimation of population size given multiple capture occasions assuming there may exist 3 major types of variation in capture probabilities;

(2) to extend and make available a procedure for estimating density (number of animals per unit area) from grid trapping studies.

[9] SIRKEN, M. G. (1978). Dual-system Estimators Based on Multiplicity Surveys (With Discussion). Chapter 4 in *Developments in Dual-System Estimation of Population Size and Growth,* (Ed. K. Krotki). Edmonton: University of Alberta Press, 81-91.

This paper is concerned with the problem of improving the reliability of dual-system estimators of vital statistics derived from single retrospective sample surveys. The paper's objectives is to investigate the effect of alternative counting rules in single retrospective surveys on the sampling errors of dual system estimators of vital statistics, especially mortality statistics. The alternative counting rules considered are conventional and multiplicity. There is a difference between *conventional* and *multiplicity* rules in single retrospective surveys. The conventional counting rule distributes the vital events that occurred during the reference period among the housing units such that every event is uniquely linked to and hence eligible to be enumerated at only one housing unit. In household surveys, conventional counting rules are often referred to as residence rules. On the other hand, a multiplicity rule distributes vital events among the housing units such that every event is linked to one or more housing units where it is eligible to be enumerated. Multiplicity rules have been proposed that would link persons who experienced vital events to the residences of their relatives.

The technique is of major potential pay-off: by significantly reducing the sampling variance of estimates of births and deaths, it may permit a major reduction of sample sizes and hence costs.

[10] SIRKEN, M., GRAUBARD, B., and LA VALLEY, R. (1978). "Evaluation of Census Population Coverage by Network Surveys," *Proceedings of the Section on Survey Research Methods, American Statistical Association,* 239-244.

The Census Bureau is currently testing and developing the post-enumeration survey methods (dual system estimation) that it will use to evaluate the completeness of population coverage in the 1980 Census. But there is concern about the level of correlation bias under dual-system estimation due to failure of independency. The network (multiplicity) survey represents a new approach for designing post-enumeration surveys that is currently being investigated by the Census Bureau. For testing, the post-enumeration survey (PES) and the post-enumeration multiplicity survey (PEMS) are both envisioned as household sample surveys of which one would be conducted after the census. Except for the counting rule, the design features of both surveys are virtually the same. The PES adopts a de jure residence rule, and the PEMS adopts a multiplicity counting rule. The de jure residence rule specifies that people are eligible to be enumerated only at their usual places of residence. On the other hand, the multiplicity counting rule adopted by PEMS specifies that people are eligible to be enumerated at the households of specified close relatives as well as at their own de jure residences. Dual system estimators are investigated under both approaches with a focus on when PEMS would have a smaller correlation bias than PES.

[1] FAY, R. E., III and HERRIOT, R.A. (1979). "Estimates of Income for Small Places: An Application of James-Stein Procedures to Census Data," *Journal of the American Statistical Association, Vol. 74, No. 366, Part I,* 269-277.

An adaptation of the James-Stein estimator is applied to sample estimates of income for small places (i.e., population less than 1,000) from the 1970 Census of Population and Housing. The adaptation incorporates linear regression in the context of unequal variances. Evidence is presented that the resulting estimates have smaller average error than either the sample estimates or an alternate procedure of using country averages. The new estimates for these small places now form the basis for the Census Bureau's updated estimates of per capita income for the General Revenue Sharing Program.

[2] HEER, D.M. (1979). "What is the Annual Net Flow of Undocumented Mexican Immigrants to the United States?,"*Demography, Vol. 16, No. 3,* 417-423.

Senior government officials have claimed that in recent years an average of 1.4 million illegal aliens have entered the United States annually without apprehension. This conjectural figure does not take into account the fact that the net flow of immigrants is always less than the gross flow. In this paper, seven estimates are made concerning the net flow of undocumented Mexican immigrants to the United States in the period 1970-1975. These estimates are based on the growth of the population of Mexican origin according to the Current Population Survey. According to these estimates the annual net flow ranged from 82,300 to 232,400 persons.

[3] KEYFITZ, N. (1979). "Information and Allocation: Two Uses of the 1980 Census," *The American Statistician, Vol. 33, No. 2* (with discussion):45-55. Discussion of three approaches to adjusting, with recommendations for synthetic estimation. (Comments by Harold Nisselson and Harry V. Roberts, 50-54, with "Rejoinder" by Keyfitz, 55-56.)

This paper argues for simplicity and for a convention agreed on in advance. Any adjustment of the census should be simple and understandable. A convention should be agreed on in advance of the announcement of the census figures. The convention may be the count as made by the methods used in the past, or it may be the count adjusted for race in some simple way. A third possibility is asking a trusted agency (say the Census Bureau itself) to improve the figures that come out of the census process by using its discretion. If this possibility were followed, the convention would consist in agreement to accept whatever the agency produced.

[4] KISH, L. (1979). "Samples and Censuses," *International Statistical Review, 47,* 99-109.

Two related topics receive brief but comprehensive reviews, for guiding decisions about three sources for collecting data. First, the relative advantages of samples, censuses, and registers are compared along eight criteria: cost, detail, timeliness, relevance, etc. Second, 15 methods are indicated for using samples in connection with censuses; they are sorted into five kinds of purposes: as substitutes for, or as aids to, censuses; sampling from census tapes; censuses as auxiliary data for sampling. Finally, current and future paths are indicated for combining the strengths of the three sources, in order to obtain accurate estimates which are both timely and detailed for local areas and small domains.

[5] ROBINSON, J.G. and SIEGEL, J. (1979). "Illustrative Assessment of the Impact of Census Under-enumeration and Income Underreporting on Revenue Sharing Allocations at the Local Level," *Proceedings of the Social Statistics Section, American Statistical Association*, 646-656.

The specific purpose of this study is to assess illustratively the effect of under-enumeration of the population, and the underreporting of income, on the distribution of Revenue Sharing funds among the counties and local areas in two States, New Jersey and Maryland.

1980

[1] **Conference on Census Undercount, July 1980.** *Proceedings of the 1980 Conference,* Washington, D.C.: Government Printing Office.

a) "Major Conference Findings," Conrad Taeuber, 3-4.

Although it was not expected that the conference participants would reach unanimity on the issues examined at the conference, Conrad Taeuber (Conference Chairman, Georgetown University) did note the following general directions identified in the discussion:

- Obtain as nearly as possible a complete count.
- There appeared to be general consensus that some form of adjustment for the undercount is needed.
- There was lack of agreement on the desirability of making adjustments to the traditional census reporting for apportionment.
- There was one strong statement arguing that no adjustment should be made. It was felt that the presumed greater accuracy of adjusted counts would not be critical to business users. In addition, the improvement in accuracy would not offset the delays involved and the confusion of "two sets of books."
- There appeared to be general support for the view that if an adjustment were to be made, it should be as simple as possible.
- There was some uncertainty concerning the timetable under which any adjustments might be made. If full reliance were to be placed on demographic methods of estimating the undercount, the results would be available earlier than if the results of the postenumeration survey are to be brought into the computations.
- Users would probably be willing to sacrifice some fine tuning of the estimates of the undercount if that would lead to a more timely release of the estimates and of any adjustments that might be made.
- There was general agreement that the decision to adjust or not should be made before the census results are available.
- There was little discussion of the form in which adjusted numbers should be released.
- There are special problems involved in securing adjustment factors for Hispanics and other minority groups.
- The subject of illegal aliens or undocumented workers was discussed as a question that needs to be recognized, though there was no clear proposal by which they might be included in estimates of the undercount.
- It was presumed that adjustments, if any, would contribute to equity in the distribution of funds and any other benefits.

- A review of the statistical needs of Federal agencies led to the conclusion that the underreporting of income in the census was potentially a more difficult issue than the undercount of population.
- Some reference was made to the variety of provisions in the laws governing the distribution of funds from the Federal Government. Some laws specify the most recent census, others speak of estimates by the Department of Commerce, and there are a number of variants of these.
- There were repeated references to the difference between "imputations" and "adjustments." It was pointed out that the proposed adjustments would not be significantly different from the procedures used for 1970 when additions were made to the enumerated population. The post-enumeration post office check and the vacancy check in connection with the 1970 Census were viewed as on the thin edge.
- There was a call for more and intensive research into the means of reducing the undercount as well as into appropriate methods for making adjustments.
- There was a plea that the data from any post-enumeration analysis be made available promptly to research workers outside the Bureau of the Census for independent analyses.
- Attention was called to the likelihood that the undercount would lead to a dilution of the strength of liberal and big city representatives in the House.

b) "The Bureau's Agenda on the Undercount Decision," Vincent Barabba, 5.

The Director of the Census Bureau outlines how the Census Bureau plans to use the comments from this conference in its decision process for deciding whether or not to adjust the 1980 Census.

c) "Census Undercount: Time to Adjust," Robert Garcia, 12-14.

Congressman Garcia argued for the need to adjust census results, urged a consensus, and supported Keyfitz's (1980) call for a convention in advance.

d) "The Census Bureau Experience and Plans," J.S. Siegel and Charles Jones, 15-24.

This document includes a summary of previous evaluation programs and their results, a description of the various techniques currently planned for use in measuring the coverage of the 1980 Census, the plans for combining the various estimates, as well as a discussion of the effects of census errors on fund allocations.

e) "Facing the Fact of Census Incompleteness," Nathan Keyfitz, 27-36.

This paper expresses no preference among the options for handling the undercount, but attempts to set forth the advantages and drawbacks of each. The reader who is concerned only with action on the undercount can proceed directly to the concluding section and see where his preferences fall.

f) "Adjusting for Decennial Census Undercount: An Environmental Impact Statement," Peter Francese, 37-43.

In an effort to determine the impact of adjusting for census undercount, this paper follows this format: any unavoidable adverse effects, any irreversible commitment of resources, the possible impact on long-term use or productivity, any mitigating measures that might be taken, and any alternatives to the proposed action.

g) "The Congressional Perspective," Daniel P. Moynihan, 49-51.

Senator Moynihan challenged the conference to address three questions:

(1) What does the Constitution require?

(2) Assuming that it will never be possible to obtain a complete enumeration through traditional census procedures, what is the availability and reliability of methods by which completeness and accuracy can be enhanced?

(3) What uses should be made of the estimated population data as opposed to the enumerated population data?

He further challenged the conference, the Secretary of Commerce, and the Census Bureau "...to make every effort that can be made within the bounds of sound statistical methodology to estimate the undercount and to publish the results of these estimates."

h) "Can Regression Be Used to Estimate Local Undercount Adjustments?", Eugene Ericksen, 55-61.

The objective of this paper is to discuss the problems and challenges of deriving final estimates of local undercount.

i) "Modifying Census Counts," I. Richard Savage, 62-75.

This paper discussed the needs for modification of population counts and the associated problems.

j) "Diverse Adjustments for Missing Data," Leslie Kish, 83-87.

This paper discusses (1) types of missing data, (2) diverse effects on different statistics of missing data , (3) methods of adjustments for the census undercounts, and (4) policy decision about adjustments for census undercounts.

k) "The Analysis of Census Undercount From a Post-Enumeration Survey," A.P. Dempster and T.J. Tomberlin, 88-94.

More specifically, an intensive analysis of a post-enumeration survey (PES) is seen as potentially very informative. Empirical Bayes analysis of logistic models with random effects opens up a wide range of models which a priori seem to reflect the inherent structure in a complex PES and, in addition, could lead to improved estimates of census undercount for small subgroups. A Bayesian analogue to the simple ratio-expansion technique for extrapolating from the PES estimates to the population using census data is presented, and the extent of uncertainty in the estimates obtained is seen as being available through their approximate posterior variances. Finally, some comments are made with regard to the implications of these proposals on the design of a PES.

l) "Some Empirical Bayes Approaches to Estimating the 1980 Census Undercount for Counties," Robert E. Fay, III, 95-99.

The focus of this paper is on the technical issues associated with the estimation of *net census error*, as opposed to the policy issues arising from adjustment of the census counts. Also the paper proceeds on a presumption that there will be tolerance of potentially complex estimation procedures, provided that such an approach can be shown to have attractive statistical properties. The author seeks: (1) to outline for the purposes of other researchers the basic scope of the evaluation data; (2) to emphasize aspects of the data that may impact on the question of small area estimation; and (3) to sketch a possible program of estimation that might be developed to produce estimates for counties and other sub-State areas.

m) "The Impact of Census Undercoverage on Federal Programs," Courtenay M. Slater, 107-111.

This paper attempts to identify some of the Federal program considerations which should enter into decisions on whether corrections for census underenumeration should be made and, if so, how they should be made statistically.

n) "The Impact of the Undercount on State and Local Government Transfers," Herrington J. Bryce, 112-124.

Billions of dollars from the Federal Government are distributed annually among State and local governments on the basis of their population size. In addition to Federal funds, State governments also distribute revenues to their localities on the basis of population size. Although there are no currently precise estimates, it is accurate to conclude that literally tens of billions of Federal and State dollars are distributed on the basis of populations. This paper considers the impact of a census undercount on this distribution process. It looks at some specific programs, identifies potential losers and gainers, and analyzes the equity of readjustment of the census for the undercount.

o) "The Synthetic Method: Its Feasibility for Deriving the Census Undercount for States and Local Areas," Robert B. Hill, 129-141.

There is widespread agreement that some adjustment of the population figures for States and local areas to correct for the census undercount is desirable. But there is little consensus regarding such related issues as:

(a) What methods can be used to correct for the census undercount for States and local areas – the synthetic, demographic, or matching method?

(b) Which method is most feasible and reliable for adjusting for the undercount for localities?

(c) Should adjusted population figures be used for purposes of political apportionment as well as for financial allocations to states and localities?

This paper attempts to address these questions by assessing the comparative strengths and weaknesses of the synthetic method for adjusting the census undercount for states and local areas.

The second section of this paper briefly describes the *synthetic method* and its basic assumptions, while the third section provides an overview of research studies that have used the synthetic method. In the fourth section, the comparative advantages and disadvantages of the synthetic method are assessed according to various criteria: internal consistency, simplicity, timeliness, flexibility, equity, and reliability. The concluding section proposes specific recommendations for using the synthetic method to adjust for the census undercount for states and local areas.

p) "The Impact of An Adjustment to the 1980 Census on Congressional and Legislative Reapportionment," Carl P. Carlucci, 145-152.

The most common discussions of reapportionment and redistricting focusing on questions of legal rulings and court intent are addressed. This paper discusses reapportionment and redistricting as impacted by adjustment of the 1980 Census.

q) "Adjustment for Census Underenumeration: The Australian Situation," Brian Doyle, 157-163.

Following some background on Australia and its political system, this paper examines what has been done in Australia with regard to underenumeration in the census.

r) "Census Undercount: The International Experience," Meyer Zitter and Edith K. McArthur, 164-180.

This paper reviews the experience of other countries on the general issue of census undercount. It is designed to provide tone and flavor as to the general level of concern of other developed and developing countries on the undercount issue.

s) "Legal and Constitutional Constraints on Census Undercount Adjustment," Donald P. McCullum, 185-188.

This paper presents the developing law on the utilization and adjustment of the decennial census of population. The permissibility of adjustments to the census undercount for apportionment of Representatives in Congress, and allowed deviations for federally funded programs are reviewed. Feasible legal considerations by the Bureau of the Census to adjust the census undercount for the 1980 decennial census and the mid-decade census of 1985 are suggested.

t) "Should the Census Count Be Adjusted for Allocation Purposes: Equity Considerations," Ivan P. Fellegi, 193-203.

This paper examines a very special kind of census data use: its legislated utilization as input to formulas on the basis of which funds are allocated from one level of government to another. To the extent that the census counts are subject to underenumeration, their use for this purpose represents a deviation from the legislated intent that (implicitly) assumes the counts to be free of error.

u) "Implications of Equity and Accuracy for Undercount Adjustment: A Decision-Theoretic Approach," Bruce Spencer, 204-216.

This paper addresses considerations of accuracy and equity separately. The author next considers how to make adjustments that maximize equity, subject to the accuracy of the estimates of undercount and given criteria of equity. Illustrative calculations are presented.

[2] DARROCH, J.N. and RATCLIFF, D. (1980). "A Note on Capture-Recapture Estimation," *Biometrics, 36*, 149-153.

A new estimate of the size of a closed population when the samples are of size one is considered. It is adapted from Robbin's estimate of the total probability of the unobserved outcomes of an experiment and is interesting because of its high efficiency. The bias and variance of the new estimate, and those of the maximum likelihood estimate, are examined numerically.

[3] DOYLE, B. and CHAMBERS, R. (1980). "Census Evaluation in Australia," *Proceedings of the Section on Survey Research Methods, American Statistical Association,* 275-280.

Most discussions on census evaluation concentrate on studies that have been conducted after census day. This paper commences in a similar vein, with a discussion of the use made of the evaluation studies conducted after the 1976 Census. The emphasis then shifts to a discussion of the pre-census evaluation for the 1981 Census and covers two main aspects: (1) the procedures that were involved in evaluating whether a topic should be included in the 1981 Census, and (2) the processes of ensuring that accurate information would be collected.

[4] GONZALEZ, M. (1980). "Characteristics of Formulas and Data Used in the Allocation of Federal Funds," *The American Statistician, Vol. 34, No. 4*, 200-211.

The formulas and data used for 13 federal programs that allocate funds to state and local areas are described. Suggestions for types of formulas and data appropriate for allocation of funds are made. Some recommendations in the *Report for Statistics for Allocation of Funds* published by the Office of Federal Statistical Policy and Standards are discussed The possible effects of the formulas and data used in the allocation of funds for federal programs are examined in the light of the recommendations given in the report.

[5] GOSSELIN, J.F. (1980). "Reverse Record Check: Tracing People in Canada," *Survey Methodology, Vol. 6, No. 1,* 84-103.

The Reverse Record Check is the main vehicle used to assess the level of undercoverage in the Canadian Census of Population. A sample of persons is selected from sources independent of the current census and extensive tracing operations are undertaken to determine the usual address of each selected person as of Census day. Census records are then checked to determine whether or not each selected person was enumerated. The tracing is by far the most complex, costly and time-consuming operation associated with this study. It involves extensive use of administrative records as well as tracing in the field. This paper describes the various tracing methods used as well as the success obtained from each of them.

[6] GOSSELIN, J.F. and BRACKSTONE, G.J. (1980). "Reverse Record Check: Tracing People in Canada," Statistics Canada, *Proceedings of the Section on Survey Research Methods, American Statistical Association,* 269-274.

This paper describes the various tracing methods used as well as the success obtained from each of them. A brief description of the methodology of the study will first be presented. The Reverse Record Check method is generally recognized as one of the best procedures to evaluate the level of undercoverage in the census. The main advantage of this method lies in the fact that it does not involve any form of re-enumeration which generally leads to underestimates of coverage errors because of the strong tendency for persons missed in the census also to be missed in the reenumeration process.

[7] HOGAN, H. and COWAN, C.D. (1980). "Imputations, Response Errors, and Matching in Dual System Estimation," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 263-268.

The authors propose a simple solution when imputations create problems for matching that is needed in dual system estimation. Their proposed solution - "one should determine the number of nonmatchable cases and subtract them from the counts of both systems." The paper discusses this proposed solution.

[8] NATIONAL RESEARCH COUNCIL (1980). *Estimating Population and Income of Small Areas,* National Academy Press, Washington, D.C.

This report presents the work, findings, and recommendations of a Panel on Small-Area Estimates of Population and Income which was formed at the request of the Census Bureau and charged with the general task of evaluating the Census Bureau's procedures for making postcensal estimates of population and per capita income for local areas. More specifically, the Panel was asked to review methods currently used and possible alternate methods, review data sources currently used and possible alternate sources, and assess levels of accuracy of current estimates in light of the uses made of them and of the effects of potential errors on these uses.

[9] PASSEL, J.S. and ROBINSON, J.G. (1980). "Estimating Coverage of the 1980 United States Census: Demographic Analysis," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 259-262.

The Census Bureau's plan for evaluating the completeness of coverage of the 1980 Census will include Demographic Analysis. *Demographic analysis* as a tool for census evaluation involves developing expected values for the population in various categories (such as age, sex, race categories) at the census date by the combination and manipulation of various types of demographic data and then comparing these values with the corresponding census counts. The accuracy of the method depends on the quality of the demographic data and the corrections. This paper presents an overview of the demographic analysis being planned to evaluate coverage of the 1980 Census.

[10] SPITLER, J.F. and ARRIAGA, E.E. (1980). "Missing and Misplaced Persons: The Case of Census Evaluation in Developing Countries," U.S. Bureau of the Census. *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 281-286.

The purpose of this paper is to discuss the utility individual record checks and aggregate comparisons offer in population census coverage evaluation.

[11] THOMPSON, J. and BRITTON, M. (1980). "Some Socio-Economic Differentials in Fertility in England and Wales," in *Demographic Patterns in Developed Societies, Vol. XIX,* (Ed. R.W. Hiorns). London: Taylor & Francis, 1-13.

This paper looks at some of the more recent information on family size differentials yielded by the 1971 Census and the General Household Survey and registration data in the period 1971 to 1976. The aspects picked out for particular examination are the social group of the husband and wife in combination (where she is working), the terminal age of full-time education, and country of birth of the women.

[12] U.S. BUREAU OF THE CENSUS (1980). "Census Undercount Adjustment: Basis for Decision," *Proceedings of the Second Census Undercount Workshop,* September 2-5, 1980, Washington, D.C.: Government Printing Office.

This report examines the most critical underlying assumptions that we believe establish a proper framework for deciding whether, when, and how to adjust 1980 Census results for undercoverage. Its purposes are to distill into meaningful information two years of deliberation on the issues, and to provide a direct and practical response mechanism for a final round of comment and discussion before decisions are made later this year. This volume contains the workshop papers and the discussion of the papers at the conference.

[13] U.S. BUREAU OF THE CENSUS, (December 16, 1980). "Position on Adjustment of the 1980 Census Counts for Underenumeration," *Federal Register*, *Vol. 45, No. 243,* 82872-82885.

This notice transmits the Census Bureau's decision on whether and how a statistical adjustment of census data should be implemented. This decision is presented independent of the pending judicial actions that may impose other procedures, timing, or applications. In a few words, it states, "...At present, the Bureau has no sound statistical basis for estimating the true undercount or introducing adjustments."

[14] WARREN, R. and PECK, J.M. (1980). "Foreign-Born Emigration from the United States: 1960 to 1970," *Demography*, *Vol. 17, No. 1*, 71-84.

This paper presents estimates of emigration of foreign-born persons by age and sex from 1960 to 1970, based on 1960 and 1970 Census counts of the foreign-born population, adjusted life table survival rates, and annual statistics on alien immigration published by the Immigration and Naturalization Service. The effects of nativity bias are discussed.

1981

[1] BOGUE, D.S. (1981). "Against Adjustment." Commentaries: Census Politics, *Society, Vol. 18, No. 2,* January/February, 18.

Opposition to adjust the 1980 Census count for underenumeration is expressed.

[2] CASTELDINE, B.J. (1981). "A Bayesian Analysis of Multiple-recapture Sampling for a Closed Population," *Biometrika, 67*, 197-210.

This paper considers from a Bayesian viewpoint inferences about the size of a closed animal population from data obtained by a multiple-recapture sampling scheme. The method developed enables prior information about the population size and the catch probabilities to be utilized to produce considerable improvements in certain cases on ordinary maximum likelihood methods. Several ways of expressing such prior information are explored and a practical example of the uses of these ways is given. The main result of the paper is an approximation to the posterior distribution of sample size that exhibits the contributions made by the likelihood and the prior ideas.

[3] CORMACK, R.M. (1981). "Loglinear Models for Capture-Recapture Experiments on Open Populations," in *The Mathematical Theory of the Dynamics of Biological Populations II,* Proceedings of a conference organized by Institute of Mathematics and its Applications, Oxford, 1-3 July, 1980. (Eds. R.W. Hiorns and D. Cooke). London: Academic Press, 197-215.

The paper develops a sequence of models representing a closed population, birth, death, trap dependence, with variables or constant sampling effort, and shows how the GLIM computer package can readily be used to select the model from among combinations of these factors most appropriate for the data set.

[4] DURAN, J.W. and WIORKOWSKI, J.J. (1981). "Capture-recapture Sampling for Estimating Software Error Content," *IEEE Transactions on Software Engineering, SE-7,* 147-148.

Mills' capture-recapture sampling method allows the estimation of the number of errors in a program by randomly inserting known errors and then testing the program for both inserted and indigenous errors. This correspondence shows how correct confidence limits and maximum likelihood estimates can be obtained from the test results. Both fixed sample size testing and sequential testing are considered.

[5] GREENE, M.A. and STOLLMACK, S. (1981). "Estimating the Number of Criminals," in *Models In Quantitative Criminology,* (Ed. J.A. Fox). New York: Academic Press, 1-24.

This chapter develops and applies a methodology for estimating the size of the criminal population from arrest history records. The first section outlines the conceptual framework and the array of methods that can be applied to this problem and then presents a mathematical development of the specific method chosen. Section II applies the methodology to a set of arrest histories for adults from Washington, D.C. The data are then described, followed by a discussion of results. Section III concludes by discussing other areas of criminology that contain applications for this methodology. We focus on the application of parametric models, specifically those based on the Poisson distribution.

[6] HAUSER, P.M. (1981). "The U.S. Census Undercount," *Asian and Pacific Census Forum. November 1981, Vol. 8, No. 2,* 1-10.

The worst problem encountered in the 1980 U.S. Census was the litigation over the accuracy of the count – more than 50 lawsuits were filed against the Bureau of the Census, forcing the bureau to answer for its policies and procedures. This article discusses the problem and offers some solutions.

[7] KEYFITZ, N. (1981). "Statistics, Law, and Census Reporting," Commentaries: Census Politics, *Society, Vol. 18, No. 2*, January/February, 5-12.

The purpose of the census is not to establish the total population of the U.S.– that can be obtained from births, immigration, and other sources – but to find the populations and characteristics of some 39,000 states, cities, and smaller jurisdictions, an even larger number of census tracts, and other geographical detail. We are in the midst of a major redistribution of population, and another purpose of taking censuses is to show such redistributions. A combination of elements out of the past presents the Bureau with some of the most puzzling dilemmas that statisticians have had to face. This paper discusses these dilemmas.

[8] KIRK, D. (1981). "Politics of Demography," Commentaries: Census Politics, *Society, Vol. 18, No. 2*, January/February, 22-25.

This paper discusses why the decennial census is the center of intensive and bitter political controversy.

[9] MAXIM, L.D., HARRINGTON, L., and KENNEDY, M. (1981). "A Capture-recapture Approach for Estimation of Detection Probabilities in Aerial Surveys," *Photogrammetric Engineering and Remote Sensing, 47*, 779-788.

A simple approach for estimating detection probabilities from imagery when ground truth data are non-existent is presented. Based upon what are termed capture-recapture statistics, the method requires only an independent examination of the imagery by two or more observers. In its simplest form the approach requires the assumptions that detections are independent and that no false positives occur. When data from three or more observers are available, checks upon model assumptions can be performed and less restrictive models can be developed. The approach is illustrated with several numerical examples.

[10] RYDER, N.B. (1981). "Demographic Uncertainty," Commentaries: Census Politics, *Society, Vol. 18, No. 2*, January/February, 14.

Demographers success in employing analytic methods to estimate undercount is the topic of discussion. The note focuses on the limitations of demographic analysis in estimating undercount in a census.

[11] TRUSSELL, J. (1981). "Should State and Local Area Census Counts Be Adjusted?," *Population Index, 47 (1)*, 4-12.

The Bureau of the Census has conducted extensive research to evaluate the completeness of enumeration of the U.S. Population in the Censuses of 1950, 1960, and 1970. While the findings of these studies differ in detail, a common finding is that of differential completeness by sex, age, and particularly race. The recognition that blacks, and particularly black males, are thought to have been selectively underenumerated has led to much public concern that relatively large proportions of other minority groups, especially Hispanics, were also not counted. Hence, there has arisen an acute demand for the Census Bureau to adjust the population counts for local and state areas to eliminate the distortion caused by selective underenumeration.

Two methods of estimating the undercount have been proposed, and the results of each can be used to obtain adjusted figures. Both levels and geographical patterns of estimated underenumeration differ according to the methodology and assumptions employed. Does one method appear to be superior to the other and, therefore, does one particular set of estimates appear to be more soundly based? Morever, even if one methodology is judged superior, can it be judged accurate enough to warrant tampering with the reported population counts. These questions are discussed in detail in this paper.

[12] U.S. BUREAU OF THE CENSUS (February 1981). "Critical Assumptions for the Undercount Adjustment Decision," *Data User News, Vol. 16, No. 2.*

This article summarizes the basis for the Census Bureau's decision against attempting to adjust 1980 Census figures for undercount.

[13] WEINSTEIN, J. (1981). "Social Goals and Census Protests," Commentaries: Census Politics, *Society, Vol. 18, No. 2,* January/February, 19-21.

This article examines the ethical and legal issues relating to the question of whether or not to adjust and, if so, how, when, and by whom.

1982

[1] BALINSKI, M. L. and YOUNG, H.P. (1982). *Fair Representation: Meeting the Ideal of One Man, One Vote.* New Haven: Yale University Press.

The aim of this book is to establish a solid logical foundation for choosing among the available methods of apportioning power in representative systems. It is an example of mathematical reasoning applied to a problem of public policy. The style of analysis is similar to the axiomatic approach used in mathematics, when the object is to discover the logical consequences of certain principles. The validity of the approach depends on identifying the right principles as revealed through history, political debate, and common sense.

[2] HOOK, E. and REGAL, R. (1982). "Validity of Bernoulli Census, Loglinear, and Truncated Binomial Models for Correcting for Underestimates in Prevalence Studies," *American Journal of Epidemiology, 116,* 168-176.

Most prevalence studies using health records are likely to miss some affected cases and thus be biased to underestimates. An adjustment for under ascertainment is often necessary, but to the authors knowledge, no validity studies of proposed methods have been done. Using a data set on Down Syndrome which gives distributions by five different sources, the number listed in, say source X, i.e., the known "prevalence" (KP) of those in X, was compared with estimates of this prevalence derived (using only information on the intersections of X with other sources) by using several different models: (1) truncated β-binomial or Skellam (TS); (2) truncated binomial (TB); (3) Bernoulli census-independent sources (IS); (4) Bernoulli census-merged sources (MS); and (5) log-linear (LL). The estimates derived from the log-linear models had in general the best agreement with the values of the known prevalences.

[3] MAURICE, A.J. and NATHAN, R.P. (1982). "The Census Undercount – Effects on Federal Aid to Cities," *Urban Affairs Quarterly, Vol. 17, No. 3,* 251-284.

An adjustment of census population figures for the undercount in the decennial census, contrary to what some have suggested, would not dramatically affect federal grant allocations to cities. Local officials have estimated losses of federal grant funds of as much as $200 per uncounted person in the 1980 Census. An undercount adjustment (the terms are explained) could be expected to add little more than $20 per uncounted person in a few large cities – with most large cities experiencing much smaller gains or even federal aid losses after an adjustment. Several reasons are given for this finding. They relate to the significant limitations of available techniques for estimating the census undercount; the fact that population data are not used in all formula allocation systems; the varied ways in which population data can affect formula allocation systems when they are used; and our assumption that federal aid funds would not increase in proportion to the population added as part of an undercount adjustment procedure for federal grants.

[4] SAVAGE, I.R. (1982). "Who Counts," *The American Statistician, Vol. 36, No. 3, Part I* (with discussion), 195-207. ("Comment" – Bailer, Barbara A., Preston, Samuel H., Stoto, Michael A., and Trussell, James, 200-207.)

This essay outlines what is known about the population undercount in the census. The exposition is non-technical, but the author indicates how this knowledge was acquired. For those who want to learn more or who might consider doing research in this area, the references will bring them quickly to the basic work and current activity.

[5] SEBER, G.A.F. (1982). "Capture–recapture Methods," in *Encyclopedia of Statistical Sciences, Vol. 1,* (Eds. S. Kotz and N.L. Johnson). New York: Wiley, 367-374.

The idea of obtaining information about a population by marking or labeling some of its members can be traced back several centuries. Since the 1940s, the capture–recapture method has been widely used for estimating population numbers and related parameters such as survival and immigration rates. Extensive reviews of the methods are given by Cormack (1968, 1979) and Seber (1973, 1980), and the technique has been recently considered in relation to estimating the size of a human population from several incomplete lists of the population. A historical overview of the subject is given by Otis et. al. [24].

[6] SEBER, G.A.F. (1982). *The Estimation of Animal Abundance and Related Parameters (Second Edition),* New York: Hafner. (First published (1973). New York: Macmillian.)

This book is an attempt to systematize the growing body of literature according to types of statistical models used and, where possible, to discuss in some detail the assumptions underlying the models for estimation of animal abundance.

[7] SPENCER, B.D. (1982). "A Note on Statistical Defensibility," *The American Statistician, Vol. 36, No. 3, Part I* (with discussion), 208-209. ("Comments" – Wolter, Kirk M., Fairley, William B., Fellegi, Ivan P., and Simon, Richard, 209-216.)

The issue of adjusting the 1980 Census for undercoverage has led to questions of *statistical defensibility.* This terminology is interpreted and criticized. Some necessary kinds of politicization of statistics are briefly discussed.

[8] U.S. BUREAU OF THE CENSUS (1982). "1990 Planning Conference Series: No. 1, The Meaning of Enumeration," Washington, D.C.: U.S. Government Printing Office.

This is a summary of a 1990 Census Planning conference held in July 1982. It was attended by 17 Bureau Staff and 18 participants from the community of census advisors and data users. Prior to the meeting, it was evident that there were many conflicting ideas existing about what enumeration is, or should be, in the minds of the litigants, the judiciary, the Congress, and other decision makers. The July conference was intended to examine this important question in depth, not with the purpose of obtaining a definitive answer but rather to develop a better understanding of the wide--ranging implications of any definition. There were four starting positions on what enumeration is that were on a continuum ranging from the strict interpretation "I will not count people unless I can actually see them" to the broader interpretation "I will count people if I can estimate that they are there." In between these extremes were alternatives allowing proxy responses, the use of administrative lists, sampling for follow-up, etc. This report is an attempt to provide a conference proceedings.

1983

[1] BARABBA, V.P., MASON, R.O., and MITROFF, I.I. (1983). "Federal Statistics in a Complex Environment: The Case of the 1980 Census," *The American Statistician, Vol. 37, No. 3,* 203-212.

The taking and the interpretation of something as big and as complicated as the national census is more than an exercise in statistical thinking. It involves other diverse fields such as ethics, epistemology, law, and politics. This article shows that a national census is more akin to so-called ill-structured problems. Unlike well-structured problems, the formulation of an ill-structured problem varies from field-to-field and from person-to-person, and the various aspects of an ill-structured problem (i.e., ethics, epistemology, etc.) cannot be clearly separated from one another. The 1980 Census is discussed as an ill-structured problem, and a method for treating such problems is presented, within which statistical information is only one component.

[2] BEAN, F.D., KING, A.G., and PASSEL, J.S. (1983). "The Number of Illegal Migrants of Mexican Origin in the United States: Sex Ratio-Based Estimates for 1980," *Demography, Vol. 20, No. 1,* 99-109.

This article reports the results of applying a sex ratio-based method to estimate the number of undocumented Mexicans residing in the United States in 1980. The approach centers on a comparison between the hypothetical sex ratio one would expect to find in Mexico in the absence of emigration to the United States and the sex ratio that is in fact reported in preliminary results from the 1980 Mexican Census. The procedure involves, *inter alia,* assuming a range of values for the sex ratio at birth and for census coverage differentials by sex in Mexico.

Even the combinations of these values most likely to result in large estimates suggest that no more than 4 million illegal migrants of Mexican origin were residing in the United States in 1980.

[3] CHILDERS, D.R. and HOGAN, H. (1983). "Census Experimental Match Studies," *Proceedings of the Section on Survey Research Methods. American Statistical Association*, 173-176.

This paper discusses various matching studies and methods for evaluating census coverage.

[4] DIFFENDAL, G.J., ISAKI, C.T., and MALEC, D. (1983). "Some Small Area Adjustment Methodologies Applied to the 1980 Census," *Proceedings of the Section on Survey Research Methods, American Statistical Association,* 164-167.

The Census Bureau has instituted several programs for measuring the quality of the 1980 Census, especially the undercount of the population.

Demographic Analysis (DA) and the Post-Enumeration Program (PEP) are the two major programs to estimate the 1980 undercount. DA provided population estimates of the legal population at the national level while PEP, a sample survey, was designed to provide population estimates at states and some major SMSA's. Using data from DA and the PEP, several methods for adjusting 1980 Census county total population are illustrated.

[5] FAY, R.E. and COWAN, C. (1983). "Missing Data Problems in Coverage Evaluation Studies," *Proceedings of the Section on Survey Research Methods, American Statistical Association,* 158-167.

The purpose of this paper is to establish a theoretical framework in which to discuss the problem of missing data in the studies of census coverage. The approach will be to suggest a synthesis of two more general areas of research. One of these is the growing methodological research into nonresponse in sample surveys. An important reference in this area, a paper by Little (1982), will be cited almost exclusively in the presentation here, because it summarizes or develops the applicable theory from this area of research that will be related in this paper to the general problems of nonresponse in studies of census coverage. The second theoretical development to be cited here is the methodology of causal analysis for categorical data by Goodman (1972, 1973a, 1973b, 1978). This second body of literature develops the correct applications of log-linear models to situations in which relationships among variables are structured by causal mechanisms.

[6] GREENFIELD, C.C. (1983). "On Estimators for Dual Record Systems," *Journal of the Royal Statistical Society, Series A,* 273-280.

Three estimators of the number of events missed in a dual record system of data collection are briefly reviewed. An empirical study by Chandrasekaran and Deming which compares the performance of their estimator with that of Greenfield is then considered and some further calculations on their data are presented.

[7] NICHOLS, J.D. and POLLOCK, K.H. (1983). "Estimating Taxonomic Diversity, Extinction Rates, and Speciation Rates from Fossil Data Using Capture-recapture Models," *Paleobiology, 9*, 150-163.

Methods currently used to estimate taxonomic extinction probabilities from fossil data generally assume that the probability of encountering a specimen in a particular stratum, given that the taxon was extant in the time period and location represented by the stratum, either equals 1.0 or else is a constant for all strata. Methods used to estimate taxonomic diversity (number of taxa) and speciation rate generally assume that encounter probabilities equal 1.0. We suspect that these assumptions are often false. Capture-recapture models were historically developed for estimation in the face of variable and unknown sampling probabilities. These models can thus be used to estimate parameters of interest from paleobiological data when encounter probabilities are unknown and variable over time. These models also permit estimation of sampling variances, and goodness-of-fit tests are available for assessing the fit of data to most models. Here we describe capture-recapture models which should be useful in paleobiological analyses and discuss the assumptions which underlie them. We illustrate these models with examples and discuss aspects of study design. We conclude that these models should prove useful in paleobiological analyses.

1984

[1] ASA TECHNICAL PANEL ON THE CENSUS UNDERCOUNT (1984). "Report of the ASA Technical Panel on the Census Undercount (with comments)," *The American Statistician, Vol. 38,* 252-260.

This report contains recommendations reflecting the views of the ASA Technical Panel on the Census Undercount concerning Census Bureau procedures and plans in the fall of 1982. The recommendations are those of the Panel alone. With one exception, the recommendations were agreed to by all panel members, although individuals stressed the importance of different measures. The papers include recommendations under several broad topics including: demographic analysis methods, statistical methods (PEP and synthetic estimates), strategies for estimation, 1990 Census Plans, and resources.

[2] BOONE, M.S. and WHITFORD, D.C. (1984). "Analysis of Inner City Census Coverage Using Local Hospital Administrative Records," *Proceedings of the Section on Survey Research Methods, American Statistical Association,* 319-322.

This report summarizes findings from a study during the past year of 1980 Census coverage in samples of inner city Black residents. Samples were drawn from the administrative records of a large northeastern city's only public hospital. The use of medical records to develop rosters of individuals for census coverage improvement research has not been previously tried, although similar sources such as drivers' licenses or Internal Revenue Service records have been used. The goal of this research project was to understand better the types of individuals who may be more likely to be missed by 1980 Census mailback and field procedures. The study focused on inner city Black samples because evaluation of census coverage of the population and demographic analysis suggest that the undercount rate in this population segment (or in sub-groups of it) is higher than in the general population. The purpose of this and many other research projects sponsored by the Census Bureau is to learn more about how to provide the best coverage possible in all future decennial censuses of the American population.

[3] CHILDERS, D.R. and HOGAN, H. (1984). "Matching IRS Records to Census Records: Some Problems and Results," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 301-306.

The project discussed in this paper has two principal aims: to investigate the feasibility of using the Internal Revenue Service Individual Master File (IMF) as a frame for matching to the census in order to estimate gross undercoverage in the census, and to study the difficulties in tracing individuals to the census using the IMF address. The study was a research effort to better understand tracing and matching techniques and to investigate the use of the IMF address as a starting point for matching to the census and tracing the initial not matched persons to their present address to obtain their 1980 Census day residence.

[4] COWAN, C.D. and FAY, R.E. (1984). "Estimates of Undercount in the 1980 Census," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 566-571.

The Post-Enumeration Program (PEP) provided estimates of undercount in the 1980 Census. The Post-Enumeration Program was conducted in two parts. The first, designated as the P-Sample, was designed to measure gross undercoverage in the 1980 Census. Because of methodological problems, the P-Sample actually overestimated gross undercoverage, and an adjustment must be made in the estimation process. The second part, designated as the E-Sample, was designed to estimate gross overcoverage in the census; this would include duplicate and erroneous enumeration. These parts are discussed as well as the effects on estimates of undercount due to missing data.

[5] HIDIROGLOU, M.A., MORRY, M., DAGUM, E.B., RAO, J.N.K., and SÄNDAL, C.E. (1984). "Evaluation of Alternative Small Area Estimators Using Administrative Records," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 307-313.

Due to increasing emphasis on planning and administering economic programs at local level, there has been a demand for more and better quality data at these levels on a wide range of economic data. Such data available from surveys may not have adequate precision and hence there is an increasing demand on the use of administrative records to produce this data. Administrative sources, however, may not contain all the required information on a one-hundred percent basis. It may therefore be necessary to pool this information with the survey data.

In this paper, some estimators for small areas are evaluated in the context of producing Census Division level by Major Industrial Division estimates, using the unincorporated data compiled at Statistics Canada and Revenue Canada. Some of the collected variables are candidates for small area estimation, but we will focus on Wages and Salaries.

[6] HOGAN, H. (1984). "Research Plan on Adjustment for the 1990 Decennial Census," *Proceedings of the Social Statistics Section, American Statistical Association*, 452-457.

Should the Bureau use statistical estimating techniques to adjust any of the data obtained in the 1990 Census by the more traditional counting and self-enumeration techniques? If so, what characteristics of population and housing should be adjusted, and what geographic level should be adjusted? In order to resolve these global issues, one must break them into separate sub-issues which can be researched. For the purpose of this paper seven groupings will be used. These are: How would adjustment affect critical uses of census data; What is the legal and policy context for adjustment; How can census coverage best be measured; How can local area estimates of coverage best be made; How should adjustment be implemented as part of the census process; How should the adjusted figures be published and used; What are the other implications of census adjustment?

[7] PASSEL, J.S. and WOODROW, K.A. (1984). "Geographic Distribution of Undocumented Immigrants: Estimates of Undocumented Aliens Counted in the 1980 Census by State," *International Migration Review, Vol. 18, No. 3*, 642-671.

This article presents estimates of the number of undocumented aliens counted in the 1980 Census for each State and the District of Columbia. The estimates, which indicate that 2.06 million undocumented aliens were counted in the 1980 Census, are not based on individual records, but are aggregated estimates derived by a residual technique. The census count of aliens (modified somewhat to account for deficiencies in the data) is compared with estimates of the legally resident alien population based on data collected by the Immigration and Naturalization Service in January 1980. The final estimates represent extensions to the state level of national estimates developed by Warren and Passel (1984). Estimates are developed for each of the states for selected countries of birth and for age, sex, and period of entry categories.

The article describes the origins of the undocumented alien population, as well as some of their demographic characteristics. Some of the implications of the numbers and distribution of undocumented aliens are also discussed.

[8] PASSEL, J.S. and ROBINSON, J.G. (1984). "Revised Estimates of the Coverage of the Population in the 1980 Census Based on Demographic Analysis," *Proceedings of the Section on Social Statistics, American Statistical Association*, 160-165.

Demographic analysis is one of two principal methods for evaluating coverage. The other is the Post-Enumeration Program (PEP). Preliminary demographic estimates of coverage for 1980 were published in February of 1982. This paper reports on the major revisions to the estimates of coverage for 1980 based on the method of demographic analysis. Revisions include: (1) new estimates of births for estimating corrected population 45 to 64 in 1980, (2) adjustment of data on net immigration, (3) use of 1980 aggregate Medicare data for the population 65 and over, (4) substitution of final data covering 1978-1980 for provisional data on births, deaths, and immigrants. Estimates of coverage of the resident population in 1980, including and excluding undocumented aliens, are discussed.

[9] SANDLAND, R.L. and CORMACK, R.M. (1984). "Statistical Inference for Poisson and Multinomial for Capture-recapture Experiments," *Biometrika, 71*, 27-33.

The classical multinomial model used for estimating the size of a closed population is compared to the highly flexible Poisson models introduced by Cormack (1981). The multinomial model, and generalizations of it which allow for dependence between samples, may be obtained from that of Cormack by conditioning on the population size. The maximum likelihood estimators for N, the population size, and θ, the vector of parameters describing the capture process, are the same in both models. Completely general formulae for the asymptotic variances of the maximum likelihood estimates of N for both models are given. The substantial differences between the variances under the two models are discussed. Hypotheses concerning θ may be

tested using the log likelihood ratio: the procedures which result from both models are asymptotically equivalent under the null hypothesis but differ in power under the alternative.

1985

[1] BROWNIE, C., ANDERSON, D.R., BURNHAM, K.P., and ROBSON, D.S. (1985). "*Statistical Inference from Band Recovery Data — A Handbook,*" *U.S. Fish and Wildlife Service Resource Publication 131,* Washington, D.C.

The handbook was prepared as an aid to those engaged in the analysis of several kinds of bird banding and other animal tagging studies. A common objective in most of these studies is the estimation of parameters which will reflect population survival. Here the authors focus considerable attention on the estimation of survival rates and specifically concentrate on inference procedures (estimation and hypothesis tests) regarding time- and age-specific survival rates.

This handbook covers the analysis of banding studies for one, two, or three identifiable age classes; it also presents methods for use when banding is done twice a year on the same population. In all, we discuss 14 models, each allowing different and testable assumptions. For each model they present optimal estimators of certain parameters, the most important of which are annual survival and recovery rates (other parameters include mean life span and average annual survival and recovery rates). Estimates of sampling variation (precision) are given for all parameters estimators. Confidence intervals on parameters are presented and, for models currently of practical value, goodness-of-fit tests are presented. Also, tests between models are presented which are useful for selection of the appropriate model and for pooling data sets. The last chapter is devoted to the subject of planning a banding study.

[2] ERICKSEN, E.P. and KADANE, J.B. (1985). "Estimating the Population in a Census Year: 1980 and Beyond (with discussion)," *Journal of the American Statistical Association, Vol. 80,* 98-131.

Decennial census results should not be viewed as counts to be reported directly, but as data to be used in estimating the population and its characteristics. We propose methods by which the results of the 1980 Census could be so analyzed using both other nationally collected information currently available at the Census Bureau and locally collected information especially likely to be needed in areas where undercount rates are high. Finally, the paper addresses the questions of how the 1990 Census might be designed with estimation in mind.

[3] FAY, R.E. (1985). "Implications of the 1980 PEP for Future Census Coverage Evaluation," *Proceedings of the Section on Survey Research Methods, American Statistical Association,* 413-418.

The undercount of the population censuses, a concern of the U.S. Bureau of the Census for many years, has become an issue of more intense public and professional interest and debate during the last decade. Much of the attention has focused on whether geographic differentials in the census undercount can be adequately estimated or measured, and whether the census counts or other characteristics should be adjusted to compensate for such differentials. The decision of the Census Bureau is that none of the evaluations of the undercount of the 1980 Census are suitable for adjustment. At the same time, the Bureau has undertaken a program of research to investigate the feasibility and implications of incorporating an adjustment into the counts of the 1990 Census.

The complex issues of census adjustment have been addressed by a number of authors, including Bailar (1983) and Keyfitz (1979). A paper of Ericksen and Kadane (1985) states their own position on the feasibility of adjustment and includes accompanying discussion from a number of other points of view. Part of the debate has centered on the importance of measurement of undercount for geographic units through direct sample survey methods, and on the methodological difficulties and limitations of such an approach. In particular, the specific merits and deficiencies of the undercount study conducted for the 1980 Census, the Post-Enumeration Program (PEP), has been part of this public discussion. The intent of this paper is to examine issues in the measurement of net census error by survey methods, as these issues are illustrated by specific problems of the PEP.

[4] JEWELL, W.S. (1985). "Bayesian Estimation of Undetected Errors," in *Bayesian Statistics 2,* (Eds. J.M. Bernardo, et al.). New York: Elsevier, 663-671.

An unknown number, *N*, of errors or defects exist in a certain product, and I inspectors with unknown competencies are put to work to find the errors. Given the lists of errors found by each inspector, how can we estimate the number of undetected errors? A similar problem arises in capture-recapture sampling in population biology, where the MLE of *N*, attributed to Petersen, Chapman, and Darroch, has been known for many years. The author's Bayesian model assumes that *N* is Gamma-mixed-Poisson, that errors are equally difficult to detect, and that inspector error detection probabilities are independent and Beta-distributed, a priori. The predictive density for undetected errors is obtained as a simple, recursive relationship that gives Negative Binomial tails. The predictive mode for undetected errors is given by a generalized Petersen-Chapman-Darroch form involving credibility formulae; as the prior parameter variances increase without limit, this predictive mode approaches the classical estimator.

[5] PANEL ON DECENNIAL CENSUS METHODOLOGY (1985). *The Bicentennial Census*: *New Directions for Methodology in 1990,* C.F. Citro and M.L. Cohen, editors, Washington, D.C.: National Academy Press.

This report is an attempt to assess the merits of proposed changes in the next decennial census that represent important departures from past practice and, specifically, to recommend concepts and procedures that should be assigned high priority in the Census Bureau's research and testing program for the nation's bicentennial census. The report offers general and specific planning recommendations in five areas: (1) overall strategy for planning the 1990 Census, (2) procedures for coverage improvement as part of the Census, (3) uses of sampling and administrative records in taking the census, (4) adjustment of census counts and characteristics, and (5) measuring the completeness of the 1990 Census.

[6] SPENCER, B.D. (1985). "Statistical Aspects of Equitable Apportionment," *Journal of the American Statistical Association, 80,* 815-822.

Two problems that arise in apportioning the U.S. House of Representatives are: (a) fractional numbers of representatives cannot be allocated, so states receive different per capita representation, and (b) the state population sizes are known only with error. Both problems are addressed in a unified way with decision theory. Although the method currently in use, *equal proportions*, has poor properties when the populations are assumed perfectly known, it performs surprisingly well in the presence of modest errors in the data. The converse is true for the *quota method*. Previously developed qualitative notions of bias in apportionment methods are extended to provide a quantitative definition of bias. The new definition accounts both for bias in the apportionment method and for bias arising from imperfect population measurements. Illustrative estimates of the bias against states with large black populations are developed.

[7] STEINBERG, B. and HOGAN, H. (1985). "The Effects of Population Adjustment on the Allocations of Three Government Programs," *Proceedings of the Social Statistics Section, American Statistical Association*, 256-260.

This paper deals with population undercount in the Decennial Census and the effects on fund allocation which would result from an attempt to adjust the census.

1986

[1] ALONSO, W. and STARR, P. (Eds.) (1986). *The Politics of Numbers,* for the *National Committee for Research on the 1980 Census,* New York: Russell Sage Foundation.

The chapters in this volume were initially prepared for a conference on "The Political Economy of National Statistics," held in Washington on October 13-15, 1983. The conference was sponsored by the Social Science Research Council's Committee for Research on the 1980 Census.

In designing this collaborative project, Alonso and Starr have brought together authors from different fields - economics, history, politics, sociology, and planning - to write on topics that they thought would be interesting in their own right and of broad intellectual reach. Their aim was not to contribute to statistical policy or methodology but to open up a field that scarcely exists - the political economy and sociology of statistics. They hoped the collection would be suggestive, without pretending that it might be definitive. The book also represents an effort to sort out the analytical issues in the sociology of statistics and to put them in intellectual content and perspective. A central tenet of this book is that statistics cannot be constructed on purely technical grounds alone but require choices that ultimately turn on considerations of purpose and policy. The 14 papers in the book are distributed among five parts: The Politics of Economic Measurement, The Politics of Population Measurement, Statistics and Democratic Politics, Statistics and American Federalism, and The New Political Economy of Statistics.

[2] CLOGG, C., MASSAGLI, M., and ELIASON, S. (1986). "Population Undercount as an Issue in Social Research," in the *Proceedings of the Second Annual Research Conference of the U.S. Bureau of the Census*, Washington, D.C., 335-343.

Much social research relies on census data. This includes direct analysis of census data and the use of census data to make comparisons or calculate rates. It also includes the use of the census to construct sampling frames or to adjust surveys for nonresponse. Usually the effects of census undercount are both ignorable and ignored. In some problems, however, the effects of the undercount are so important that they must not be ignored. This paper surveys some of these problems and suggests what both researchers and the Census Bureau might do to handle them.

[3] COWAN, C.D. and MALEC, D.J. (1986). "Capture-recapture Models When Both Sources Have Clustered Observations," *Journal of the American Statistical Association, 81,* 347-353.

Capture-recapture models assume that individuals in the population are captured one at a time and independently of each other. There are often situations, however, where individuals are captured in small clusters or groups. This article provides a model that allows individuals to be captured in groups; the EM algorithm is used to estimate parameters in the model that include capture probabilities and the size of the population under study.

[4] DAHIYA, R.C. and BLUMENTHAL, S. (1986). "Population Or Sample Size Estimation," in *Encyclopedia of Statistical Sciences, (Vol. 7),* (Eds. S. Kotz and N.L. Johnson). New York: Wiley, 100-110.

Suppose that $X_1, \ldots, X_N$ are independent random variables with a common probability density function (PDF) $f(x|\theta)$ where θ is a scalar or vector parameter. Let X_i be observable only if it lies outside a given region R. Thus the number M of observed X's is a binomial (N, p) variate, $p = 1 - P(X \varepsilon R)$. This contribution considers a survey of the recent work where N itself is of considerable interest and is estimated, along with θ, from observed values of M and X's. We give several examples below where estimation of the sample size, N , is of primary interest. In some of these situations, N represents the population size, but the problem of estimation is similar in both the situations.

[5] FIENBERG, S. (1986). "Adjusting the Census: Statistical Methodology for Going Beyond the Count," *Proceedings of the Second Annual Research Conference of the U.S. Bureau of the Census,* Washington, D.C., 570-577.

With the growing consensus for the need to adjust decennial census results, attention has been focused primarily on the estimation of population counts at the national or state level and secondarily on methods to carry these adjusted estimates down to lower levels of geographic aggregation. But the census collects extensive qualitative and quantitative information and issues remain regarding how to extend a systematic program of estimation from the population counts to these other quantities. This paper will review some of the procedures in current use and suggest how existing statistical methodology might be brought to bear on estimation beyond the count.

[6] FREEDMAN, D.A. and NAVIDI, W.C. (1986). "Regression Models for Adjusting the 1980 Census (with discussion)," *Statistical Science, Vol. 1,* 3-39.

After the 1980 Census, New York State sued to compel the Bureau of the Census to adjust the population counts, using a regression model. The appropriateness of such models is considered in this paper.

[7] GARRETT, J., HOGAN, H., and PAUTLER, Jr., C. (1986). "Coverage Concepts and Issues in Data Collection and Data Presentation," *Proceedings of the Second Annual Research Conference of the U.S. Bureau of the Census*, Washington, D.C., 329-334.

Coverage error is the error in an estimate that results from (1) failure to include in the frame all units belonging to the target population or failure to include specified units in the conduct of the survey (undercoverage), and (2) inclusion of some units erroneously because of a defective frame, inclusion of unspecified units or inclusion of specified units more than once (overcoverage).

Coverage errors are distinguished from content errors and other nonsampling errors. This paper studies coverage as an issue in data quality for the business, agriculture, and population and housing census and surveys. Various illustrations of coverage error and its sources are given. This paper also raises some questions which provide areas of future research.

[8] ISAKI, C.T., DIFFENDAL, G., and SCHULTZ, L. (1986). "Statistical Synthetic Estimates of Undercount for Small Areas," *Proceedings of the Second Annual Research Conference of the U.S. Bureau of the Census,* Washington, D.C., 557-567.

The magnitude of errors resulting from the use of three statistical synthetic estimation procedures for small area adjustment are presented. Because the actual undercount is unknown, artificial populations are constructed and used as standards to evaluate the adjustment methods. Adjusted population counts at both the state and county level are examined in this simulation using 1980 Census data.

[9] ISAKI, C.T. (1986). "Bias of the Dual-system Estimator and Some Alternatives," *Communications in Statistics, Theory and Methods, 15,* 1435-1450.

A dual system estimator was used to estimate the coverage of the 1980 Census. The estimator assumes that the response of a randomly selected individual to one system is independent of its response to the other systems. When this is not the case, the resulting correlation induces a bias in the estimator. Several alternative estimators are proposed to handle this situation under a simple model and their average absolute relative errors are compared under two frequency distributions.

[10] ISAKI, C.T. and SCHULTZ, L.K. (1986). "Dual-system Estimation Using Demographic Analysis Data," *Journal of Official Statistics, 2,* 169-179.

This paper will address the issue of statistical dependence. More specifically, the authors propose several total population estimators that can be used when one suspects that dependence exists between the two data collection procedures.

[11] MULRY-LIGGAN, M. and HOGAN, H. (1986). "Research Plan on Census Adjustment Standards," *Proceedings of the Second Annual Research Conference of the U.S. Bureau of the Census,* Washington, D.C., 381-392.

The Bureau of the Census has decided to establish in advance of the 1990 Decennial Census standards or criteria that will be used to judge the quality and characteristics of potential census adjustments relative to unadjusted data. The paper describes the research necessary to develop explicit and objective standards and the steps to establish the standards. The major components of the research are the development of a conceptual framework to measure improvement in census counts and the development of operational measures of the accuracy of the estimates of census error. The paper summarizes previous research, including the standards proposed during the litigation concerning the 1980 Decennial Census. The results to date of current research projects also are discussed.

[12] NICHOLS, J.D., MORRIS, R.W., BROWNIE, C., and POLLOCK, K.H. (1986). "Sources of Variation in Extinction Rates, Turnover, and Diversity of Marine Invertebrate Families During the Paleozoic," *Paleobiology, 12*, 421-432.

They authors have recently shown how capture-recapture models can be used in conjunction with stratigraphic range data to estimate taxonomic extinction rates and taxonomic diversity. Here they present a new method that can be used to estimate taxonomic turnover (defined here as the proportion of taxa extant at time i, that originated in the interval $i - 1$ to i).

[13] SPENCER, B. (1986). "Conceptual Issues in Measuring Improvement in Population Estimates," *Proceedings of the Second Annual Research Conference of the U.S. Bureau of the Census*, Washington, D.C., 393-407.

Conceptual issues in defining accuracy are addressed. The expected value of a loss function is considered as a measure of accuracy and alternative grounds for choosing a loss function are analyzed. Recommendations are presented concerning choice of loss functions for use in deciding whether to adjust the census and how to allocate resources for data collection and analysis.

[14] WOLTER, K.M. (1986). "Some Coverage Error Models for Census Data," *Journal of the American Statistical Association, Vol. 81*, 338-346.

Alternative models are presented for representing coverage error in surveys and censuses of human populations. The models are related to the capture-recapture models used in wildlife applications and to the dual-system models employed in the vital events literature. Estimation methodologies are discussed for one of the coverage error models. The theoretical foundations of the methodology are developed and distinctions are made between two kinds of error: (a) sampling errors and (b) error associated with the model. An example involving data from the 1980 U.S. Census is presented. The problem of adjusting census and survey data for coverage error is also discussed.

1987

[1] BURNHAM, K.P., ANDERSON, D.R., WHITE, G.C., BROWNIE, C., and POLLOCK, K.H. (Eds.)(1987). *Design and Analysis Methods for Fish Survival Experiments Based on Release-Recapture, American Fisheries Society Monograph 5*.

This monograph presents design and analysis methods for a large class of survival experiments based on release-recapture of marked populations. The authors developed the underlying theory primarily to address fishery issues involving spillways, hydroelectric turbines, bypass systems, and related structures on the Columbia River in the northwestern United States. Many other applications exist, however. Treatment might include dosing of lead or various pesticides to determine the chronic effect of a contaminant on survival. The general theory is for the analysis of multiple interrelated release-recapture data sets; the methods presented herein apply to any experiments involving treatment and control groups of marked animals.

[2] CHAO, A. (1987). "Estimating the Population Size for Capture-recapture Data with Unequal Catchability," *Biometrics, 43,* 783-791.

A point estimator and its associated confidence interval for the size of a closed population are proposed under models that incorporate heterogeneity of capture probability. Real data sets are used to illustrate this method and to compare it with other estimates. The performance of the proposed procedures is also investigated by means of Monte Carlo experiments. The method is especially useful when most of the captured individuals are caught once or twice in the sample, for which case the jackknife estimator usually does not work well. Numerical results also show that the proposed confidence interval performs satisfactorily in maintaining the nominal levels.

[3] CHILDERS, D., DIFFENDAL, G., HOGAN, H., SCHENKER, N., and WOLTER, K. (1987). "The Technical Feasibility of Correcting the 1990 Census," *Proceedings of the Social Statistics Section, American Statistical Association,* 36-45.

In this paper, the authors discuss the issue of whether there exists a rigorous and professionally sound body of statistical theory, methods, and operations for correcting the 1990 Census enumeration so as to produce census figures with reduced differential undercount. They show that such methods exist and that corrections to the census are technically feasible.

[4] ERICKSEN, E.P. and KADANE, J.B. (1987). "Sensitivity Analysis of Local Estimates of Undercount in the 1980 U.S. Census," in *Small Area Statistics: An International Symposium,* (Eds. R. Platek, J.N.K. Rao, C.E. Sändal, and M.P. Singh). New York: Wiley, 23-45.

The authors have used a hierarchical Bayesian model to compute local estimates of the undercount in the 1980 U.S. Census. This chapter analyzes the sensitivity of these estimates to variations in the assumptions on which they are based. These assumptions concern the numbers and racial composition of undocumented aliens, strategies for imputing values to missing data in the survey on which the estimates are based, and methods of computing standard errors. This chapter also investigates the problem of extrapolating to areas other than those on which the model is estimated.

[5] HOGAN, H. and MULRY, M. (1987). "Operation Standards for Determining the Accuracy of Census Results," *Proceedings of the Social Statistics Section, American Statistical Association*, 46-55.

This document establishes in advance of the 1990 Decennial Census technical standards that shall be used to decide whether it is statistically sound to adjust the census figures. These standards reflect accepted statistical practice for judging data quality. By developing standards that are agreed upon in advance, the Bureau of the Census removes the need to trust the judgement of any one specific person or any one concern. The decision is based upon definite knowledge about the results of the census coverage evaluation program and the quality of both the census and the evaluation. The methods for measuring the error are the post -enumeration survey and demographic analysis.

[6] ISAKI, C.T., SCHULTZ, L.K., SMITH, P.J., and DIFFENDAL, G.J. (1987). "Small Area Estimation Research for Census Undercount–Progress Report," in *Small Area Statistics*: *An International Symposium,* (Eds. R. Platek, J.N.K. Rao, C.E. Sändal, and M.P. Singh). New York: John Wiley and Sons, 219-238.

The Bureau of the Census is currently investigating the potential use of several strategies for adjusting the census count for small areas. The strategies investigated consist of combinations of regression and synthetic estimation methods.

This chapter summarizes background information on the nature of the undercount and its impact on major uses of census data, and describes the available information pertaining to undercount. Adjustment strategies under study are presented together with results obtained to date and plans for future work.

[7] ISAKI, C.T. and SCHULTZ, L.K. (1987). "The Effects of Correlation and Matching Error in Dual-system Estimation," *Communications in Statistics, Theory and Methods, 16,* 2405-2427.

In a previous paper, Isaki (1986), it was shown that the relative bias of the dual system estimator can be substantially reduced in the presence of correlation of responses. Two alternative estimators were compared with the usual dual system estimator assuming no matching error. In the following, a simple matching error model is used to compare the three dual system estimators with respect to bias and mean square error in the presence of correlation. For the parameter values used, the authors found that the usual dual system estimator is competitive with that of the alternative estimators.

[8] KISH, Leslie (1987). *Statistical Design for Research,* New York: John Wiley and Sons.

In this book, some basic aspects of research design that are central and common to many related fields are addressed. The aims and contents of this book concern the methods and philosophy of statistics, but they are mostly nonmathematical.

[9] SCHIRM, A.L. and PRESTON, S.H. (1987). "Census Undercount Adjustment and the Quality of Geographic Population Distributions (with discussion)," *Journal of the American Statistical Association, 82,* 965-990.

The authors develop a simulation procedure to measure the effects of synthetic adjustment for census undercounts on the quality of estimated proportionate geographic population distributions. Analyzing the influences of both interstate variations in census coverage and measurement errors in national undercount estimates, they find that, over a wide range of environments, nearly two out of every three simulated applications of synthetic adjustments improve the state proportions for a majority of the national population. There is always, however, a substantial probability that adjustment will produce a much poorer geographic distribution in any particular application. They derive analytical expressions showing as precisely as possible the conditions on which improvements from census adjustment depend.

1988

[1] BIEMER, P.P. (1988). "Modeling Matching Error and Its Effect on Estimates of Census Coverage Error," *Survey Methodology, 14,* 117-134.

Dual system estimators of census undercount rely heavily on the assumption that persons in the evaluation survey can be accurately linked to the same persons in the census. Mismatches and erroneous nonmatches, which are unavoidable, reduce the accuracy of the estimators. Studies have shown that the extent of the error can be so large relative to the size of census coverage error as to render the estimate unusable.

In this paper, the author proposes a model for investigating the effect of matching error on the estimators of census undercount and illustrate its use for the 1990 Census undercount evaluation program. The mean square error of the dual system estimator is derived under the proposed model and the components of MSE arising from matching error are defined and explained. Under the assumed model, the effect of matching error on the MSE of the estimator of census undercount is investigated. Finally, a methodology for employing the model for the optimal design of matching error evaluation studies will be illustrated and the form of the estimators will be given.

[2] BOSWELL, M.T., BURNHAM, K.P., and PATIL, G.P. (1988). "Role and Use of Composite Sampling and Capture–recapture Sampling in Ecological Studies," in *Handbook of Statistics Vol. 6: Sampling,* (Eds. P.R. Krishnaiah and C.R. Rao). Amsterdam: North Holland, 469-488.

The physical mixing of samples with other samples or with the population has turned out to be a basis of some important sampling procedures. Sampling with replacement may be interpreted as returning a sample to the original population and thoroughly mixing it before the next sample is selected. This type of sampling has been quite common in practice. A relatively recent sampling procedure, called *composite sampling*, involves physically mixing of samples before measuring, counting, or otherwise analyzing the composite sample. Pertinent statistical analysis is able to extract most of the information from the composite sample that can otherwise be extracted from the measurements on the individual original samples before they are physically mixed. The savings in the cost of measuremental analyses can be substantial. Another sampling procedure, called *capture–recapture sampling*, involves physical mixing of a sample back into the original population. While composite sampling and sampling with replacement are used to estimate the population density/abundance, capture–recapture sampling is used to estimate size and survival of individuals. Both composite sampling and capture–recapture sampling techniques have been refined and adapted in response to the varying needs involving different kinds of parameters of the populations of interest. The purpose of this paper is to provide a perspective of these sampling procedures.

[3] BURGESS, R.D. (1988). "Evaluation of Reverse Record Check Estimates of Undercoverage in the Canadian Census of Population," *Survey Methodology*, 137-156.

Estimates of undercoverage in the Canadian Census of Population have been produced for each census since 1961, using a Reverse Record Check method. The reliability of the estimates is important to how they are used to assess the quality of the census data and to identify significant causes of coverage error. It is also critical to the development of methods and procedures to

improve coverage for future censuses. The purpose of this paper is to identify potential sources of error in the Reverse Record Check, which should be understood and addressed, where possible, in using this method to estimate coverage error.

[4] CHOI, C.Y., STEEL, D.G., and SKINNER, T.J. (1988). "Adjusting the 1986 Australian Census Count for Under Enumeration," *Survey Methodology, 14*, 173-189.

In Australia, population estimates have been obtained from census counts, incorporating an adjustment for underenumeration in 1976, 1981, and 1986. The adjustments are based on the results of a Post-Enumeration Survey and demographic analysis. This paper describes the methods used and the results obtained in adjusting the 1986 Census. The formal use of sex ratios as suggested by Wolter (1986) is examined as a possible improvement of the less formal use made of these ratios in adjusting census counts.

[5] CRESSIE, N. (1988). "When Are Census Counts Improved by Adjustment?," *Survey Methodology, 14*, 191-208.

There are persuasive arguments for and against adjustment of the U.S. decennial census counts, although many of them are based on political rather than technical considerations. The decision whether or not to adjust depends crucially on the method of adjustment. Moreover, should adjustment take place using say a synthetic-based or a regression-based method, at which level should this occur and how should aggregation and disaggregation proceed? In order to answer these questions sensibly, a model of undercount errors is needed which is "level-consistent" in the sense that it is preserved for areas at the national, state, county, *etc.* level. Such a model is proposed in this article; like subareas are identified with strata such that within a stratum the subareas' adjustment factors have a common stratum mean and have variances inversely proportional to their census counts. By taking into account sampling of the areas (e.g., by dual system estimation), empirical Bayes estimators that combine information from the stratum average and the sample mean value, can be constructed. These estimators are evaluated at the state level (51 states, including Washington, D.C.) and stratified on race/ethnicity (3 strata) using data from the 1980 postenumeration survey (PEP 3-8, for the noninstitutional population).

[6] DIFFENDAL, G. (1988). "The 1986 Test of Adjustment Related Operations in Central Los Angeles County," *Survey Methodology, 14,* 71-86.

As part of the planning for the 1990 Decennial Census, the Census Bureau investigated the feasibility of adjusting the census for the estimated undercount. A test census was conducted in Central Los Angeles County, in a mostly Hispanic area, in order to test the timing and operational aspects of adjusting the census using a post-enumeration survey (PES). This paper presents the methodology and the results in producing a census that is adjusted for the population missed by the enumeration. The results from the test census demonstrate that undercount estimates can be produced in a timely manner. The test census measured an undercount of 9 percent for the Central Los Angeles County. Separate dual system estimates are presented for 70 race-tenure by age by sex categories.

[7] FAY, R.E., PASSEL, J.S., ROBINSON, J.G., and COWAN, C.D. (1988). *The Coverage of Population in the 1980 Census*. Bureau of the Census, Washington, D.C.: U.S. Department of Commerce.

This report discusses both the conclusions and limitations of two different evaluations of the accuracy of the 1980 Census. The first of these is based on the method of demographic analysis. This method constructs estimates of the total U.S. population and its components by race, age, and sex from aggregate statistics on births, deaths, immigration, emigration, past censuses, Medicare enrollment, and other sources. The second evaluation, the 1980 Post-Enumeration Program (PEP), employs sample survey methods to measure directly the distinct components of census error for a sample of persons, thereby to estimate the net error of the census. Both demographic analysis and the 1980 PEP are subject to substantial limitations on their accuracy. Section 1.C states some of these limitations, which are a major subject of the balance of this report. Indeed, as will be shown, the estimates from demographic analysis and the 1980 PEP are in conflict in important respects. In spite of the limitations of the methods, the available evidence appears to support a number of general conclusions concerning the completeness of coverage of the 1980 Census. One major conclusion is that coverage in 1980 was better than in 1970.

[8] FEIN, D.J. and WEST, K.K. (1988). "The Source of Census Undercount: Findings from the 1986 Los Angeles Test Census," *Survey Methodology, 14,* 223-240.

This paper presents results from a study of the causes of census undercount for a hard-to-enumerate, largely Hispanic urban area. A framework for organizing the causes of undercount is offered, and various hypotheses about these causes are tested. The approach is distinctive for its attempt to quantify the sources of undercount and isolate problems of unique importance by controlling for other problems statistically.

[9] HOGAN, H. and WOLTER, K.M. (1988). "Measuring Accuracy in A Post-enumeration Survey," *Survey Methodology, 14,* 99-116.

The U.S. Bureau of the Census will use a post-enumeration survey to measure the coverage of the 1990 Decennial Census. The Census Bureau has developed and tested new procedures aimed at increasing the accuracy of the survey. This paper describes the new methods. It discusses the categories of error that occur in a post-enumeration survey and means of evaluation to determine that the results are accurate. The new methods and the evaluation of the methods are discussed in the context of a recent test post-enumeration survey.

[10] ISAKI, C.T., SCHULTZ, L.K., DIFFENDAL, G.J., and HUANG, E.T. (1988). "On Estimating Census Undercount in Small Areas," *Journal of Official Statistics, 4,* 95-112.

Net undercount rates in the U.S. decennial census have been steadily declining over the last several censuses. Differential undercounts among race groups and geographic areas, however, appear to persist. In this paper, the authors examine and compare several methodologies for providing small area estimates of census coverage by constructing artificial populations. Measures of performance are also introduced to assess the various small area estimates. Synthetic estimation in combination with regression modeling provides the best results over the methods considered. Sampling error effects are also simulated. The results form the basis for determining coverage evaluation survey small area estimates of the 1990 Decennial Census.

[11] LASKA, E.M., MEISNER, M., and SIEGEL, C. (1988). "Estimating the Size of a Population from a Single Sample," *Biometrics, 44,* 461-472. (Correction, (1989), *45,* 1347.)

Methods for estimating the size of a population of individuals usually require multiple samples from the group. The authors consider a population composed of an unknown number, N*, of individuals on one or more of K > 1 ordered lists. A single sample of individuals from the population, those on list K, together with the identification of the list on which they last appeared prior to list K is obtained. Under relatively weak assumptions on the probability model, an unbiased maximum likelihood estimator of N* is obtained. An expression is derived for the bias of the estimator and its consequence on the true probability of coverage of the confidence internal when the model's assumptions do not hold. Applications of this method are discussed and an illustrative example is presented.

[12] MULRY, M.H. and SPENCER, B.D. (1988). "Total Error in the Dual-system Estimator: The 1986 Census of Central Los Angeles County," *Survey Methodology, 14*, 241-263.

The U.S. Bureau of the Census uses dual system estimates (DSEs) for measuring census coverage error. The dual system estimate uses data from the original enumeration and a Post-Enumeration Survey. In measuring the accuracy of the DSE, it is important to know that the DSE is subject to several components of nonsampling error, as well as sampling error. This paper gives models of the total error and the components of error in the dual system estimates. The models relate observed indicators of data quality, such as a matching error rate, to the first two moments of the components of error. The propagation of error in the DSE is studied and its bias and variance are assessed. The methodology is applied to the 1986 Census of Central Los Angeles County in the Census Bureau's Test of Adjustment Related Operations. The methodology also will be useful to assess error in the DSE for the 1990 Census as well as other applications.

[13] ROMANIUC, A. (1988). "A Demographic Approach to the Evaluation of the 1986 Census and the Estimates of Canada's Population," *Survey Methodology, 14*, 157-171.

A significant increase in coverage error in the 1986 Census is revealed by both the Reverse Record Check and the demographic method presented in this paper. Considerable attention is paid to an evaluation of the various components of population growth, especially interprovincial migration. The paper concludes with an overview of two alternative methods for generating postcensal estimates: the currently-in-use, census-based model, and a flexible model using all relevant data in combination with the census.

[14] RUBIN, D.B., SCHAFER, J.L., and SCHENKER, N. (1988). "Imputation Strategies for Missing Values in Post-enumeration Surveys," *Survey Methodology, 14*, 209-221.

This paper reviews the imputation methods used to handle missing data in the 1986 Test of Adjustment Related Operations (Schenker1988) and proposes two alternative model-based methods: (1) a maximum-likelihood contingency-table estimation procedure that ignores the missing-data mechanism; and (2) a new Bayesian contingency table estimation procedure that does not ignore the missing-data mechanism. The first method is computationally simpler, but the second is preferred on conceptual and scientific grounds.

[15] SCHENKER, N. (1988). "Handling Missing Data in Coverage Estimation, with Application to the 1986 Test of Adjustment Related Operations," *Survey Methodology, 14*, 87-97.

This paper discusses methods used to handle missing data in post-enumeration surveys for estimating census coverage error, as illustrated for the 1986 Test of Adjustment Related Operations (Diffendal 1988). The methods include imputation schemes based on hot-deck and logistic regression models as well as weighting adjustments. The sensitivity of undercount estimates from the 1986 Test to variations in the imputation models is also explored.

[16] SMITH, P.J. (1988). "Bayesian Methods for Multiple Capture-recapture Surveys," *Biometrics, 44*, 1177-1189.

To estimate the total size of a closed population, a multiple capture-recapture sampling can be used. This sampling design has been used traditionally to estimate the size of wildlife populations and is becoming more widely used to estimate the size of hard-to-count human populations. This paper presents Bayesian methods for obtaining point and interval estimates from data gathered from capture-recapture surveys. A numerical example involving the estimation of the size of a fish population is given to illustrate the methods.

[17] SUN, M. (1988). "Plan to Assess Census Undercounting Dropped," *Science, Vol. 239*, 456-457.

Discusses the Commerce Department decision to cancel plans to calculate the number of blacks and other minorities inadvertently missed by the 1990 Census.

[18] ZASLAVSKY, A.M. (1988). "Representing Local Area Adjustments by Reweighting of House-holds," *Survey Methodology, 14*, 265-288.

Suppose that undercount rates in a census have been estimated and that block-level estimates of the undercount have been computed. It may then be desirable to create a new roster of households incorporating the estimated omissions. It is proposed here that such a roster be created by weighting the enumerated households. The household weights are constrained by linear equations representing the desired total counts of persons in each estimation class and the desired total count of households. Weights are then calculated that satisfy the constraints while making the fitted table as close as possible to the raw data. The procedure may be regarded as an extension of the standard "raking" methodology to situations where the constraints do not refer to the margins of a contingency table. Continuous as well as discrete covariates may be used in the adjustment, and it is possible to check directly whether the constraints can be satisfied. Methods are proposed for the use of weighted data for various census purposes, and for adjustment of covariate information on characteristics of omitted households, such as income, that are not directly considered in undercount estimation.

1989

[1] CHAO, A. (1989). "Estimating Population Size for Sparse Data in Capture-recapture Experiments," *Biometrics, 45*, 427-438.

Estimators of population size under two commonly used models (the time-variation model and the heterogeneity model) for sparse capture-recapture are proposed. A real data set of Illinois

mud turtle is used to illustrate the methods and to compare them with other estimators. A simulation study was carried out to show the performance and robustness of the proposed estimators.

[2] CLOGG, C.C., MASSAGLI, M.P., and ELIASON, S.R. (1989). "Population Undercount and Social Science Research," *Social Indicators Research, 21*, 559-598.

The undercount problem in the decennial census has important implications for social science research based directly or indirectly on census data. Because undercount rates (or coverage rates) vary by age, race, residence, and other factors typically studied in social research, important conceptual difficulties arise in using census results to corroborate sampling frames or to validate survey results. Differential undercount, particularly for analyses based on small areas, could produce substantial variability in prevalence rates in cases where the denominators for those rates are derived from the census. Several examples where the undercount problem arises in social science research, including survey research, are considered. The adjustment problem – whether to adjust, how to adjust, and how much to adjust – is also considered from the point of view of social science research.

[3] CORMACK, R.M. (1989). "Log-linear Models for Capture-recapture," *Biometrics, 45,* 395-413.

Log-linear models are developed for capture-recapture experiments, and their advantages and disadvantages discussed. Ways in which they can be extended, sometimes with only partial success, to open populations, subpopulations, trap dependence, and long chains of recapture periods are presented. The use of residual patterns, and analysis of subsets of data, to identify behavioral patterns and acceptable models is emphasized and illustrated with two examples.

[4] CRESSIE, N. (1989). "Empirical Bayes Estimation of Undercount in the Decennial Census," *Journal of the American Statistical Association, 84,* 1033-1044.

Census undercount is defined simply as the difference between the true count and the census count, expressed as a percentage of the true count. Small-area estimation of this undercount is considered here, using empirical Bayes methods based on a new and, it is argued, more realistic model than has been used before. Grouping of like subareas from areas such as states, counties, and so on into strata is a useful way of reducing the variance of undercount estimators. By modeling the subareas within a stratum to have a common mean and variances inversely proportional to their census counts, and by taking into account sampling of the areas (e.g. by dual system estimation), empirical Bayes estimators that compromise between the (weighted) stratum average and the sample value can be constructed. The amount of compromise is shown to depend on the relative importance of stratum variance to sampling variance. These estimators are evaluated at the state level and stratified on race/ethnicity (3 strata) using data from the 1980 postenumeration survey.

[5] ERICKSEN. E.P., KADANE, J.B., and TUKEY, J.W. (1989). "Adjusting the 1980 Census of Population and Housing," *Journal of the American Statistical Association, 84*, 927-944.

We present adjustment results obtained by two simple methods – synthetic estimation, and sample estimation for a few large subclasses. In 1980, several cities and states sued the U.S. Bureau of the Census to correct census results. This correction would adjust for the differential undercounting of Blacks and Hispanics, especially in cities. In this article, the authors describe

the likely pattern of the undercount and present a method to adjust for it. They offer an explanation of why the undercount is concentrated among minority populations living in large cities. They describe the demographic and survey data available for adjustment from the Census Bureau's Post-Enumeration Program. They present adjustment results obtained by two simple methods – synthetic estimation, and sample estimation for a few large subclasses. (The Census Bureau used the latter method, known as the National Vacancy Check, to adjust the results of the 1970 Census.) They also describe their regression-based, composite method for adjustment. This method takes sample estimates of the undercount rate for a set of mutually exclusive geographic areas, and regresses these estimates upon available predictor variables. The composite estimates of the undercount rate are matrix-weighted averages of the original sample and regression estimates. They compute estimates for 66 areas (16 large cities, the remainder of the 12 states in which those cities are located and 38 whole states). As expected, they find that the highest undercount rates are in large cities, and the lowest are in states and state remainders with small percentages of Blacks and Hispanics. Next, they analyze how sensitive their estimates are to changes in data and modeling assumptions. They find that these changes do not affect the estimates very much. Their conclusion is that regardless of whether they use one of the simple methods or the composite method and regardless of how they vary the assumptions of the composite method, an adjustment reliably reduces population shares in states with few minorities, and increases the shares of large cities.

[6] FIENBERG, S.E. (1989). "An Adjusted Census in 1990?," *Chance, Vol. 2, No. 3,* 23-25.

Plans for adjusting the 1990 Census results for expected differential undercount are set back on track as a result of a last-minute settlement in a census lawsuit. This article provides details and background for the settlement which was announced on July 17, 1989.

[7] FIENBERG, S.E. (1989). "Undercount in the U.S. Decennial Census," in *Encyclopedia of Statistical Sciences,* (Supplemental Volume), (Eds. S. Kotz and N.L. Johnson). New York: Wiley, 181-185.

This entry discusses the census undercount in the United States context. A historical account of undercount measurement in the United States is given.

[8] HUGGINS, R.M. (1989). "On the Statistical Analysis of Capture Experiment," *Biometrika, 76,* 133-140.

A procedure is given for estimating the size of a closed population in the presence of heterogeneous capture probabilities using capture-recapture data when it is possible to model the capture probabilities of individuals in the population using covariates. The results include the estimation of the parameters associated with the model of the capture probabilities and the use of these estimated capture probabilities to estimate the population size. Confidence intervals for the population size using both the asymptotic normality of the estimator and a bootstrap procedure for small samples are given.

[9] JARO, M. (1989). "Advances in Record-linkage Methodology As Applied to Matching the 1985 Test Census of Tampa, Florida," *Journal of the American Statistical Association, 84,* 414-420.

A test census of Tampa, Florida and an independent postenumeration survey (PES) were conducted by the U.S. Census Bureau in 1985. Matching the individuals in the census to the individuals in the PES is an important aspect of census coverage evaluation and consequently a very important

process for any census adjustment operations that might be planned. For such an adjustment to be feasible, record-linkage software had to be developed that could perform matches with a high degree of accuracy and that was based on an underlying mathematical theory. A principal purpose of the PES was to provide an opportunity to evaluate the newly implemented record-linkage system and associated methodology. This article discusses the theoretical and practical issues encountered in conducting the matching operations and presents the results of that operation. A review of the theoretical background of the record-linkage problem provides a framework for discussions of the decision procedure, file blocking, and the independence assumption. The matching algorithm (discussed in detail) uses the linear sum assignment model to "pair" the records. The Tampa, Florida, matching methodology is described in the final sections of the article. Included in the discussion are the results of the matching itself, an independent clerical review of the matches and nonmatches, conclusions, problem areas, and future work required.

[10] O'HARE, W.P. (1989). "Effects of Census Adjustment," *Population Today,* 6-8.

Many are beginning to think about the impact the next census will have on the apportionment of Congress. With large population shifts from the Northeast and Midwest to the Sunbelt states, many seats in Congress will change. But another, separate issue is whether the decennial census count should be *adjusted*, with the theoretical goal of making it more accurate. The potential impact of various adjustment scenarios on the apportionment of Congressional seats following the 1990 Decennial Census is discussed.

[11] WINKLER, W.E. (1989). "Methods for Adjusting for Lack of Independence in An Application of the Fellegi-Sunter Model of Record Linkage," *Survey Methodology, 15,* 101-117.

In applying a record linkage model (Fellegi and Sunter, 1969), an independence assumption is often made that allows estimation of the probabilities. If the assumption is not met, then a record linkage procedure using estimates computed under the assumption may not be optimal. This paper contains an examination of methods for adjusting linkage rules when the independence assumption is not valid. The presentation takes the form of an empirical analysis of lists of businesses for which the truth of matches is known. The number of possible links obtained using standard and adjusted computational procedures may be dependent on different samples. Bootstrap methods (Efron 1987) are used to examine the variation due to different samples.

1990

[1] ALHO, J.M. (1990). "Logistic Regression in Capture-recapture Models," *Biometrics, 46,* 623-635.

The effect of population heterogeneity in capture-recapture, or dual registration, models is discussed. An estimator of the unknown population size based on a logistic regression model is introduced. The model allows different capture probabilities across individuals and across capture times. The probabilities are estimated from the observed data using conditional maximum likelihood. The resulting population estimator is shown to be consistent and asymptotically normal. A variance estimator under population heterogeneity is derived. The finite-sample properties of the estimators are studied via simulation. An application to Finnish occupational disease registration data is presented.

[2] BAKER, S.G. (1990). “A Simple EM Algorithm for Capture-recapture Data with Categorical Covariates (with discussion),” *Biometrics, 46,* 1193-1200.

A simple EM algorithm is proposed for obtaining maximum likelihood estimates when fitting a log-linear model to data from *k* capture-recapture samples with categorical covariates. The method is used to analyze data on screening for the early detection of breast cancer.

[3] COHEN, M.L. (1990). “Adjustment and Reapportionment – Analyzing the 1980 Decision,” *Journal of Official Statistics, 6,* 241-250.

Gilford (1983) has demonstrated that, if the adjusted counts from the U.S. Census Bureau’s 1980 coverage evaluation program had been used to apportion the U.S. House of Representatives, the variability of the adjusted counts would have had a substantial effect on the resulting apportionment. He further argues that this is sufficient evidence to conclude that the adjusted numbers were unsuitable in 1980 for the purpose of reapportionment. We extend his analysis to take into account the likely bias present both in the unadjusted census counts and the adjusted counts. This extended analysis also indicates that the decision in 1980 not to use adjusted counts for reapportionment was justifiable. We also discuss circumstances under which adjusted counts might be preferred to census counts for purposes of apportionment in the 1990 decennial census.

[4] DING, Y. (1990). “Capture-Recapture Census with Uncertain Matching,” Ph.D. dissertation, Department of Statistics, Carnegie Mellon University, Pittsburgh, PA.

The capture-recapture census technique has been used widely to estimate the size of a population. In this research, we reconsider this method by relaxing one of the assumptions made, the *perfect matching assumption*. The capture-recapture or dual system estimation (DSE) rely heavily on the assumption that individuals in both the census and the sample can be perfectly matched. The unavoidable mismatches and erroneous nonmatches reduce the accuracy of the DSE.

The types of matching errors can be classified into two categories: the false matches of nonmatching cases and false nonmatches of matching cases. For the two-sample census, we propose models to characterize the error prone matching mechanism. Under the proposed models and the assumptions of sample independence, equal catchability and closure required in the usual capture-recapture census, the problem is to estimate the unknown size of a multinomial sample with one missing cell. The author adopts the conditional likelihood approach for this problem developed by Sanathanan (1972) that shows the unconditional maximum likelihood estimates (MLEs) and the conditional MLEs for the parameters in the multinominal distribution have the same asymptotic normal distribution. The author studies the asymptotic properties of the resulting estimates as extensions to the DSE and use an illustrative example to show that the impact of matching error on the census undercount estimate can be tremendous for high matching error rates. The author derives estimates of matching error rates using the data from the matching error study (rematch study), one of the operations conducted by the Census Bureau to evaluate the Post-Enumeration Program. The author analyzes the data from the 1986 Los Angeles Test Census using the method developed to illustrate its use for correcting the census undercount. In addition, the author studies the issue of correlation (heterogeneity) bias due to the failure of equal catchability assumption. During the 1980's, the Census Bureau has experimented with various post-stratification schemes in an attempt to reduce the correlation bias. The author proves an asymptotic result that theoretically justifies the empirical finding that post-stratification does little to reduce the correlation bias.

Other issues investigated include: (1) formulation of the two-sample census with uncertain matching problem in a Bayesian framework, (2) investigation of the probabilistic matching problem, and (3) investigation of the matching problem in the multiple-sample census.

[5] FIENBERG, S.E. (Winter 1990). "An Adjusted Census in 1990? An Interim Report," *Chance, Vol. 3, No. 1,* 19-21.

Plans on adjustment-related activities in the 1990 U.S. decennial census move forward--albeit slowly. This article provides an update on the events that have transpired since a previous report on the July 17, 1989, settlement of the New York City adjustment lawsuit. (See *Chance*, Summer 1989).

[6] FIENBERG, S.E. (Spring 1990). "An Adjusted Census in 1990? Back to Court Again," *Chance, Vol. 3, No. 2,* 32-35.

Plaintiffs return to court, questioning the commitment of the Department of Commerce to proceed with plans to correct the decennial census counts. This article is part of an ongoing series on census adjustment and related issues and provides an update on the events that have transpired since our most recent report (see the two previous articles in *Chance,* Summer 1989, and Winter 1990).

[7] FIENBERG, S.E. (Summer 1990). "An Adjusted Census in 1990? The Judge Rules and the PES Begins," *Chance, Vol. 3, No. 3,* 33-36.

As the taking of the 1990 decennial census progresses, albeit fitfully, the controversy over the adjustment of the census to correct for the differential undercount of minorities continues to rage. This article is part of an ongoing series on the possible adjustment of the 1990 U.S. decennial census to correct for the differential undercount of black and other minorities and provides an update on the events that have transpired.

[8] GARTHWAITE, P.H. and BUCKLAND, S.T. (1990). "Analysis of Multiple-recapture Census by Computing Conditional Probabilities," *Biometrics, 46,* 231-238.

In a multiple-recapture census of a closed population using fixed sample sizes, the total number of different animals captured during the census is a sufficient statistic for the population size. Conditional on the population size, the exact probability distribution of this sufficient statistic may be calculated and an algorithm for doing this is given. Standard techniques are applied to describe methods for using the conditional probabilities to form median and interval estimates of the population size. The methods are illustrated with examples.

[9] GLEICK, J. (1990). "Why We Can't Count," *The New York Times Magazine,* 26-54.

This article discusses the problems that even the smoothest running part of the census–the millions of forms properly mailed back and well-enough filled out that no follow-up interviews are conducted– has. The author argues that the population is too large, too mobile, and too diverse to count in conventional ways.

[10] GOUDIE, I.B.J. (1990). "A Likelihood-based Stopping Rule for Recapture Debugging, *Biometrika, 77,* 203-206.

Consideration is given to determining when all the fault in a reliability system have been detected, assuming the use of the recapture debugging procedure introduced by Nayak (1988). A stopping rule based on the likelihood ratio is proposed. Compared to the stopping rule suggested by Nayak, this likelihood-based rule makes better use of the available information, and, for a given error level, yields a small reduction in the average time taken to research a decision. A generalization is suggested for the situation where the faults in the software can be categorized into two or more classes, between which detection rates are permitted to differ.

[11] ROSSMO, D.K. and ROUTLEDGE, R. (1990). "Estimating the Size of Criminal Populations," *Journal of Quantitative Criminology, Vol. 6, No. 3,* 293-314

The estimation of total population size for various phenomena of crime is an important factor critical for criminal justice policy formulation and criminological theory development. In this paper, methods are discussed for estimating the size of a criminal population from police records. Capture-recapture analysis techniques, borrowed from the biological sciences, are used to predict the size of population for migrating (or fleeing) fugitives and for street prostitutes. Heterogeneity and behavioral responses to previous police encounters are identified as major complicating factors. The basic problem is that the police records are virtually unaffected by a potentially large pool of cryptic criminals. It is shown how independently collected auxiliary data can address this problem.

[12] WOLTER, K.M. (1990). "Capture-recapture Estimation in the Presence of A Known Sex Ratio," *Biometrics, 46,* 157-162.

New methods of estimating population size are presented based on capture-recapture data. The methods exploit knowledge of the sex ratio, males per female, and permit estimability even when both time of sampling and marking affect the catchability of an animal. An example is presented involving a *Microtus pennsylvanicus*. (meadow voles) population.

[13] ZASLAVSKY, A.M. and WOLFGANG, G.S. (1990). "Triple System Modeling of Census, Post-enumeration Survey, and Administrative List Data," *Proceedings of the Section on Survey Research Methods, American Statistical Association,* 668-673.

Dual system measurement of census coverage using a post-enumeration survey (PES) has been criticized for correlation bias, resulting when responses to the census and survey are not independent. Use of a third system (information source) can provide additional information to assess that independence. The data for this study come from a population subgroup of the 1988 Dress Rehearsal Census and its PES and from rosters from other government sources. This study focuses on Black male adults. Preliminary results using a variety of models confirm that, as previously suspected, their population is underestimated by dual system methods. Potential problems involving classification and matching errors are also discussed. The results suggest that triple system modeling has great potential for more precise estimation of the hard-to-count population and its census coverage.

1991

[1] BATEMAN, D., CLARK, J., MULRY, M., and THOMPSON, J. (1991). "1990 Post-Enumeration Survey Evaluation Results," *Proceedings of the Section on Social Statistics, American Statistical Association*, 21-30.

The purpose of this paper is to present highlight results from studies that were implemented to evaluate the 1990 Post-Enumeration Survey.

[2] CAUSEY, B.D. and WOLTER, K.M. (1991). "Extension of Wolter and Causey's Evaluation of Procedures," *Journal of the American Statistical Association, 86,* 1153.

Wolter and Causey (1991) (WC) provided evaluations of two techniques for improving decennial census population estimates for small areas. Here we wish to extend the evaluation of the second technique–synthetic estimation–which is of particular interest because it corrects for inequities in population estimates.

[3] CORMACK, R.M. and JUPP, P.E. (1991). "Inference for Poisson and Multinomial Models for Capture-recapture Experiments," *Biometrika 78,* 911-916.

Capture-recapture models have been formulated both as Poisson and as multinomial distributions. Maximum likelihood estimates of parameters under the two models are compared. For parameters which do not involve the population size the asymptotic covariances are shown to be the same.

[4] CRESSIE, N. and DAJANI, A. (1991). "Empirical Bayes Estimation of U.S. Undercount Based on Artificial Populations," *Journal of Official Statistics, 7,* 57-67.

Estimators of undercount are difficult to assess and compare because true population counts are not available. Isaki, et al. (1988) made the comparison by constructing an artificial population where "true" population counts were known. We show that the synthetic estimator they used is a special case of an empirical Bayes estimator of undercount, derived from a compound-distribution model for the undercount mechanism. The validity of this model, for the artificial population, can then be examined.

[5] FIENBERG, S.E. (Summer 1991). "An Adjusted Census in 1990? Commerce Says 'No'," *Chance, Vol. 4, No. 3*, 44-51.

The U.S. decennial census results for 1990 are official and the Department of Commerce has announced that they will not be adjusted. The controversy continues. Described in four previous *Chance* articles are the adjustment dispute, the temporary settlement, and aspects of the taking of the 1990 Census. This article brings these issues up to date providing information on the accuracy of the 1990 Census and the July 15 decision of the Department of Commerce regarding the correction of the census results.

[6] FIENBERG, S.E. (Fall 1991). "An Adjusted Census in 1990? A Full-scale Judicial Review Approach," *Chance, Vol.4, No. 4,* 22-24, 29.

A pending lawsuit will challenge the accuracy of the year-old "official" results of the 1990

Census. The controversy over census adjustment moves back to a New York City courtroom. This article is the sixth in a series, reporting on the possible adjustment of the 1990 U.S. Census to correct for the differential undercount of Blacks and other minorities.

[7] FREEDMAN, D.A. (1991). "Adjusting the 1990 Census," *Science, 252,* 1233-1236.

In this article, the author outlines the process and reviews the two current techniques for evaluating or adjusting the census. In demographic analysis, administrative records are used to make independent population estimates, which can be compared to census counts. With capture-recapture methods, data from an independent sample survey are used to estimate population coverage in the census. If there is a large undercount, these techniques may be accurate enough for adjustment. With a small undercount, it is unlikely that current adjustment methodologies can improve on the census; instead, adjustment could easily degrade the accuracy of the data.

[8] HUGGINS, R.M. (1991). "Some Practical Aspects of A Conditional Likelihood Approach to Capture Experiments," *Biometrics, 47,* 725-732.

The use of conditional likelihood procedures to construct models for capture probabilities is discussed and illustrated by an example.

[9] MULRY, M.H. and SPENCER, B.D. (1991). "Total Error in PES Estimates of Population (with discussion)," *Journal of the American Statistical Association, 86,* 839-863.

This article develops and applies a methodology for estimating the error in the dual system estimate (DSE) of population based on the 1988 dress rehearsal census conducted in St. Louis and east-central Missouri prior to the 1990 U.S. Census (Childers and Hogan 1989).

[10] SMITH, P.J. (1991). "Bayesian Analyses for a Multiple Capture-recapture Model," *Biometrika, 78,* 399-407.

In this paper, we discuss the multiple capture-recapture model for estimating *N* when capture probabilities vary between sampling occasions.

[11] TREMBLAY, A., STOKES, S.L., and GREENBERG, B.S. (1991). "Estimation of PES Fabrications from Quality Control Data," *Proceedings of the Section on Survey Research Methods, American Statistical Association,* 242-247.

This paper focuses on P-Sample interviewer fabrication, which is a potential source of error in the estimates of census undercount from the PES. The Quality Control (QC) operation of the PES interviewing phase was designed to detect fabricated data and correct it. This paper describes the use of Quality Control records to produce estimates of the number of fabricated persons which remain after the Quality Control operation concludes.

[12] WOLTER, K.M. (1991). "Accounting for America's Uncounted and Miscounted," *Science, 253,* 12-15.

The difference between the true but unknown population count and an original census count is called the net undercount. In this article, the author presents evidence about the size of the net undercount, explains how it is measured, explains why it is an important problem, and demonstrates new statistical methodology that can ameliorate the problem.

[13] WOLTER, K.M. and CAUSEY, B.D. (1991). "Evaluation of Procedures for Improving Population Estimates for Small Areas," *Journal of the American Statistical Association, 86,* 278-284.

The authors provide and illustrate methods for evaluating across-the-board ratio estimation and synthetic estimation, two techniques that might be used for improving population estimates for small areas. The methods emphasize determination of a break-even accuracy of knowledge concerning externally obtained population totals, which marks the point at which improvement occurs.

[14] ZASLAVSKY, A.M. (1991). "Combining Census and Dual-system Estimates of Population," *Proceedings of the Section on Survey Research Methods, American Statistical Association,* 670-675. (Discussion: Benjamin King, 676-677).

In this paper, the author considers a number of issues related to the question of how to obtain optimal estimates using the census counts and DSE.

1992

[1] CLARK, C.Z.F. (1992). "Coverage Improvement and Measurement," *Proceedings of the Section on Survey Research Methods, American Statistical Association,* (Discussion: 524-525).

This session contains an interesting combination of papers investigating aspects of coverage in different types of censuses–population, housing, economic, and agriculture– with representation from both Statistics Canada and the Census Bureau. The three Census Bureau studies reported on use of the capture-recapture dual-system estimator to estimate coverage errors.

[2] FIENBERG, S.E. (1992a), "Bibliography on Capture-Recapture Modeling With Application to Census Undercount Adjustment," *Survey Methodology, Vol. 18, No. 1,* 143-154.

This article presents a selected annotated bibliography of the literature on capture-recapture (dual system) estimation of population size, on extensions to the basic methodology, and the application of these techniques in the context of census undercount estimation.

[3] FIENBERG, S.E. (1992b). "An Adjusted Census in 1990? The Trial," *Chance, Vol. 5, No. 3-4,* 28-38.

The New York City lawsuit challenging the accuracy of the year-old "official" results of the 1990 Census goes to trial. At issue is the decision of the Secretary of Commerce overturning the Census Bureau recommendation to use "adjusted" census data. This article is part of *Chance's* continuing coverage of developments surrounding the possible adjustment of the 1990 Census. Stephen Fienberg writes about the recent trial from his perspective as a witness for the plaintiffs.

[4] FREEDMAN, D.A. and NAVIDI, W.C. (1992). "Should We Have Adjusted the U.S. Census of 1980?," *Survey Methodology, Vol. 18, No.* 3-24. (Discussion: 25)

This paper reviews some of the arguments for and against adjusting the U.S. Census of 1980, and the decision of the court.

[5] GRIFFIN, D.H. and MORIARITY, C.L. (1992). "Characteristics of Census Errors," *Proceedings of the Section on Survey Research Methods, American Statistical Association,* 512-517 (Disc: 524-525).

This paper analyzes characteristics of *enumeration errors.* Enumeration errors include persons who were duplicated, persons who were counted in the wrong census geography or at the wrong address, fictitious persons, and other persons who should not have been included in the census. In particular, this report examines the enumeration errors identified by the Post-Enumeration Survey to determine if rates varied by: (a) how the data were collected, (b) who provided the data, (c) when the data were collected, or (d) the type of household or address. The results presented in this paper are based on PES results and therefore focus on those factors that might cause persons to be enumerated in error in the census. The analysis is limited to persons living in housing units.

[6] HOGAN, H. (1992). "The 1990 Post-Enumeration Survey: An Overview," *The American Statistician, 46,* 261-69.

The 1990 Post-Enumeration Survey (PES) constituted the major vehicle for measuring coverage by area of the 1990 Decennial Census. It was designed to be used to adjust the census enumeration. This article discusses the background of the survey, the sampling plan, the methods used to measure census omissions and census erroneous enumerations, the treatment of nonresponse, the use of dual system estimation to estimate the total population by post-strata, and the use of these estimates to calculate adjusted census data.

[7] MISKURA, S. (1992). "Forward from 1990: Designing the 2000 Census," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 38-46.

The Research, Evaluation, and Experimental (REX) Programs for each census are major contributors to changes for the subsequent ones. The generic objectives for any REX Program are to provide: information to data users about the quality of census data, and data for improving and changing methods and operations. As in the past, the 1990 REX Program will provide this information as we explore new designs for the 2000 Census. In order to explain specifically how the 1990 REX Program will contribute to the design of the Census 2000, this paper describes the process for researching changes to that design. The paper also describes some major ways that the REX results support evaluating those design changes.

1993

[1] **JOURNAL OF THE AMERICAN STATISTICAL ASSOCIATION, Vol. 88.** Special Section: "UNDERCOUNT IN THE 1990 CENSUS."

a) "The 1990 Post-Enumeration Survey: Operations and Results," H. Hogan, 1047-1060.

The Census Bureau has struggled for decades with the problem of undercount in the population census. Although the net national undercount has been greatly reduced in recent censuses, it still tends to display important differences by race, ethnic origin, and geographic location. The 1990 Post-Enumeration Survey (PES) was designed to produce census tabulation of states and local areas corrected for the undercount or overcount of population. The PES was the subject

of litigation between the federal government and a coalition of states and local governments. Because of the litigation, the PES was conducted under specific guidelines concerning timing, prespecification, and quality. The PES measured census omissions by independently interviewing a stratified sample of the population. It measured census erroneous enumerations by a dependent reinterview of a sample of census records and by searching the records for duplicates. A dual system estimator (DSE) was used to prepare estimates of the population by post-strata. Adjustment factors were computed as the ratio of these estimates to the census count. These factors were smoothed using a generalized linear model and then applied to the census counts by block and post-strata to produce adjusted census estimates. Although the government decided not to release these numbers as the official census results, the Census Bureau has conducted further research to improve these estimates to incorporate them into the postcensal estimates program. The revisions have included new post-strata and corrections of errors found in the original estimates. The results of the PES show a differential undercount by race and ethnic group and by owner/nonowner status. They also demonstrate differences in undercount by geography.

b) "Estimation of Population Coverage in the 1990 United States Census Based on Demographic Analysis," J.G. ROBINSON, B. AHMED, P.D. GUPTA, and K.A. WOODROW, 1061-1071. (Comments by C.C. CLOGG and C.L. HIMES; J.S. PASSEL, 1072-1077. Rejoinder by J.G. ROBINSON, B. AHMED, P.D. GUPTA, and K.A. WOODROW, 1077-1079.)

   This article presents estimates of net coverage of the national population in the 1990 Census, based on the method of demographic analysis. The general techniques of demographic analysis as an analytic tool for coverage measurement are discussed, including use of the demographic accounting equation, data components, and strengths and limitations of the method. Patterns of coverage displayed by the 1990 estimates are described, along with similarities or differences from comparable demographic estimates for previous censuses. The estimated undercount in the 1990 Census was 4.7 million, or 1.85 percent. The undercount of males (2.8%) was higher than for females (.9%), and the undercount of Blacks (5.7%) exceeded the undercount of Non-Blacks (1.3%). Black adult males were estimated to have the highest rate of undercounting of all groups. Race-sex-age patterns of net coverage in the 1990 Census were broadly similar to patterns in the 1980 and 1970 Censuses. A final section presents the results of the first statistical assessment of the uncertainty in the demographic coverage estimates for 1990.

c) "Accuracy of the 1990 Census and Undercount Adjustments," M.H. MULRY and B.D. SPENCER, 1080-1091.

   In July 1991 the Census Bureau recommended to its parent agency, the Department of Commerce, that the 1990 Census be adjusted for undercount. The Secretary of Commerce decided not to adjust, however. Those decisions relied at least partly on the Census Bureau's analyses of the accuracy of the census and of the proposed undercount adjustments based on the Post-Enumeration Survey (PES). Error distributions for the nation, states, and smaller geographic units were estimated with extensions of methods applied to test censuses. To summarize and assess the relative importance of errors in different units, the Census Bureau used aggregate loss functions. This article describes the total error analysis and loss function analysis of the Census Bureau. In its decision not to adjust the census, the Department of Commerce cited different criteria than aggregate loss functions. Those criteria are identified and discussed.

d) "Combining Census, Dual System, and Evaluation Study Data to Estimate Population Shares," A.M. ZASLAVSKY, 1092-1105.

The 1990 Census and Post-Enumeration Survey produced census and dual system estimates (DSE) of population by domain, together with an estimated sampling covariance matrix of the DSE. Estimates of the bias of the DSE were derived from various PES evaluation programs. Of the three sources, the unadjusted census is the least variable but is believed to be the most biased, the DSE is less biased but more variable, and the bias estimates may be regarded as unbiased but are the most variable. This article addresses methods for combining the census, the DSE, and bias estimates obtained from the evaluation programs to produce accurate estimates of population shares, as measured by weighted squared - or absolute - error loss functions applied to estimated population shares of domains. Several procedures are reviewed that choose between the census and the DSE using the bias evaluation data or that average the two with weights that are constant across domains. A multivariate hierarchical Bayes model is proposed for the joint distribution of the undercount rates and the biases of the DSE in the various domains. The specification of the model is sufficiently flexible to incorporate prior information on factors likely to be associated with undercount and bias. When combined with data on undercount and bias estimates, the model yields posterior distributions for the true population shares of each domain. The performance of the estimators was compared through an extensive series of simulations. The hierarchical Bayes procedures are shown to outperform the other estimators over a wide range of conditions and to be robust against misspecification of the models. The various composite estimators, applied to preliminary data from the 1990 Census and evaluation programs, yield similar results that are closer to the DSE than to the census. Analysis of a revised data set yields qualitatively similar estimates but shows that the revised post-stratification improves on the original one.

e) "Using Information from Demographic Analysis in Post-Enumeration Survey Estimation," W.R. BELL, 1106-1118.

Population estimates from the 1990 Post-Enumeration Survey (PES), used to measure decennial census undercount, were obtained from dual system estimates (DSEs) that assumed independence within strata defined by age-race-sex-geography and other variables. We make this independence assumption for females, but develop methods to avoid the independence assumption for males within strata by using national level sex ratios from demographic analysis (DA). This is done by using DSE results for females and the DA sex ratios to determine national level control totals for male population by age-race groups. These control totals are then used to determine some function of the individual strata 2×2 table probabilities for males that is assumed constant across strata within age-race groups. One such candidate function is the cross-product ratio, but other functions can be used that lead to different DSEs. We consider several such alternative DSEs, and use DA results for 1990 to apply them to data from the 1990 U.S. Census and PES.

f) "Assessing Between-Block Heterogeneity Within the Post-Strata of the 1990 Post-Enumeration Survey," N. HENGARTNER and T.P. SPEED, 1119-1125. (Comments by J.L. SCHAFFER; D. YLVISAKER, 1125-1128. Rejoinder by N. HENGARTNER and T.P. SPEED, 1128-1129.)

The 1990 Post-Enumeration Survey (PES) stratified the population into 1,392 subpopulations called post-strata based on location, race, tenure, sex and age, in the hope that these subpopulations were homogeneous in relation to factors affecting the census coverage. Homogeneity is necessary to justify the use of the same adjustment factor for many, sometimes quite small, subgroups of the post-strata. With block-level data from the PES for sites around Detroit and Texas, we are able to examine empirically the extent to which this hope was realized. Using various measures, we find that between-block variation in erroneous enumeration and gross omission rates is about the same magnitude as, and largely in addition to, the corresponding between-post-stratum variation.

g) "Estimating Heterogeneity in the Probabilities of Enumeration for Dual-System Estimation," J.M. ALHO, M.H. MULRY, K. WURDEMAN, and J. KIM, 1130-1136.

The authors show how conditional logistic regression can be used to estimate the probability of being enumerated in a census and apply the model to the 1990 Post-Enumeration Survey (PES) in the United States. The estimates can be used in the estimation of population size and the estimation of correlation bias, for example. Unlike the classical stratification approach, the logistic approach permits the use of continuous explanatory variables. Model choice can be based on the standard techniques of the generalized linear models. They discuss some special problems caused by the fact that the PES sample area is open to migration between the captures. They also consider the effect of data errors in estimation. They characterize hard-to-enumerate populations and give some tentative estimates of correlation bias.

h) "A Three-Sample Multiple-Recapture Approach to Census Population Estimation with Heterogeneous Catchability," J.N. DARROCH, S.E. FIENBERG, G.F.V. GLONEK, and B.W. JUNKER, 1137-1148.

A central assumption in the standard capture-recapture approach to the estimation of the size of a closed population is the homogeneity of the "capture" probabilities. In this article we develop an approach that allows for varying susceptibility to capture through individual parameters using a variant of the Rasch model from psychological measurement situations. Our approach requires an additional recapture. In the context of census undercount estimation, this requirement amounts to the use of a second independent sample or alterative data source to be matched with census and Post-Enumeration Survey (PES) data. The models we develop provide a mechanism for separating out the dependence between census and PES induced by individual heterogeneity. The resulting data take the form of an incomplete 2^3 contingency table, and we describe how to estimate the expected values of the observable cells of this table using log-linear quasi-symmetry models. The projection of these estimates onto the unobserved cell corresponding to those individuals missed by all three sources involves the log-linear model of no second-order interaction, which is quite plausible under the Rasch model. We illustrate the models and their estimation using data from a 1988 dress-rehearsal study for the 1990 Census conducted by the U.S. Bureau of the Census, which explored the use of administrative data as a supplement to the PES. The article includes a discussion of extensions and related models.

i) "Hierarchical Logistic Regression Models for Imputation of Unresolved Enumeration Status in Undercount Estimation," T.R. BELIN, G.J. DIFFENDAL, S. MACK, D.B. RUBIN, J.L. SCHAFER, and A.M. ZASLAVSKY, 1149-1159. (Comments by R.J.A. LITTLE; K.W. WACHTER, 1159-1163. Rejoinder by T.R. BELIN, G.J. DIFFENDAL, S. MACK, D.B. RUBIN, J.L. SCHAFER, and A.M. ZASLAVSKY, 1163-1166.)

In the process of collecting Post-Enumeration Survey (PES) data to evaluate census coverage, it is inevitable that there will be some individuals whose enumeration status (outcome in the census-PES match) remains unresolved even after extensive field follow-up operations. Earlier work developed a logistic regression framework for imputing the probability that unresolved individuals were enumerated in the census, so that the probability of having been enumerated is allowed to depend on covariates. The covariates may include demographic characteristics, geographic information, and census codes that summarize information on the characteristics of the match (e.g., the before-follow-up match code assigned by clerks to describe the type of match between PES and census records). In the production of 1990 undercount estimates, the basic logistic regression model was expanded into a mixed hierarchical model to allow for the presence of group-specific effects, where groups are characterized by common before-follow-up match-code. Parameter estimates for individual match-code groups thus "borrow strength" across groups by making use of observed relationships between group-specific parameter estimates in the various groups and the characteristics of the groups. This allows predictions to be made for groups for which there are few or no resolved cases to which to fit the model. The model was fitted by an approximate expectation-conditional-maximization (ECM) algorithm, using a large-sample approximation to the posterior distributions of group parameters. Uncertainty in estimation of model parameters was evaluated using a resampling procedure and became part of the evaluation of total error in PES estimates of population. Results from fitting the model in the 1990 Census and PES are described.

[2] FAY, R.E. and THOMPSON, J. (1993). "The 1990 Post Enumeration Survey: Statistical Lessons, In Hindsight," *Proceedings of the 1993 Annual Research Conference of the Bureau of the Census*, Washington, D.C., 71-91. (Discussion: B.D. Spencer,, 92-95.)

The 1990 Post Enumeration Survey (PES), to measure the undercount of the 1990 Decennial Census, followed years of planning. In spite of numerous improvements over previous evaluation efforts, the PES presented a number of challenges. The purpose of this paper is to review critically many of the statistical problems that arose and to show that some were interconnected. The hope is to achieve a view of the forest, or at least several of the trees, at once.

The paper will revisit topics: 1) the homogeneity assumption, that undercount rates were fixed within poststrata; 2) the measurement and implication of bias in the PES estimates; 3) the properties of the empirical Bayes estimator originally designed for the adjustment; 4) assessment of the benefits and harm of adjustment, through loss function analysis and hypothesis testing; and 5) the Census Bureau's 1992 estimates produced for potential adjustments to the base of the postcensal estimates and alternatives. Our emphasis is on the current state of knowledge and recent work in each of these areas. Finally, the authors remark on how these lessons might inform planning for Census 2000.

[3] ISAKI, C.T., TSAY, J.H., and THIBAUDEAU, Y. (1993). "Sampling for the Count in a Census," *Proceedings of the Section on Survey Research Methods, American Statistical Association,* 492-497.

As part of a program of continuing research regarding Census 2000, the authors conducted an empirical study concerning the possibility of sampling for the count. The main purpose of this research was to construct several sample designs and provide empirical results concerning estimates of Voting Rights Act data at the block, address register area (ARA), and district office (DO) level. This paper describes our assumptions, methodology, design, and some results.

[4] NAVARRO, A. and GRIFFIN, R. (1993). "Matrix Sampling Design for the Year 2000 Census," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 480-485.

A very important goal of the Census 2000 is to improve coverage and reduce the differential undercount. If content (questions) is essentially kept the same as in 1990, then spreading this content over several sample forms will likely reduce respondent burden while providing sample forms that are shorter than the 1990 sample forms. This could increase mail return rates. Results from the 1990 Census evaluation studies indicate that the quality of data, particularly in terms of coverage, is somewhat better for mail return questionnaires than for those not returned by mail and subsequently completed by enumerators during follow-up operations (Griffin and Moriarity, 1992). Therefore, the use of shorter multiple sample forms could help to improve coverage for Census 2000. This paper describes and discusses reliability and respondent burden issues related to five alternative *matrix sampling plans*, the first four could be used for sample data collection for Census 2000.

[5] *PROCEEDINGS OF THE 1993 RESEARCH CONFERENCE ON UNDERCOUNTED ETHNIC POPULATIONS, May 5-7, 1993*, U.S. Bureau of the Census, Washington, D.C.

The purpose of the Research Conference on Undercounted Ethnic Populations was to understand the magnitude of the undercounting problem in the 1990 Census and identify areas for developing ways to reduce undercount in the Census 2000. These proceedings contain the full record of the conference.

[6] ROBINSON, J.G., AHMED, B., and FERNANDEZ, E.W. (1993). "Demographic Analysis as an Expanded Program for Early Coverage Evaluation of the 2000 Census," *Proceedings of the 1993 Annual Research Conference of the U.S. Bureau of the Census*, Washington, D.C., 166-200.

This paper discusses new plans for the *demographic analysis program*, with the goal of increasing the utility of the demographic estimates for evaluation of coverage in the Census 2000. It describes how the demographic estimates of population for the nation, states, and substate areas could be available early in 2000 and thus provide useful (and inexpensive) coverage indicators whenever the preliminary 2000 Census population counts become available.

[7] SCHINDLER, E., GRIFFIN, R., and NAVARRO, A. (1993). "Sampling and Estimation for the Homeless Population," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 468-473.

The Census Bureau is conducting research into methodologies for estimating the size of the homeless population. These alternative statistical methods concentrate on shelters, soup kitchens, and other selected locations. Two classes of estimates are being considered. One estimate, based on capture-recapture methods, matches results from samples for two or more days to produce dual-system estimates. The second type of estimate avoids matching, but relies on respondents' answers to "site use history" questions. Both methods are consistent with the Census 2000 research goal of studying sampling and statistical methods to "count" the population.

[8] THOMAS, K.F. and DINGBAUM, T.L. (1993). "Data Quality in the 1990 Census – The Content Reinterview Survey," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 250-255.

The Content Reinterview Survey (CRS), the largest content (questions) evaluation conducted by the Census Bureau, is a part of the 1990 Research, Evaluation and Experimental (REX) program. A similar survey has been conducted after each decennial census since 1950. The CRS is designed to measure response error associated with selected population and housing items. The CRS sample was restricted to long form census households. Census households responding by mail and enumerator return households were reinterviewed. Highlights of results are presented in this paper.

[9] TORTORA, R.D., MISKURA, S.M., and DILLMAN, D.A. (1993). "Onwards Towards a 2000 Census Design: Research Results," *Proceedings of the Section on Survey Research Methods, Vol. 1., American Statistical Association,* 120-128. (Disc: Ivan P. Fellegi, 141-143).

This paper reports the general results of research undertaken by Census Bureau staff. The views expressed are attributable to the authors and do not necessarily reflect those of the Census Bureau.

1994

[1] BELIN, T.R. and ROLPH, J.E. (1994). "Can We Reach Consensus on Census Adjustment?," *Statistical Science, Vol. 9*, 486-508.

Attempting a complete headcount is an imperfect method for carrying out a census, as is modifying an attempted headcount with sample-based adjustments. It is a mistake to assume that one approach enjoys a scientific presumption over the other. There are important details available from evaluation studies of the 1990 Decennial Census that reflect upon the accuracy of adjusted and unadjusted census figures. Decisions about adjustment might therefore be based on comparing the accuracy of alternative census-taking strategies at some level of aggregation of the population. In any such comparison, the choices of an appropriate level of aggregation, the factors defining the aggregation, and appropriate loss criteria are important issues to decide in advance. After providing context for decisions about census-taking strategy, the authors comment on the recent literature on census adjustment, including the papers by Freedman and Wachter and by Breiman contained in this issue; they also discuss the Census Bureau's plans for Census 2000. They conclude that the 1990 approach to summarizing the accuracy of an adjusted census can be improved upon, but that many of the criticisms of census adjustment do not reflect a balanced decision-making perspective. They also conclude that the Census Bureau is pursuing constructive research in evaluating a "one-number census," and they suggest that statisticians have a role to play in avoiding the costly legal battles that have plagued recent censuses by assisting in the process of deciding on a design for Census 2000.

[2] BELL, R.M. (1994). "Sampling and Statistical Estimation in the Decennial Census," *Proceedings of the Survey Research Methods Section, Vol. 1., American Statistical Association,*71-79.

This paper discusses two major innovations that the Census Bureau is considering for producing

counts in the 2000 Census: Sampling for nonresponse follow-up and integrated coverage measurement. These innovations respond to the two main criticisms of the 1990 Census: that costs grew out of control and that there was differential coverage among demographic groups and geographic areas.

[3] BREIMAN, L. (1994). "The 1991 Census Adjustment: Undercount or Bad Data?," *Statistical Science, Vol. 9,* 458-475.

The question of whether to adjust the 1990 Census using a capture-recapture model has been hotly argued in statistical journals and courtrooms. Most of the arguments to date concern methodological issues rather than data quality. Following the Post-Enumeration Survey, which was designed to provide the basic data for adjustment, the Census Bureau carried out various evaluation studies to try to determine the accuracy of the adjusted counts as compared to the census counts. This resulted in the P-project reports, which totaled over a thousand pages of evaluation descriptions and tables. Careful scrutiny of these studies together with auxiliary sources of information provided by the Census Bureau is used to examine the issue of whether the data gathered in the Post-Enumeration Survey can provide reliable undercount estimates.

[4] CHOLDIN, H. (1994). *Looking for the Last Percent*: *The Controversy Over Census Undercounts,* New Brunswick, N.J.: Rutgers University Press.

The goal of this book is to tell the story of a conflict that pitted census administrators against mayors, governors, and others with primarily political concerns. They clashed over the question of what to do about undercounts in the 1980 and 1990 Censuses. This book tells how the census administrators, many of whom were technical-scientific specialists, dealt with "outsiders" who got powerfully involved in the census process.

[5] COMMENTS ON THREE PAPERS IN *STATISTICAL SCIENCE (1994), Vol. 9,* by DIAMOND, I., and SKINNER, C., ERICKSEN, E.P., FIENBERG, S.E., and KADANE, J.B., LYBERG, L., and LUNDSTRÖM, S., and STEEL, D., 508-519. (Rejoinders on 520-537.)

Comments are provided for three papers in *Statistical Science, Vol. 4* (1994). The authors of the three papers being discussed are (Paper 1) Breiman; (Paper 2) Freedman and Wachter; and (Paper 3) Belin and Rolph.

[6] DIFFENDAL, G.J., ZASLAVSKY, A.M., BELIN, T., and SCHENKER, N. (1994). "Influential Observations in the 1990 Post-Enumeration Survey," *Proceedings of the 1994 Annual Research Conference,* U.S. Bureau of the Census, 523-548.

The results of the 1990 Post-Enumeration Survey (PES) included over three dozen blocks in which there was a particularly poor match between census and PES rosters. The high levels of nonmatch were due to specific large-scale errors that affected whole blocks or substantial portions of them, such as errors in geocoding (assigning addresses to census blocks), errors in processing and field operations, or clustered errors in the original census enumeration. Although some of the effects of block-level geocoding and processing errors balance out in expectation, they can still contribute substantially to the variance of undercount estimates. Extreme sampling weights were applied to certain blocks, which made some of them unusually influential. This paper suggests methods for handling influential blocks in a PES; such methods potentially have broader relevance to surveys in general. Drawing on ideas from jackknife variance estimation and robust estimation, the authors suggest a systematic and principled basis for downweighting of extremely influential blocks, yielding estimates with potentially large reductions in variance. In the context of the PES, the authors suggest that large-scale geocoding and processing problems arise sufficiently often that there should be standard procedures for dealing with these cases in both the processing and estimation phases. They illustrate their ideas with data from a newly available block-level file from the 1990 PES.

[7] ERNST, L. (1994). "Apportionment Methods for the House of Representatives and the Court Challenges," *Management Science, 40,* 1207-1227.

Four different methods have been used to apportion the seats in the United States House of Representatives among the states following the decennial census. The current method, the *method of equal proportions*, has been used for each census since 1940. In 1991, for the first time in U.S. history, the constitutionality of an apportionment method was challenged in court, by Montana and Massachusetts in separate cases. Montana proposed two methods as alternatives to equal proportions, the methods of harmonic means and smallest divisors, while Massachusetts proposed the method of major fractions. On March 31, 1992, in a unanimous decision, the U.S. Supreme Court upheld the constitutionality of equal proportions. The author wrote the declarations on the mathematical and statistical issues used by the defense in these cases. The declarations in the Massachusetts case contain several new theoretical and empirical results. This paper discusses the technical issues of these cases together with a brief history of the apportionment problem.

[8] FAY, R.E. (1994). Comment on "Alternative Methods for the 2000 Census," *Proceedings of the Section on Survey Methods, American Statistical Association*, 90-92.

In discussing papers by Robert Bell (1994) and Keith Rust (1994), the author challenges the statistical profession to bring more "science" into statistical science, especially the literature that deals with census undercount.

[9] FIENBERG, S.E. (Fall 1994). "An Adjusted Census in 1990? Trial Judgement Set Aside," *Chance, Vol. 7, No. 4,* 31-32.

As we approach mid-decade, the controversy over the 1990 decennial census continues to rage. A major court ruling favors adjustment. This is the eighth in a series of articles on census adjustment in *Chance*.

[10] FREEDMAN, D. and WACHTER, K. (1994). "Heterogeneity and Census Adjustment for the Intercensal Base," *Statistical Science, Vol. 9,* 476-485.

Current techniques for census adjustment involve the "synthetic assumption" that undercount rates are constant within "poststrata" across geographical areas. A poststratum is a subgroup of people with given demographic characteristics; poststrata are chosen to minimize heterogeneity in undercount rates. This paper will use 1990 Census data to assess the synthetic assumption. The authors find that heterogeneity within poststrata is quite large, with a corresponding impact on local undercount rates estimated by the synthetic method. Thus, any comparison of error rates between the census and adjusted counts should take heterogeneity into account.

[11] ISAKI, C.T., TSAY, J.H., and FULLER, W.A. (1994). "Design and Estimation for Samples of Census Nonresponse," *Proceedings of the 1994 Annual Research Conference of the U.S. Bureau of the Census*, Washington, D.C., 289-305.

The main purpose of this research was to construct several sample designs and provide empirical results concerning estimates of Voting Rights Act data at the block, address register area (ARA), and district office (DO) level.

[12] MULRY, M.H. and SINGH, R.P. (1994). "New Applications of Sampling and Estimation in the 1995 Census Test," *Proceedings of the Section on the Survey Research Methods, American Statistical Association*, 742-747.

The Census Bureau is testing a combination of counting with sampling and estimation for producing census numbers for the size of the population in the 1995 Census Test. The new approach is under consideration for Census 2000. The plans for the 1995 Census Test call for applications of sampling and estimation at two points in the census process. The first one is conducting follow-up interviews for only a sample of the nonrespondents to the mail questionnaires. The Census Bureau will not try to contact all the nonrespondents as in previous censuses. The sampling and estimation based on nonresponse follow-up is expected to lower the cost of the census. The second application of sampling and estimation is a coverage measurement survey at the end of nonresponse follow-up. The results of the estimation based on this survey will be incorporated into the census numbers. The end product is known as the one-number census. The methodology of integrated coverage measurement (ICM) is expected to reduce the differential undercount. This paper describes the methodology under development and the plans for its evaluation.

[13] SCHINDLER, E. and NAVARRO, A. (1994). "CENSUS PLUS: An Alternative Coverage Methodology," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 248-253.

The 1990 Post-Enumeration Survey (PES) used capture-recapture or dual system methods to estimate coverage in the 1990 Census. CensusPlus is an alternative coverage measurement method in which, after completion of the normal census operations, a sample of blocks is revisited. This second collection effort applies intensive independent and dependent methods, including matching to the original census forms, to obtain the best possible count of usual residents in the sample blocks on Census Day. Final estimates are based on the total number of usual residents found in the sample blocks in either the original census or the re-enumeration. Unlike the dual system estimate where the so-called "fourth cell" estimates usual residents not found in either enumeration, there is no attempt to estimate persons missed in both enumerations. It is therefore very important for CensusPlus to locate all usual residents in the sampled blocks on Census Day. See Wright (1993) for a complete theoretical discussion of CensusPlus.

This paper describes an empirical study in which CensusPlus estimation procedures are applied to the 1990 PES data. Two results were noted: (1) Estimates of standard errors from CensusPlus and dual system estimation are close to one another with no clear advantage for either method, (2) As expected, the simulated CensusPlus estimates in this study measure a smaller undercount than the dual system estimates, especially for the hardest to collect demographic groups.

[14] STEFFEY, D.L. and BRADBURN, N.M. (Eds.) (1994). *Counting People in the Information Age*. Panel to Evaluate Alternative Census Methods, Committee on National Statistics, National Research Council. Washington, D.C.: National Academy Press.

This report provides details of the work of the Panel to Evaluate Alternative Census Methods. The panel's work emphasizes those aspects of census methodology that have the greatest potential effect on two primary objectives of census redesign: reducing differential undercount and controlling costs. In particular, the panel focused on processes for the collection of data, the quality of coverage and response that these processes engender, and the use of sampling (and subsequent estimation) in the collection process. The panel looked beyond Census 2000. A significant number of the panel's findings and recommendations look beyond 2000 to future censuses, relate to other Census Bureau demographic programs (current population estimates and sample surveys), and discuss the collection of small-area data from administrative files.

[15] ZANUTTO, E. and ZASLAVSKY, A.M. (1994). "Model for Imputing Nonsample Households with Sample Nonresponse Follow-up," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 236-241.

This paper looks at the problem of estimating/imputing the characteristics of households at addresses in nonsample blocks from which no response was obtained at the mailback of questionnaires stage.

1995

[1] EDMONSTON, B. and SCHULTZ, C. (Eds.) (1995). *Modernizing the U.S. Census*. Panel on Census Requirements in the Year 2000 and Beyond, Committee on National Statistics, National Research Council, Washington, D.C.: National Academy Press.

The report provides details of the work of the Panel on Census Requirements in the Year 2000 and Beyond. The panel's first task was to investigate whether and to what extent various types of essential data can best be collected by the decennial census or by other means. The second task was to consider and recommend the most cost-effective methods of conducting the census and otherwise collecting census-type data. The panel evaluated a wide range of methods for meeting the requirements of the decennial census, including radical proposals that would sharply alter the way the data are collected, substantial changes in the context of the traditional census, and incremental changes in the census. The basic conclusions are:

(1) "It is fruitless to continue trying to count every last person with traditional census methods of physical enumeration."

(2) "It is possible to improve the accuracy of the census count with respect to its most important attributes by supplementing a reduced intensity of traditional enumeration with statistical estimates of the number and characteristics of those not directly enumerated."

(3) "Once a decision is made to use statistical estimation for completing the count, a thorough review and reengineering of census procedures and operations could achieve substantial cost savings in the next census, even as accuracy is being improved."

(4) "With regard to proposals to drop the long form in the next decennial census and substitute a continuous monthly survey to obtain relevant data, substantial further research and preparatory work are required to thoroughly evaluate the likely effect and costs of these proposals. . .Therefore, the 2000 Census should include the long form."

[2] MULRY, M.H. and NAVARRO, A. (1995). "Methodology for the Evaluation of Sampling and Estimation in the Census," *Proceedings of the Section on Survey Research Methods, American Statistical Association,* 742-747.

This paper discusses the major evaluations of sampling and estimation in the 1995 Census Test. A description of the data collection and processing methodology for the enumeration, nonresponse follow-up and ICM can be found in Mulry and Singh (1994). The evaluation of sampling for nonresponse follow-up will assess its effectiveness by investigating the coverage properties and other aspects of two basic sampling designs, a block sample and a housing unit sample. The evaluation of the integrated coverage measurement (ICM) will focus on measuring data collection and processing errors plus determine whether the procedure adds persons in the traditionally undercounted groups to the census numbers. Two methodologies for integrated coverage measurement are considered: dual system estimation and a new methodology known as CensusPlus which uses ratio estimation.

[3] NAVARRO, A. and WOLTMAN, H.F. (1995). "1995 Census Test: Integrated Coverage Measurement Sample Design," *Proceedings of the Section on Survey Research Methods, American Statistical Association,* 718-723.

This paper provides an overview of the design, size of the sample and expected standard errors of population size due to sampling the nonrespondents and for coverage measurement. Design issues that are discussed include stratification, sample allocation, and expected measures of reliability of CensusPlus estimates for various demographic subgroups of the population.

[4] PETRONI, R.J., IKEDA, M., and SINGH, P.S. (1995). "Impacts of Sampling for Nonresponse Follow-up and Integrated Coverage Measurement on Census Methodology for a One Number Census," *Proceedings of the Section on Survey Research Methods, American Statistical Association,* 730-735.

The 1995 Census Test is researching two fundamental changes to traditional U.S. Census methodology – following up only a sample of nonresponding households (NRFU sampling) and integrating coverage measurement into estimation (Thompson, 1994). This paper describes the 1990 Census, the 1995 Census Test, and the implications of adopting the two fundamental changes for other census methodologies.

[5] PETRONI, R.J., KEARNEY, A.T., TOWN, M.K., and SINGH, R.P. (1995). "Should We Account for Missing Data in Dual-system Estimation?" in *International Perspective on Nonresponse, Proceedings of the Sixth International Workshop on Household Survey Nonresponse, Oct. 25-27, 1995*, 166-176.

The U.S. Census Bureau conducted a Post-Enumeration Survey (PES) to evaluate coverage after the 1990 Census. To accomplish this, the Bureau selected a sample of census blocks and conducted an independent canvas. Persons and households listed in the census were identified as the E–sample, while those listed in the independent canvas were identified as the P–sample. Analysts matched cases from the two samples and used results to obtain dual system estimation

(DSE) population estimates. For both samples, statisticians imputed missing data items and used hierarchical logistic regression models to impute unresolved enumeration or match status for persons. For the P–sample, statisticians also adjusted weights to account for noninterviewed households. From the point-of-view of reducing data processing time and effort, an attractive alternative is to treat persons in noninterviewed households, persons with any missing data items, and persons with unresolved enumeration or match status as not captured. That is, ignoring such persons by doing no noninterview adjustment, no imputation, and no modeling. This paper analyzes whether this alternative is reasonable for DSE from a statistical viewpoint.

[6] SCHAFER, J.L. (1995). "Model-Based Imputation of Census Short-Form Items," *Proceedings of the 1995 Annual Research Conference,* U.S. Bureau of the Census, 267-299.

Proposed changes in census design for the year 2000 will inevitably result in greater amounts of missing data than in previous censuses. These changes have prompted serious re-examination of the sequential hot deck and investigation of possible alternatives. This paper describes a stochastic method for imputing census short-form items based on explicit probability models. The characteristics of housing units, and the persons within those units, are described by a sequence of hierarchical regression models for discrete response. These models, developed through analysis of data from the 1990 Census, reflect the geographic heterogeneity and strong serial dependence that exists in the census roster. Model fitting is carried out by an algorithm for iterative simulation, a variation of the method proposed by Karim and Zeger (1991). Potential uses of this work include (a) imputation for item nonresponse, and (b) mass imputation of data for nonresponding housing units not included in a nonresponse follow-up sample.

[7] SCHINDLER, E. and NAVARRO, A. (1995). "The Effect of Sampling for Nonresponse Follow-up in the Census Environment on Population Estimates," *Proceedings of the 1995 Annual Research Conference,* U.S. Bureau of the Census, Washington, D.C., 69-86.

In a 1992 report to Congress, the General Accounting Office specifically argues in favor of sampling for nonresponse and reports potential savings on the order of 400 million dollars if the Bureau of the Census were to move in that direction. Two panels of the National Academy of Sciences commissioned by the Bureau of the Census have reiterated this statement.

Approximately 35 percent of all housing units and 25 percent of occupied housing units did not return the 1990 Census form by mail. All of these housing units were contacted by personal visit, adding significantly to the overall cost of taking the census. Enhancements to mail collection procedures tested in 1991 and 1992 may reduce the nonresponse problem by as much as one-third. Further savings can be achieved by selecting a sample of the remaining nonresponding housing units for personal visit follow-up. However, the variance introduced by the sampling can be a major contributor to the total error of the estimates.

The 1990 Post-Enumeration Survey (PES) data were used to obtain factors to adjust for undercoverage by the 1990 Census for 357 population groups defined by geography, tenure, race, sex, and age. The adjustment factors are used to obtain synthetic estimates of the population size by multiplying them by the number of persons counted by the census in an area.

This paper discusses an empirical study of the effect of sampling for nonresponse follow-up on estimates for a "one-number" census which incorporates the adjustment for undercoverage by the census into the official census tallies. Both dual system and CensusPlus adjustment factors are calculated. The primary focus is on block estimates for a "one-number" Census. Population targets for the 5000 PES blocks are derived by calculating direct Dual System or CensusPlus estimates from only the census and PES data from each individual block. At the block level, the average relative root mean square error for the synthetic estimates with complete nonresponse follow-up compared to the target estimates of the actual Census Day population is almost doubled by the introduction of a one-in-three sample of the nonresponding housing units.

[8] THIBAUDEAU, Y. and NAVARRO, A. (1995). "Optimizing Sample Allocation of the (Census) 2000 Nonresponse Follow-up," *Proceedings of the Survey Research Methods, American Statistical Association*, 736-740.

The paper explores avenues open to the Bureau in applying a plan for sampling for nonresponse follow-up. The research is guided by two principles: The first is the efficiency principle. It is motivated entirely by the goal of providing a census with maximum accuracy, for a given cost. The second principle is equity. It is desired to allocate the sample for the follow-up of nonrespondents so that the accuracy of estimates of comparable geographic areas would be the same. Simulations are done using 1990 Census data.

[9] THOMPSON, J.H., KILLION, R.A., MULRY, M.H., and MISKURA, S. (1995). "Census 2000: Statistical Issues in Reengineering the Decennial Census," *Proceedings of the Social Statistics Section, American Statistical Association*, 1-10.

This paper provides a description of the environment in which staff at the Census Bureau are developing the plans for the 2000 Census, describes how the Census Bureau has responded, and provides an overview of research planned in the next few years.

[10] TOWN, M.K. and FAY, R.E. (1995). "Properties of Variance Estimators for the 1995 Census Test," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 724-729.

The 1995 Census Test includes two fundamental changes in census design: sampling for nonresponse follow-up and integrated coverage measurement (ICM), both to be tested as precursors for 2000. After a determination of occupancy status by the Postal Service, housing units not responding to the mail census will be sampled and survey estimation approaches employed, in contrast to an attempt to follow up all nonresponses as in previous mail censuses. For ICM, a subsample will be drawn to estimate the residual undercoverage of the census, and estimates of the undercoverage will be integrated into the final count. The estimation incorporates aspects of both ratio estimation and imputation. This paper evaluates, using data from past censuses and Monte Carlo simulation, variances estimators developed for the 1995 Census Test and some potential alternatives.

[11] WRIGHT, T. (1995). "CensusPlus: A Sampling and Prediction Approach for the 2000 Census of the United States," *Proceedings of the 1995 Annual Research Conference, U.S. Bureau of the Census*, Washington, D.C., 37-68.

For a general audience, this paper offers details of a simple proposal (Wright, 1993) for estimation of the population (and housing) in the Year 2000 for the United States. The two important tools which help to accomplish the estimation are *sampling* and *prediction*. Under CensusPlus, two surveys (*mass* enumeration and *plus* sample enumeration) are made of a universe with *M* blocks. The mass enumeration results in an initial preliminary count for each and every block in the country. The plus sample blocks undergo a second *extra high* quality count which when compared with the initial count leads to *observed* resolved counts for the sample blocks. Under a simple model, resolved counts are *predicted* for the nonsample blocks. Hence an optimal estimator of *N*, the universe size, is obtained by adding these observed (in sample) and predicted (not in sample) resolved block counts. In fact, this sum turns out to be the *classical ratio estimator.* This one number census collection is additive and consistent for all levels of geography.

In addition, this paper presents sample sizes for the number of blocks required by the plus sample enumeration to support reliable state level estimates of population produced by CensusPlus. In particular and using data from the 1990 Census Files and the 1990 PES Block Data File, it is shown that a nationwide deeply stratified probability sample of 22,120 blocks is needed to ensure that the housing unit population of a given state is estimated with a standard error of 40,000 persons. The 1990 PES Block Data File also provides some early empirical evidence that the model is very likely to hold.

[12] ZANUTTO, E. and ZASLAVSKY, A.M. (1995). "A Model for Imputing Nonsample Households with Sampled Nonresponse Follow-up," *Proceedings of the 1995 Annual Research Conference,* U.S. Bureau of the Census, 608-613.

The potential cost savings for nonresponse follow-up (NRFU) sampling are large, but it is necessary to show that we can attain an acceptable level of accuracy for small areas before such a sampling scheme can be adopted. The problem is to estimate/impute the characteristics of households at addresses in nonsample blocks from which no response was obtained at the first stage. Once the census roster is completed by imputation, all tabulations prepared from the completed roster are guaranteed to be consistent with each other. In this paper, the authors consider, through simulations, the gains in accuracy that are possible with increasingly sophisticated models.

[13] ZASLAVSKY, A.M. (1995). "Discussion: Sampling From the 1995 Census Test Buffett," *Proceedings of the Section on Survey Research Methods, American Statistical Association,* 748-750.

These comments discuss the Census Bureau's plans for the 1995 Census Test with a focus on the sampling and estimation methodology.

1996

[1] AMERICAN STATISTICAL ASSOCIATION BLUE RIBBON PANEL REPORT ON CENSUS 2000 (1996), *AMSTAT News*, No. 235, 10-13.

In its report, this panel points out that sampling is an integral part of the scientific discipline of statistics and explains how its use can be an appropriate part of the methodology for conducting censuses. While not endorsing the Census Bureau's specific planned uses of sampling in Census 2000, the panels states, "The appropriate use of sampling can improve the count of the population."

[2] ANDERSON, M. and FIENBERG, S.E. (1996). "An Adjusted Census in 1990: The Supreme Court Decides," *Chance, Vol. 9, No. 3,* 4-9.

This is the ninth and final in a series of articles in *Chance* on the topic of census adjustment for the 1990 results and the litigation and controversy that has surrounded it. The Supreme Court rules that the Secretary of Commerce acted within his constitutional and legal mandate in deciding not to adjust the 1990 decennial census to correct for the differential undercount.

[3] ANOLIK, I. and GBUR, P. (1996). "Results of the 1995 Test of Integrated Coverage Measurement Mover Operations," *Proceedings of the Section on Survey Research Methods, American Statistical Association,* 854-858.

This paper discusses the methodology used in implementing the out-mover operation in the 1995 Census Test of ICM and reports on the results of a study that evaluates the quality and effectiveness of out-mover tracing and interviewing.

[4] BEIMER, P., TREAT, J., WOLTMAN, H., and VACCA, E.A. (1996) "An Investigation of Latent Class Models for Evaluating Census Coverage Error," *Proceedings of the Section on Survey Research Methods, American Statistical Association,* 275-280.

The reinterview survey is an important method for estimating and reducing nonsampling errors in surveys, particularly reinterview surveys that seek the truth, so-called *true-value* or *gold standard* reinterviews. In these surveys, a sample of survey elements are reinterviewed to measure the same characteristics obtained in the first interview. Discrepancies between the first and second responses are discussed with the respondent for the purpose of arriving at the "best" response. The reconciled measurement is then assumed to be the truth for purposes of evaluating the measurement bias in the original responses. The current paper focuses on a method for evaluating the quality of data collected in these types of reinterview surveys using latent class models.

[5] CHILDERS, D.R. (1996). "Integrated Coverage Measurement Processing Evaluations," *Proceedings of the Section on Survey Research Methods, American Statistical Association,* 842-847.

The 1995 Integrated Coverage Measurement (ICM) was designed to collect data from one Computer Assisted Personal Interview (CAPI) instrument to produce two estimates of the population using CensusPlus and dual system estimation (DSE) models. There are two processes that are required for producing the two populations estimators: (1) the residence status coding operations and (2) the matching and follow-up operations for dual system estimation. This paper discusses these processes and their evaluation during the 1995 Census Test.

[6] DORINSKI, S.M., PETRONI, R.J., IKEDA, M., and SINGH, P.R. (1996). "Comparison and Evaluation of Alternative ICM Imputation Methods," *Proceedings of the Section on Survey Research Methods, American Statistical Association,* 299-304.

To produce Dual System Estimates for the 1990 Census, the Census Bureau imputed missing items based on conditional distributions or from previous records using a hot-deck approach. For the 1995 Census Test, the Bureau primarily used flexible matching imputation to impute values for the Integrated Coverage Measurement (ICM) samples. This paper compared and

evaluated the two methods as a first step in selecting an imputation method for Census 2000 ICM samples. Final results indicate that in general the method used in the 1990 Census produces results which are more consistent with the reported data.

[7] FARBER, J. (1996). "A Comparison of Imputation Methods for Sampling for Nonresponse Follow-up," *Proceedings of the Section on Survey Research Methods, American Statistical Association,* 383-388.

In previous mail-out Decennial Censuses, enumerators were sent to conduct personal interviews at all households that did not return census questionnaires. This massive undertaking has become prohibitively expensive, however, and has led the Census Bureau to plan to visit only a sample of these households in Census 2000. Though it will save money, this sampling for nonresponse follow-up will also create an unprecedented amount of missing data. In particular, no data will be available for the households that do not mail back their census forms and are not chosen in the follow-up sample.

Traditionally, the Census Bureau has imputed missing data for an entire household using the responses from a nearby household. However, with sampling for nonresponse follow-up, the nearest housing unit may be quite far and thus quite different from the nonrespondent household. A number of methods have been developed to cope with this problem. This paper gives a review of these methods, and an assessment of their performance in a simulation study. The simulations yield estimates of bias and variance, which allow for comparison of the methods. This information will assist in the selection of the imputation method that will best meet the goals of improved accuracy and efficiency in Census 2000.

[8] FERRARO, D.L. (1996). "Estimation in the 1995 Census Test Service-Based Enumeration," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 746-751.

The objective of the follow-up enumeration is to test different statistical methodologies for estimating the number of people without a ususal residence who used services during the enumeration period. The 1995 Census Test was the first attempt at a fundamentally different approach to counting persons without a usual home than was used in the 1990 Census. The new methodology enumerates people at facilities where they received services. The 1995 service-based enumeration (SBE) counted people at shelters and soup kitchens. The goal of the SBE project is to test operational methods and estimation methodologies to include, in the census, persons who use services and may be missed in the standard enumeration of households and other group quarters. The methodology was not designed to provide a count of the homeless population or service users. Three classes of estimators are considered in this paper. The first class, based on capture-recapture methods, matches results from samples for two time periods to produce dual system estimates. The second type of estimator is a multiplicity estimator which relies on respondents' answers to "service-usage history," questions. A third estimator weights the data according to the case's first enumeration. Using data from the 1995 Census Test, the three estimators are discussed and evaluated.

[9] GREEN, L.S. (1996). "Evaluation of the Postal Identification of Vacant and Nonexistent Units," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 740-745.

This report documents results of the 1995 Census Test project–Evaluation of the Postal Identification of Vacant and Nonexistent Units.

[10] IKEDA, M. and PETRONI, R. (1996). "Handling of Missing Data in the 1995 Integrated Coverage Measurement Sample," *Proceedings of the Section on Survey Research Methods, American Statistical Association,* 563-568.

This paper gives an overview of the methods used to handle missing data in the 1995 Integrated Coverage Measurement (ICM) sample. It also provides an evaluation of the likely importance of any effect of the ICM missing data methods on the final results.

[11] KADANE, J.B. (1996). "A Bayesian Approach to Designing U.S. Census Sampling for Reapportionment," *Journal of Official Statistics, Vol. 12, No. 1,* 85-93.

This article proposes a design criterion for sampling in conjunction with the U.S. censuses of 2000 and beyond. Since reapportionment of Congress is the constitutional basis of the census, the loss function used here minimizes apportionment errors in a certain sense. This leads to a stochastic modification of the Hill (equal proportions) method of apportionment now used. If the sampling in the census is designed to achieve minimum constant coefficient of variation of state shares of the national population, the use of the proposed "single-number" census will result in the same apportionment as would have been obtained using the proposed loss function.

[12] KRENZKE, T.R. and NAVARRO, A. (1996). "Sampling Error Estimation in the 1995 Census Test for Small Areas," *Proceedings of the Section on Survey Research Methods, American Statistical Association,* 752-757.

Direct variances were calculated for 39 redistricting data items for three 1995 Census Test sites. These variances include components from two sources of sampling error, error in estimation due to Integrated Coverage Measurement sampling and error in estimation due to Nonresponse Follow-up sampling. The statistical relationship between estimated totals and their associated directly calculated variance estimates was modeled for each site. Three ways to proceed with the modeling were compared, three data sets containing different combinations of geographic levels were used and the resulting model parameters were compared, and seven variance models were evaluated. The result of the modeling procedures is to use one generalized variance function for each of the three Census Test sites to calculate the standard errors for estimated totals and proportions for all 39 redistricting data items. This paper serves to document the beginning of research into ways of measuring the sampling error in Census 2000. The authors hope that this paper generates ideas on enhancing the methodology that was implemented in the 1995 Census Test and to generate ideas on alternative ways of measuring sampling errors.

[13] MULRY, M.H. and GRIFFITHS, R. (1996), "Comparison of CensusPlus and Dual-system Estimation in the 1995 Census Test," *Proceedings of the Section on Survey Research Methods, American Statistical Association,* 848-853.

The Census Bureau tested integrated coverage measurement (ICM) in the 1995 Census Test because the methodology has been expected to reduce the differential coverage error observed in previous censuses. ICM also is expected to reduce overall coverage error. One goal of the 1995 Census Test was to test two methodologies for integrated coverage measurement. The primary issue has been whether a new methodology known as CensusPlus, which uses ratio estimation, is effective. Another goal was to test dual system estimation (DSE) which was used for the 1990 Post-Enumeration Survey (PES) as an alternative to CensusPlus with ratio estimation. This paper evaluates the effectiveness of two methodologies by examining whether they add persons in the traditionally undercounted groups to the census numbers.

[14] NAVARRO, A., TREAT, J., and MULRY, M.H. (1996). "Nonresponse Follow-up: Unit Vs. Block Sampling," *Proceedings of the Section on Survey Research Methods, American Statistical Association,* 551-556.

A major component of the 1995 Census Test design is to evaluate the operational feasibility of Sampling for Nonresponse Follow-up (NRFU). The motivation for sampling nonrespondents is to reduce the cost of the census while maintaining high quality data. An equally important objective of the 1995 Census Test is to evaluate the sampling element, the *census block* versus the *housing unit*. A sample design based on each of the two elements has advantages and disadvantages. From simulations using 1990 Census data, we know a unit sample design produces estimates with less bias and variance for small areas. The block sample may be easier to implement in conjunction with the integrated coverage measurement (ICM) operations, since the ICM uses a block sample. This paper reports the results of an evaluation for deciding between *block* or *housing unit* for sampling for nonresponse follow-up. Based on the results, the authors conclude that there is little to no difference between the estimates from the NRFU block sample design and the NRFU housing unit sample design. Based on this analysis, they recommend the use of the NRFU unit sample design because there is no significant difference in coverage and the unit design produces population estimates with less bias and variance for small areas than the block design.

[15] PETRONI, R.J., KEARNEY, A., and GBUR, P. (1996). "Handling Noninterviews to Provide Equitable Comparisons of ICM Estimates," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 569-574.

To develop methodology to be used in Census 2000, the Census Bureau undertook a census test program in 1995. A major goal of the test program was to develop and test a new coverage measurement methodology, Integrated Coverage Measurement (ICM). In 1995, the goal of ICM was to measure the error in coverage (overcount or undercount) of the census test in three sites: Oakland, CA; Paterson, NJ; and six parishes in Northwest Louisiana. A parallel goal was to test CensusPlus and Dual System Estimation (DSE) (Thompson, 1994). The Census Bureau tested these two methods in Oakland and Paterson. Each method had a different method for interviewing, and the methods had different noninterview rates. This paper focuses on comparing the two research approaches in assessing the impact of noninterview differences The authors conclude that the CensusPlus and DSE comparisons were not adversely influenced by differences in noninterview rates in the 1995 Census Test.

[16] ROSENTHAL, M., SCHINDLER, E., and NAVARRO, A. (1996). "Census 2000 Sample Weighting," *Proceedings of the Section for Survey Research Methods, American Statistical Association,* 377-382.

The United States Census of Population and Housing collects basic demographic information of every resident enumerated in the census. Additionally, a sample of households receives a detailed questionnaire, which collects information on a wide range of social and economic topics. To produce full population and housing estimates for the sample, weighting areas are formed to calculate weights for the persons and housing units. Sample estimates for the whole population are produced using the person and housing-unit weights. In 1990, the raking-ratio estimation procedure ensured consistency between the sample estimates and census counts of data collected on a 100-percent basis.

A redesign alternative for Census 2000 is to conduct a sample-based nonresponse follow-up (NRFU) operation. A desirable objective of the Census 2000 sample design is to produce estimates with reliability comparable to1990 with no increase in the overall sample of households receiving the detailed questionnaire. This paper explores the issue of weighting-area formation, specifically the size criterion as it relates to NRFU sampling and accuracy of sample estimates. The authors assess several weighting-area-formation schemes using exploratory data analysis methods and other efficiency criteria, such as mean-squared errors and variances of the estimates.

[17] SCHINDLER, E. and NAVARRO, A. (1996). "Effect of Sampling for Nonresponse Follow-up on Estimates from Sample Data," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 371-376.

For the 2000 Decennial Census of Population only a sample of housing units which fail to return census forms by mail will be visited by enumerators. In past censuses, all such households have been enumerated. In 1990 this follow-up operation required several hundred thousand temporary workers and cost over four hundred million dollars. Multiple sample designs are being considered. The objectives are (1) to reduce the cost of the census, (2) to give each person multiple opportunities to be counted, and (3) to improve quality by incorporating corrections for undercoverage into the estimates.

In 2000, as in past censuses, a sample of housing units will be asked to provide detailed housing unit, demographic, education, labor force, and income information. This paper discusses two empirical studies which examine the increase in sampling error caused by the introduction of sampling for the nonrespondents. These studies simulate a range of possible sample designs on data sets from the 1990 Census. For one of the studies, it is possible to develop estimates of the between systematic sample component of the variance. The information obtained from these studies will assist in the determination of an appropriate design for the nonresponse follow-up sample which minimizes the effect on estimates from sample data.

[18] TSAY, J.H., ISAKI, C.T., and FULLER, W.A. (1996). "A Block Based Nonresponse Follow-up Survey Design," *Proceedings of the Section on Survey Research Methods, American Statistical Association,* 557-561.

Sampling for nonresponse follow-up (NRFU) as a potential procedure for use in Census 2000 was conducted in the 1995 Integrated Coverage Measurement (ICM) Test. In this paper, the authors provide a detailed description of the block based sample design and the housing unit estimation method used to provide a transparent census data file (transparent to the application of sampling and estimation) of nonrespondents. They also discuss an extension of the procedure to provide a final census file that utilizes the coverage measurement survey data.

[19] VACCA, E.A., MULRY, M., and KILLION, R.A. (1996). "The 1995 Census Test: A Compilation of Results and Decisions," *1995 Census Test Results Memorandum No. 46,* U.S. Bureau of the Census, U.S. Department of Commerce, Washington, D.C.

This document is our attempt to bring some order and integration to the numerous results and findings from the 1995 Census Test. These results are detailed in approximately fifty evaluation reports.

[20] WEST, K.K. and GRIFFITHS, R.R. (1996). "Results From the 1995 Integrated Coverage Measurement Evaluation Interview," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 830-835.

The objective of this evaluation is to measure and evaluate the quality of the Integrated Coverage Measurement (ICM) Person Interview data. The evaluation focuses on errors that are relevant to the study of census coverage estimator bias and the CensusPlus estimator. The data for the evaluation are from the 1995 ICM Evaluation Interview.

[21] WHITE, A.A. and RUST, K.F. (Eds.) (1996). *Sampling in the 2000 Census*: *Interim Report I.* Panel to Evaluate Alternative Census Methodologies, Committee on National Statistics, National Research Council. Washington, D.C.: National Academy Press.

This first interim report of the Panel on Alternative Census Methodologies focuses on the use of statistical procedures, especially sampling, in the conduct of the 2000 Census. The report's final comment begins with, "A combination of sampling for nonresponse follow-up and for integrated coverage measurement is key to conducting a decennial census at an acceptable cost, with increased accuracy and overall quality, and reduced differential undercoverage."

[22] WHITFORD, D.C. (1996). "The 1996 Integrated Coverage Measurement Test," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 389-393.

For the first time in the 1995 Census Test, the Census Bureau integrated the coverage measurement process audit results into the census-taking procedures. That is, the ICM survey measured how well the census procedures counted people in the test sites, and was completed in time for the results to be incorporated into the census numbers by the end of the calendar year 1995. One of two major successes in the 1995 ICM was that we conducted the ICM interview using Computer Assisted Personal Interviewing (CAPI) technology. This allowed "on-the-doorstep" matching of the people found during the independent ICM interview with the people found in the census results that were already loaded into the computer. Despite these successes, the 1995 ICM had some room for improvement. Foremost, we have redesigned the ICM Person Interview and are pleased with the results so far. This paper discusses the planned testing of this instrument in the 1996 ICM Test.

[23] WRIGHT, T. and BATES, L. (1996). "A Monte Carlo Study Comparing CensusPES and CensusPlus When There Is the Possibility of Undercounting," *American Journal of Mathematical and Management Sciences, Vol. 16,* 395-462.

This paper presents the results of a Monte Carlo Study comparing a version of the capture-recapture estimation methodology called CensusPES with a ratio estimation methodology call CensusPlus. CensusPES and CensusPlus are similar methods for integrating sample evaluation results with mass enumeration results in an effort to provide one improved set of census numbers. The Monte Carlo Study makes use of 1990 official census block level counts by person type for the state of Alabama. When there is the possibility of missing persons in the mass enumeration as well as in the sample evaluation, it is demonstrated that statistical methods such as CensusPES or CensusPlus with appropriate data can successfully yield a high quality census count at all levels of geography.

[24] ZANUTTO, E. and ZASLAVSKY, A.M. (1996). "Estimating a Population Roster from an Incomplete Census Using Mailback Questionnaires, Administrative Records, and Sampled Nonresponse Follow-up," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 538-543.

Several methods have been proposed for completing the census roster when Nonresponse Follow-up is conducted in only a sample of blocks (Fuller, Isaki, and Tsay 1994, Schafer 1995, Zanutto and Zaslavsky 1995a,b). Recently, Zanutto and Zaslavsky (1996) extended this list of papers by considering estimation when one of the data sources is a file of administrative records. This paper applies these methods to census data and administrative records from the 1995 Census Test, and extends this methodology to incorporate a housing unit sample design for Nonresponse Follow-up sampling. Zanutto (1996) provides a more detailed description of this research.

1997

[1] ALEXANDER, C.H., DAHL, S., and WEIDMAN, L. (1997). "Making Estimates from the American Community Survey," *Proceedings of the Section on Government Statistics and Section on Social Statistics, American Statistical Association*, 88-97.

This paper discusses the estimation methods used for the 1996 American Community Survey (ACS). In particular, the weighting strategy and weighting factors are described in detail.

[2] ANDERSON, M. and FIENBERG, S.E. (1997). "Who Counts? The Politics of Censustaking," *Transaction/Social Science and Modern SOCIETY, Vol. 34, No. 3,* 19-26.

The authors focus on several issues. They begin with a brief description of the role and functions of the census. They discuss two very different worlds of decision making about "counting," first with a review of the recent Supreme Court decision in Wisconsin vs. New York, and second with a brief analysis of the Bureau's current plans for 2000. They conclude with a roadmap of where the country is heading for 2000.

[3] CHOLDIN, H.M. (1997). "How Sampling Will Help Defeat the Undercount," *Transaction/Social Science and Modern SOCIETY, Vol. 34, No. 3,* 27-30.

Two planned applications of sampling promise substantial gains toward overcoming the differential undercount in Census 2000. The first use of sampling to fill in the numbers in every census tract would give more complete counts of minority groups in poor, urban neighborhoods. The second use of sampling in the form of a very large, high-quality post-enumeration survey coupled with dual system estimation will also contribute to overcoming the differential undercount. This paper discusses these planned uses of sampling in Census 2000.

[4] DORINSKI, S.M. and GRIFFIN, R. (1997). "Accounting for Variance Due to Imputation in the Integrated Coverage Measurement Survey," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 748-753.

Variance estimation methods used in post-enumeration surveys of previous censuses have not accounted for variance due to imputation. The unresolved cases in the P-sample have imputed probabilities of matching to the initial phase, while the unresolved cases in the E-sample have

imputed probabilities of correct enumeration. In the Census 2000 Integrated Coverage Measurement (ICM) survey, the Census Bureau may impute probabilities for the enumeration or match status of unresolved cases and use a variance estimation method to account for the variance due to this imputation. We impute the probabilities by fitting hierarchical logistic regression models. This project compares three types of variance estimation: (1) a method developed by Schafer and Schenker (1991), (2) bootstrap, and (3) jackknife using the 1995 Census Test data for Oakland to determine which method is the best.

[5] FARBER, J. and NAVARRO, A. (1997). "A Comparison of Alternative Sampling Methodologies for Census 2000," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 683-688.

Since 1970, when the decennial census was first conducted largely by mail, response rates have been declining and undercoverage errors have been increasing. To remedy these problems, the Census Bureau plans to use two major sampling operations in Census 2000. Sampling for nonresponse follow-up will allow the Census Bureau to complete the initial phase in a cost-effective manner, while sampling for Integrated Coverage Measurement will provide an increase in the quality of census data by correcting for coverage errors. Sampling will enable the Census Bureau to achieve the goals of a faster, less costly, and more accurate census. However, before these sampling techniques can be accepted for use in Census 2000, their potential effect on providing an accurate accounting of the population must be assessed. One way to assess the potential effectiveness of sampling is to compare the errors introduced by sampling to the undercoverage errors of the 1990 Census. This paper describes the methodology and results of research into the levels and sources of error from simulations of the sampling operations planned for Census 2000. Additionally, a comparison is made between the sampling errors obtained from these simulations and the undercoverage errors of the 1990 Census. This comparison will allow the Census Bureau to determine the optimal enumeration strategy for Census 2000.

[6] GRIFFIN, R.A. and KOHN, F. (1997). "Sample Allocation Research for the Census 2000 ICM Survey," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 695-700.

The Census 2000 Integrated Coverage Measurement (ICS) Survey will be used to provide estimated census totals that correct for the undercount, especially the differential undercount among racial, ethnic, and socioeconomic groups, that has been observed in every decennial census from 1940 onward. The ICM survey will be designed to produce direct estimates of total population for each of the 50 states, the District of Columbia ((DC), and Puerto Rico and will have a sample size of about 750,000 housing units (HUs) excluding DC and Puerto Rico. This paper will present results of research on methods to allocate the ICM sample within a state.

[7] KEYFITZ, N. (1997). "The Case for Census Tradition," *Transaction/Social Science and Modern SOCIETY, Vol. 34, No. 3,* 45-48.

Anyone can improve the census, for instance by adding one person to the counted population of New York. Adding 1000 persons would improve it more. Adding a million would make it worse. So why not use a sample, to find the best ascertainable amount to add? Then treat the additions as through they were persons enumerated with blanks in the census form, and use a method for optimally assigning these. If we are going to have a fictional completeness in any case, why not choose the fiction that is as close as possible to reality? That as I see it is the argument for sampling to improve the census.

The argument against mostly concerns legitimacy, the credibility that goes with tradition. The traditional census procedure could claim to count at least some residents of every household whose existence was known to the enumerators. To modify it is an invitation to all those with a financial interest to work out numbers for themselves, and then to defend them in court. Once the matter got into the courts it would degenerate into a battle of experts, in a procedure very different from what scientists use for reaching consensus on technical issues. In this paper, the author calls for a traditional census, one without sampling.

[8] KRENZKE, T.R. and GRIFFIN, D.H. (1997). "Who was Counted Last in the 1990 Census?," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 701-706.

In Census 2000 most households will receive a census questionnaire to complete and return by mail. One of the many changes proposed for Census 2000 involves the use of sampling to collect data for those households that do not respond by mail (i.e., nonresponse follow-up.) In the past several years, a series of research projects has been undertaken to determine how best to design this sample. One approach that was considered was to truncate nonresponse follow-up when 90 percent of the housing units in each tract had been enumerated. A sample of the last 10 percent would be selected. Critics of this approach were concerned that such a plan might imply that only minority households would end up being sampled. This research project was designed to address those concerns.

[9] MEYER, M.M. and KADANE, J.B. (1997). "Evaluation of a Reconstruction of the Adjusted 1990 Census for Florida," *Journal of Official Statistics, Vol. 13, No. 2,* 103-112.

Meyer and Kadane (1992) report a method for reconstructing the adjusted population (by age, race, and sex) for the half of the census blocks in Florida not made available to them. This article studies the full adjusted data set, which is now available, to examine how well the original reconstruction was done. This is a rare opportunity to learn the exact value of quantities estimated. The results show that the largest difference between the Meyer and Kadane (1992) approximation and the adjusted counts at the Congressional district level was 79 persons for one district. Thus, the approximation could have been used instead of the unavailable adjusted census, had the redistricting decision-makers so chosen.

[10] MULRY, M.H., DAVIS, M.C., and HILL, J.M. (1997). "A Study in Heterogeneity of Census Coverage Error for Small Areas," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 742-747.

This paper investigates the feasibility of using estimates of the probability of a person being enumerated in the census in developing models of the heterogeneity in census coverage error for small areas. Revisions of logistic regression models for these probabilities (Alho, Mulry, Wurdeman, and Kim 1993) are developed using data from the 1990 Census and Post-Enumeration Survey (PES). The independent variables in these models are characteristics of the persons, their household, and their block derived from the short form data without using any of the characteristics of the census or PES. The probabilities may be used to develop estimates of coverage error for small areas. The paper contains a description of the methodology for block level estimation followed by its evaluation.

[11] PETRONI, R., KEARNEY, A., and ROBINSON, G.J. (1997). "Use of Hard-to-Count Scores and Inclusion Probabilities to Improve Dual System and Census Plus Estimates," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 736-741.

Dual System and CensusPlus estimation are alternative techniques the Census Bureau has used to obtain census estimates (Thompson, 1994) and evaluate the completeness of census coverage of population. Both techniques assume the probabilities of enumeration are the same for all persons of the population. Since enumeration probabilities vary by age, sex, race/ethnicity, tenure, and geographic area, the Census Bureau post-stratifies the evaluation samples and the census by these characteristics to define subsets of the population which have more homogeneous enumeration probabilities to reduce heterogeneity bias. However, Alho, et.al. (1993) and Robinson (1996) provide evidence of residual heterogeneity bias after implementation of this post-stratification. Because the Census Bureau will use Dual System Estimation (DSE) for Census 2000, the authors are conducting research to identify a way to reduce heterogeneity bias for Census 2000.

Additionally, Bell (1991) noted that in the 1990 Census the Census Bureau obtained some negative Dual System Estimates (DSE) of the number of persons missed by both the census and the evaluation sample (i.e. the fourth cell estimates). The Bureau also obtained some negative fourth cell estimates in the 1995 Test Census. Theoretically this can occur because of sampling errors (Bell, 1991). It may also occur if the data reported by census and the evaluation interview differ, hence resulting in differing post-stratification classifications for census and the evaluation survey. If post-strata can be formed to reduce the mean square error, we may reduce the "negative fourth cell problem".

Using the 1995 Test Census data for the Oakland, California site, we researched the potential of alternative post-stratification schemes to reduce heterogeneity bias in DSE and Census Plus estimates and, secondarily, the negative fourth cell phenomenon for DSE. The alternatives build upon the Hard-to-Count (HTC) score and inclusion probability concepts developed respectively by Robinson and Alho et.al.

[12] ROBINSON, J.G. (1997). "What is the Role of Demographic Analysis in the 2000 United States Census?," *Proceedings of the Statistics Canada Symposium 96*: *Nonsampling Errors*, 57-63.

Demographic Analysis is a well-developed coverage measurement and evaluation program in the United States. It has served as the standard for measuring coverage trends in recent censuses and differences in coverage by age, sex, and race at the national level. In this paper, the author explores the role that demographic analysis can play in the Census 2000.

[13] SCHINDLER, E. and GRIFFIN, R. (1997). "Census 2000 ICM: Stratification and Post-stratification," *Proceedings of the Section on Survey Research Methods, American Statistical Association,* 689-694.

In 1900, the synthetic estimation technique developed for census adjustment assumed that within poststrata undercount rates are constant across all subpopulations. A poststratum, the finest level for which direct coverage estimates are produced, is usually defined as a function of demographic and/or geographic characteristics. Poststrata are defined so as to minimize the impact of failure of the synthetic assumption; that is, to minimize heterogeneity within poststrata. This paper will use 1990 Census and Post-Enumeration Survey (PES) data to assess the use of raking to create additional poststratification cells for the Census 2000 Integrated

Coverage Measurement (ICM) in terms of variance and heterogeneity. Pearson correlations are used to assess heterogeneity at the poststratum level.

[14] SUTTON, G.F. (1997). "Is the Undercount a Demographic Problem?," *Transaction/Social Science and Modern SOCIETY, Vol. 34, No. 3,* 31-35.

The author states, "My preferred resolution to the disputed strategies and tactics of census taking is to leave settling the head count problem with the demographers and statisticians. Consequently, I would propose partitioning the decennial census work into two parts. One component would be the preparation of census results, where the demographic and statistical estimation problems associated with providing one and only one national benchmark are addressed. The other component would be that of preparing Census Special Usage Derivatives peculiar to each special need for census results. This paper discusses the technical issues to be resolved and separates them from political issues that will require negotiation and bargain for resolution.

[15] THIBAUDEAU, Y., WILLIAMS, T., and KRENZKE, T. (1997). "Multivariate Item Imputation for the 2000 Census Short Form," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 371-376.

The intent behind the paper is to expose a simple methodology for short form item imputation in the 2000 Census. The short form records seven demographic items for each occupant of a housing unit (HU) and is delivered to all the HUs in the United States. The authors constructed the methodology with two objectives in mind: to design a system that is adaptable to the wide spectrum of multivariate contingencies generated by the short form, and to build a system from commonly available off-the-shelf software components to keep the programming to a minimum.

[16] VACCA, E.A. and KILLION, RUTH ANN (1997). "Sampling and Estimation in Census 2000: A Road Map to Success," *Proceedings of the Section on Government Statistics and Section on Social Statistics, American Statistical Association*, 411-416.

This paper provides the plan for sampling and estimation in Census 2000. The Census 2000 plan will provide a one number census designed to correct the undercount, especially the differential undercount among racial, ethnic and socioeconomic groups that has been observed in every census since 1940.

[17] WHITE, A.A. and RUST, K.F. (Eds.) (1997). *Preparing for the 2000 Census: Interim Report II,* Panel to Evaluate Alternative Census Methodologies, Committee on National Statistics, National Research Council, Washington, D.C.: National Academy Press.

This report evaluates information from the 1995 Census Test, analyzing a variety of issues and test results that bear on the success of the 2000 Decennial Census. The panel reiterates a statement made in its *1996 Interim Report I,* "...that a census of acceptable accuracy and cost is not possible without the use of sampling procedures."

[18] ZANUTTO, E. and ZASLAVSKY, A.M. (1997). "Modeling Census Mailback Questionnaires, Administrative Records, and Sampled Nonresponse Follow-up, to Impute Census Nonrespondents," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 754-759.

The use of sampling for nonresponse follow-up (NRFU) in Census 2000 will create an unprecedented amount of missing data. Therefore, it is important to synthesize all available information to estimate the complete roster with acceptable accuracy. In particular, administrative records are a relatively inexpensive source of detailed information. However, they differ systematically in coverage, content, and reference period from the census, so simply replacing non-responding households with administrative records may introduce biases into the completed roster. To complete the roster, the authors propose fitting a hierarchical log-linear model to model characteristics of nonsample nonresponding households using low-dimensional covariates at the block level and more detailed covariates at more aggregated levels. Model estimates are then used to impute the characteristics of households at nonsample nonresponding addresses. They incorporate administrative records in this estimation and imputation method using data from sampling for NRFU to correct for systematic differences between the information sources. They evaluate our methods through simulations using data from the1995 Census Test.

1998

[1] ALEXANDER, C.H. (1998). "Recent Development in the American Community Survey," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 92-100.

The American Community Survey (ACS) is being developed by the U.S. Bureau of the Census to update, and eventually to replace, the decennial census long form survey. The ACS will cover the same topics as the long form, providing detailed economic, social and housing profiles of communities throughout the U.S. This paper gives updates about research on the ACS, with particular focus on our evolving understanding of how multi-year ACS data are likely to be used.

[2] ANDERSON, M. and FIENBERG, S.E. (1998). "Who Counts? Census Controversies for the Millennium," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 111-120.

Recent statements of Congressional leaders, public officials, political commentators and reporters in the print media about the upcoming census fall into the category of myths about the census in the past, rather than as historical statements about what the census has been or descriptions of the census plans for 2000. Census politics burst into the national news in the summer of 1997 when Republicans attached to the flood relief bill for the Dakotas a rider banning the use of sampling in the 2000 Census. The President vetoed the flood relief bill and after several more months of negotiation and politics, Congress and the President compromised on language in the appropriations bill. That compromise created a Census Board to monitor plans for and administration of the 2000 Count and effectively put off the resolution of the sampling dispute to 1998 and beyond. The Census Bureau and the Clinton administration promote the 2000 plan as thoughtful and innovative methods within the time honored tradition of counting. Some Congressmen and a number of state and local officials conjure up a pending disaster, political manipulation of the count and general incompetence within the Census Bureau officialdom. The Speaker of the House and the Southeastern Legal Foundation have filed separate lawsuits

in federal court against the Clinton administration in an effort to block key aspects of the 2000 Census Plan (*United States House of Representatives et al., vs. United States Department of Commerce, et al.; Glavin, Barr, et al., vs. Clinton et al.*). The authors' goal is to identify the myths to provide an alternative history of the plans for 2000 in the hopes of generating some dialog on the difficult technical issues of counting still to be resolved for 2000.

[3] FARBER, J. and GRIFFIN, R. (1998). "A Comparison of Alternative Methodologies for Census 2000," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 629-634.

Recent decennial censuses have followed trends of decreasing mail return rates and accuracy, and increasing data collection expenses. In response, the Census Bureau plans a number of sampling operations for Census 2000, including sampling for nonresponse follow-up (NRFU) and sampling of undeliverable-as-addressed (UAA) vacants. UAA vacant addresses are those that are identified by the United States Postal Service as vacant. NRFU addresses are those that are not UAA vacant and that do not self-respond to the census. Although sampling of these addresses will save time and control costs in the census, it also means that a fraction of the population will not be physically enumerated. An estimation method is required to account for the population residing at nonrespondent and UAA vacant addresses not in either the NRFU or UAA vacant samples.

Several methodologies have been proposed for NRFU and UAA vacant estimation. This paper outlines the underlying theory of these methods, and the advantages and disadvantages of each. In addition, this paper describes the results of empirical research conducted to compare the alternative estimation methods and to identify the method that can optimally be implemented in Census 2000.

[4] FAY, R.E. and TOWN, M.K. (1998). "Variance Estimation for the 1998 Census Dress Rehearsal," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 605-610.

This paper describes the variance estimation approach to be implemented in the Dress Rehearsal, as the basis for the methodology in Census 2000.

[5] FERRARI, P.W. (1998). "1996 American Community Survey vs. 1990 Decennial Census Household Size and Characteristics by Response Mode," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 190-195.

In an effort to identify any possible coverage problems associated with the American Community Survey (ACS), a research project was initiated to compare coverage in the 1996 ACS to the 1990 Decennial Census by looking at the distribution of household size by various demographic characteristics and mode of response. From those results, we hope to identify possible causes, such as forms designs and field and processing procedures, that might contribute to the under-coverage and suggest further research and testing. Other research projects will address within household coverage, look at residence rules, suggest alternative rostering and questionnaire design, assess the impact of nonresponse on coverage, evaluate the completeness of data for persons from large households, and experiment with methodologies to improve whole household coverage in frames for sampling.

[6] GBUR, P.M., HEFTER, S.P., and FAIRCHILD, L.D. (1998). "Long Form Design for the U.S. Census 2000 Dress Rehearsal and Plans for Census 2000," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 686-691.

This paper presents a description of the sample design and the current plans for weighting and variance estimation of the long form questionnaire data for the Census 2000 Dress Rehearsal. We will also describe the components which were changed from 1990 and those which will be examined, and therefore may be revised, for Census 2000. In general, the dress rehearsal design and the plans for Census 2000 are similar to 1990, but revisions have been introduced to improve selected aspects of the 1990 process and to allow flexibility in supporting a census with or without sampling.

[7] GRIFFIN, R. and VACCA, E.A. (1998). "Estimation in the Census 2000 Dress Rehearsal," *Proceedings of the Section on Survey Research Methods, American Statistical Association,* 635-640.

This paper provides an overview of the sampling methodology and details of the estimation methodology for the Census 2000 Dress Rehearsal. In the Dress Rehearsal, the Census Bureau is using traditional enumeration methods in Columbia, SC with a Post-Enumeration Survey (PES) as a coverage measurement survey. The Census 2000 sampling and estimation plan is being used in Sacramento, CA; that is, sampling for nonresponse follow-up (NRFU), for undeliverable as addressed (UAA) vacant follow-up, and for integrated coverage measurement (ICM). A modified Census 2000 sampling and estimation plan is being used in Menonimee, WI; that is, sampling for ICM only.

[8] HAINES, D.E. and HILL, J.M. (1998). "A Method for Evaluating Alternative Raking Control Variables," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 647-652.

Population coverage error estimates for the 1990 Decennial Census were based on dual-system estimation (DSE) where one system was the census enumeration and the second system was an enumeration for a sample of the population as part of the Post-Enumeration Survey (PES). Population coverage error estimates were based on 357 poststrata. Results from PES poststrata estimation indicated that differential undercounts existed across race and ethnic groups, renters, and rural residents. Iterative proportional fitting, or raking, will be used for the Census 2000 Dress Rehearsal to produce acceptable site-level estimates. The raking method corrects initial phase estimates by controlling to dual system estimates. Earlier research shows that increasing the number of poststrata and allowing multiple dimensions in the raking matrix yields more accurate coverage probabilities than DSE without raking. Our research focuses on constructing the best raking matrix for obtaining an accurate population estimate. We use logistic regression models to determine the optimal marginal, or control variables. We then decide the dimensions and the placement of the variables on the raking matrix. Finally, we compare the performance of alternative raking matrices using coverage factor coefficients of variation and mean square errors.

[9] HAINES, D.E. and POLLOCK, K. (1998). "Combining Multiple Frames to Estimate Population Size and Totals," *Survey Methodology, Vol. 24, No. 1,* 79-88.

Efficient estimates of population size and totals based on information from multiple list frames and in independent area frame are considered. This work is an extension of the methodology

proposed by Hartley (1962) which considers two general frames. A main disadvantage of list frames is that they are typically incomplete. In this paper, we propose several methods to address frame deficiencies. A joint list-area sampling design incorporates multiple frames and achieves fill coverage of the target population. For each combination of frames, we present the appropriate notation, likelihood function, and parameter estimators. Results from a simulation study that compares the various properties of the proposed estimators are also presented.

[10] IKEDA, M.I., KEARNEY, A., and PETRONI, R. (1998). "Missing Data Procedures in the Census 2000 Dress Rehearsal Integrated Coverage Measurement Sample," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 617-622.

This paper outlines the Integrated Coverage Measurement (ICM) missing data procedures that will be used for the Census 2000 Dress Rehearsal. A noninterview adjustment procedure is used to account for whole-household nonresponse. A characteristic imputation procedure is used to assign values for specific missing demographic variables. Finally, persons with unresolved match, residence, or enumeration status have probabilities assigned.

[11] IKEDA, M.I, KEARNEY, A.T., and PETRONI, R.J. (1998). "Handling of Missing Data in the 1996 Integrated Coverage Measurement," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 623-628.

This paper gives an overview of the methods used to handle missing data in the 1996 Integrated Coverage Measurement (ICM). It also provides evaluation of the likely importance of any effect of the ICM missing data methods on the final results.

[12] ISAKI, C.T., IKEDA, J.H., and FULLER, W.A. (1998). "A Transparent File for a One-Number Census," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 641-646.

We first present a scenario of sampling and estimation and then introduce the proposed methodology for transparent file construction. We also present the results of the construction of a transparent file for two of the 1995 Test Census sites, Paterson, NJ and Oakland, CA. Finally we discuss future work.

Given a census operation that includes sampling and estimation, we define a *transparent* file as a census data file that is devoid of any evidence of sampling and estimation.

The 2000 U.S. Census plans include sampling and estimation procedures that can easily produce non-integer estimates. A transparent decennial census data file would:

i) have the appearance of an enumeration with unit weights to avoid non-integer estimates,
ii) be constructed by duplicating or eliminating housing units on the enumeration phase data file at the block level,
iii) contain a listing of housing units and persons with their short form data and block identification, and
iv) not assign housing units a street address in the block.

In the context of a "one-number census" , a transparent file would provide person and housing unit counts that are both arithmetically and definitionally consistent. Tabulations from such a file would be simple and there would be no need to qualify person versus housing unit counts.

[13] KIM, J., HUANG, E.T., and MARQUIS, K. (1998). "Evaluation of 1996 Community Census Administrative Records File," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 196-201

Population and housing censuses are part of the nation's information infrastructure. But conventional census collection processes are expensive and burdensome to citizens and are becoming increasingly difficult to implement. Technology advances encourage examining whether administrative records, already part of the federal government information system, could be used either to improve or substitute for the conventional processes.

This report evaluates a specially-built administrative records database for Chicago by comparing information in the database to the 1996 Census Test in Chicago. We compare counts and characteristics for households, people, addresses, blocks and entire test site. High match rates or agreement rates are desirable (see Buser, et al's (1998) for other test sites results). Results consist of tables and short, accompanying discussions. The results and discussion illustrate that administrative records procedures can provide information needed for a population census but many issues must be addressed and solved before the information is considered accurate and complete.

[14] MCGRATH, D. and SANDS, R. (1998). "Integrated Coverage Measurement Sample Design for Census 2000 Dress Rehearsal," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 581-586.

The sample design for the 1998 Census Dress Rehearsal (DR) is a stratified proportionate sample of block clusters. For geographic convenience and to satisfy cost constraints, we cluster ICM housing units into block clusters. ICM interviewers enumerate all persons in selected block clusters during the ICM survey.

Research has shown that not only does the Census undercount the total population, but that differential coverage by demographic groups also occurs. The probability of being enumerated in the census varies by race, ethnicity, tenure (owner/renter), and geographic area. For this reason, we stratified the ICM universe by these variables to ensure that each group was adequately represented in the sample. Sampling strata are further substratified by the housing unit size of the block cluster.

We selected the ICM sample in several stages. The first two stages were a systematic selection of block clusters within sampling strata and substrata. Next, small block clusters were subsampled to reduce field workloads. Finally, large block clusters were subsampled to reduce the homogeneity or the clustering of the sample.

[15] OWENS, K.L. (1998). "Administrative Records Research in the 1995 and 1996 Census Tests," *Proceedings of the Section on Government Statistics and Section on Social Statistics, American Statistical Association*, 191-196.

The 1995 Census Test and the 1996 Community Census provided the opportunity to evaluate administrative records in terms of their availability, quality, and potential for improving current census operations. The 1995 Census Test was conducted in Paterson, New Jersey; Oakland, California; and six parishes in northwestern Louisiana. The 1996 Community Census was conducted in Chicago, Illinois; Fort Hall Reservation, Idaho; and Pueblo of Acoma, New Mexico. The Administrative Records Research Staff at the Census Bureau compiled an administrative records database for the 1995 and 1996 Census Test sites. The database incorporated administrative record data from a variety of sources, including tribal, federal, state, and local governments. Each database was used in research that evaluated the quality and potential uses of administrative records. These evaluations will aid in developing the basis for future use of administrative records for statistical purposes at the Census Bureau. This document will summarize the methodologies and results of the administrative record evaluations during the 1995 and 1996 Census Tests.

[16] REITER, J.P. (1998). "Estimation in Multiple Groups in the Presence of External Constraints that Prohibit Explicit Data Pooling," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 599-604.

If the Census Bureau uses sampling for integrated coverage measurement (ICM), it will need to estimate population size adjustment factors at state and sub-state levels. In many demographic groups and geographic locales, sample sizes will not be large enough to provide direct estimates with tolerable variances. In such small area problems, statisticians can improve estimation accuracy by smoothing the direct estimates across areas. For example, the adjustment factors can be smoothed with a hierarchical regression model that pools data across states.

Experience from Census 1990 suggests that the Census Bureau's clients view models that pool data across states with suspicion. Thus, to avoid controversy in Census 2000, the Census Bureau has expressed the desire to avoid explicitly pooling data across states [1, 2]. Nonetheless, there may be across-state information that, if somehow tapped, could improve the accuracy of the within-state estimates. This paper presents several ways of teasing out this across-state information without estimating adjustment factors by explicit data pooling.

[17] SAILER, P. and WEBER, M. (1998). "The IRS Population Count: An Update," *Proceedings of the Section on Government Statistics and Section on Social Statistics, American Statistical Association*, 186-190.

In a paper presented at the 1993 Annual Meetings of the American Statistical Association, the authors presented the results of their first attempt to use administrative records available at the Internal Revenue Service (IRS) to count the population of the United States (see Sailer, Weber, and Yau, 1993). In that paper, they noted that a major problem in this use of IRS administrative records was the presence in their files of information documents for deceased individuals. This was because several years could pass between the death of an individual and the closing out of all accounts listed in his or her name. In addition, they had some reason to be nervous about the accuracy of their gender coding, since it was based entirely on the interpretation of each individual s first name by some computer software they had developed. Poor reporting of social security numbers of dependents was a further obstacle to getting a correct count.

As will be discussed in the paper, a number of these problems have been dealt with over the last five years, and it appeared to be an opportune time to research whether their processing changes had improved their ability to use IRS records for the purpose of counting the population. This paper covers the results of that research.

[18] SANDS, R. and MCGRATH, D. (1998). "Causes and Possible Remedies for Sampling Weight Variation in the Census 2000 Integrated Coverage Measurement Survey," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 587-592.

The Census 2000 Integrated Coverage Measurement (ICM) Survey will be used to provide census totals designed to correct the undercount, especially a differential undercount among racial, ethnic, and socioeconomic groups, that has been observed in every decennial census since 1940. The ICM survey will be designed to produce direct estimates of total population for each of the fifty states and will have a sample size of 750,000 housing units. This paper presents results of research on the causes and proposed remedies for sampling weight variation in the Census 2000 ICM.

[19] SCHINDLER, E. (1998). "Allocation of the ICM Sample to the States for Census 2000," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 593-598.

The introduction of Integrated Coverage Measurement (ICM) for Census 2000 requires 51 state estimates based only on data from each state. The goal is to allocate the available sample of 750,000 housing units so as to achieve coefficients of variation for the dual system estimates of 0.5% in all states and standard errors of about 60,000 in the larger states. Data from the 1990 Post-Enumeration Survey are restratified and dual system estimates with Jackknife variances are calculated. The need for good data quality in both the initial phase and the ICM phase and the effect on Congressional reapportionment are also discussed.

[20] SLUD, E.V. (1998). "Predictive Models for Decennial Census Household Response," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 272-277.

Data-preparation and fitting for a comprehensive model of statewise household response to the 1990 Census is described, using a methodology of successive logistic regressions for longitudinally defined response variables, including indicators of response by mail, and enumerator check-in within quantile intervals of enumerator operational time for the ARA containing the household. The explanatory variables consist of geographic and housing-type data aggregated over census block-groups. Results of the data analysis are given for Delaware and North Carolina. Models are validated by refitting models including random effects, and by applying models with variables selected from DE to data for NC. Indicators of response by mail show a much stronger relationship than the check-in-time responses with the explanatory variables, and the indicator of late check-in-times (between the 75th and 90th percentiles) appear slightly more predictable than the earlier check-in-time indicators.

[21] STEEL, P. and ZAYATZ, L. (1998). "Disclosure Limitation for the 2000 Census of Population and Housing," *Proceedings of the Section on Government Statistics and Section on Social Statistics, American Statistical Association,* 66-69.

The Bureau of the Census is required by law (Title 13 of the U.S. Code) to protect the confidentiality of the respondents to our surveys and censuses. At the same time, we want to maximize the amount of useful statistical information that we provide to all types of data users. We have to find a balance between these two objectives. The authors are investigating techniques that will be used for disclosure limitation (confidentiality protection) for all data products stemming from the 2000 Census of Population and Housing.

This paper describes *preliminary* proposals for disclosure limitation techniques. They briefly describe the procedures that were used for the 1990 Census. They describe why some changes in those techniques may be called for. They give our initial proposals for procedures for the 2000 Census, including procedures for the 100% census tabular data, the sample tabular data, and the microdata. They also briefly describe methods of testing the resulting data in terms of retaining the statistical qualities of the data and giving adequate protection.

[22] THIBAUDEAU, Y. (1998). "Model Explicit Item Imputation for Census 2000," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 674-679.

We have invested a good deal of research effort to develop a model-based imputation methodology that provides a practical alternative to the nearest neighbor hot-deck methodology developed for the 1990 Census. We have made good progress, and we have set a benchmark for our item imputation procedure using the 1990 Census data for the district office (DO) of Sacramento for purpose of evaluation. We chose this particular DO since it is one of the sites where we are currently conducting our census dress rehearsal and we look forward to validating our benchmark with dress rehearsal data.

Throughout this short summary, the author reviews the specific imputation contingencies for the item imputation in 1990 for the Sacramento DO and recalls the base principles of the 1990 imputation methodology. Then he points out a systematic inconsistency in the imputation of the Hispanic origin item, and he explains how and why the 1990 methodology produced this inconsistency. Finally he introduces a model-based imputation procedure, and he shows how it can finesse around this pitfall. These results make up the first benchmark for our methodology.

[23] THOMPSON, J.H. and FAY, R.E. (1998). "Census 2000: The Statistical Issues," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 101-110.

Recently, Acting Director Holmes (1998) summarized the Census Bureau's overall situation and plans to the Monitoring Board, an eight-member board composed of four Presidential and four Congressional appointees. In this paper, we plan to address the same question used by Holmes to frame many of his remarks, " How did we get here?" We will summarize important milestones and evidence shaping the Census Bureau's plans. We will indicate the remaining questions that we expect to address with our Dress Rehearsal data both by Fall, 1998 and February, 1999.

[24] WAITE, P.J. and HOGAN, H. (1998). "Statistical Methodologies for Census 2000," *Proceedings of the Section on Government Statistics and Section on Social Statistics, American Statistical Association*, 40-55.

The objective of Census 2000 is to accurately measure the population in each state and substate area. We will begin with an effort to contact and enumerate every resident in the United States.

The initial census phase will include:

- multiple mail contacts
- a toll-free telephone number
- blank forms at many convenient locations
- a strong advertising and community-based publicity program.

We will accompany the multiple response options with record linkage software and possible follow-up to identify duplicates and detect incorrect responses.

Historically, we have used statistical sampling to collect detailed socioeconomic data. We will continue this and will add sampling for nonresponse follow-up and for integrated coverage measurement. This paper provides some details of the planned use of statistical methodologies.

[25] WILLIAMS, T.R. (1998). "Imputing Person Age for the 2000 Census Short Form: A Model-Based Approach," *Proceedings of the Section on Survey Research Methods, American Statistical Association,* 680-685.

The purpose of this paper is to show possible improvements that can be observed when using a model-based approach for imputing missing person age for the 2000 Census short form. This paper will concentrate solely on the missing person age portion of the household and person item imputation system we are testing at the Census Bureau (Thibaudeau, et al., 1997). Using 1990 Census data, the author will compare the imputations derived by using our modeling methodology to those created using the 1990 Census methodology. In the comparison, he will show that our method helps preserve some of the multi-variable characteristics found in the data. He will also demonstrate the ability to estimate variances associated with the imputed ages which is not currently available with the 1990 Census methodology.

[26] WRIGHT, T. (1998). "Sampling and Census 2000: The Concepts," *American Scientist, Vol. 86,* 245-253.

In this article, the author attempts to explain the concepts embodied in the Census Bureau's proposal to use sampling methods, combined with careful counting, to improve the accuracy of the decennial census. It should be understood that the Census 2000 plan has yet to be endorsed by Congress and, indeed, is meeting considerable opposition there. This article is intended to facilitate conversations about key statistical ingredients that will appear as part of the final plan, but it does not present the plan itself.

1999

[1] BEAGHEN, M, (1999). "Modeling Census and Integrated Coverage Measurement Phase Misses in the Census 2000 Dress Rehearsal," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 715-718.

The purpose of this paper is to use logistic regression models to relate these P-Sample misses and E-Sample misses to demographic characteristics and housing unit characteristics. The

limitation of univariate descriptive statistics is that they do not address the question of the relationship of one variable in the context of other variables. A regression type model avoids this limitation. Since the response is binary, that is, a person is either captured or missed, logistic regression is an obvious method. This study is observational rather than experimental. The characteristics used as regressors in the model are not controlled by the researcher but rather are random variables. Consequently the modeling is not predictive but descriptive and the hypothesis tests used to determine which variables to include in the model are not strictly correct. They are to be understood as guidelines in model building.

[2] BEAN, S.L., BENCH, K.M., DAVIS, M.C., HILL, J.M., KREJSA, E.A., and RAGLIN, D.A. (1999). "Error Profile for the Census 2000 Dress Rehearsal," *1999 Proceedings of the Section on Survey Research Methods, American Statistical Association*, 629-634.

The error profile examines specific sources of error corresponding to the Census 2000 Dress Rehearsal Integrated Coverage Measurement/Post-Enumeration Survey (ICM/PES) that are feasible to measure given the design of the ICM/PES. A sample of ICM/PES block clusters in each site was selected (187 total block clusters across three sites) to assess the magnitude of nonsampling error. This is known as the evaluation cluster sample. The errors with regard to the 'one-number census' in Sacramento, CA, and Menominee, WI, may occur in the initial dress rehearsal enumeration operation (i.e., initial phase), the ICM enumeration (i.e., final phase), or both. Similarly, the errors measured within the South Carolina site may be found in both the census enumeration and the PES activities. In all three sites, the objectives of the error profile is to measure error in the ICM/PES process. The individual sources of error that are isolated and examined separately in this report are data collection (in both the E-sample and the P-sample) and instrument error, certain errors in the processing of data (the focus here is errors from the ICM/PES clerical matching operation), and the effects of alternative data collection modes. These survey measurement and processing errors are evaluated using the following three tools: Matching Error Study, Evaluation Followup Interview, and the Data Collection Mode Study. Although production and evaluation operational problems made it impossible to conduct any of these studies as originally intended, the error profile evaluation yielded some interesting results.

[3] BELIN, T.R., SCHENKER, N., and ZASLAVSKY, A.M. (1999). "Downweighting Influential Clusters in Surveys, with Application to the 1990 Post-Enumeration Survey," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 73-82.

Certain clusters may be extremely influential on survey estimates from clustered samples and consequently contribute disproportionately to their variance. The authors propose a general approach to downweighting clusters using a robust estimation strategy based on M-estimation, using *t*-based weight functions. The method is motivated by a problem in census coverage estimation. On this context, both extreme weights and large errors can lead to extreme influence, and influence can be estimated by Taylor linearization. As predicted by theory, the robust procedure greatly reduces the variance of estimated coverage rates, more so than truncation of weights. On the other hand, the procedure may introduce bias into survey estimates when the distributions of the influence statistics are asymmetric. They demonstrate techniques for assessing the bias-variance tradeoff and consider the properties of the estimators in the presence of asymmetry. They also suggest design improvements to reduce the impact of influential clusters.

[4] ELLIOTT, M.R. and LITTLE, R.J.A. (1999). "On Combining Information from a Census, A Coverage Measurement Survey, and Demographic Analysis," *Proceedings of the Section on Government Statistics and Section on Social Statistics, American Statistical Association*, 199-204.

There is considerable interest in methods that combine information from the Census, coverage measurement surveys and demographic information to improve Census estimates of the population. A key difficulty is that methods for combining information require modeling assumptions that are difficult to assess based on fit to the data. We propose some general principles for aiding the choice among alternative models. We then pick a particular model based on these principles, and embed it within a more comprehensive Bayesian model for counts in poststrata of the population. The model is applied to data for African-Americans aged 30-49 from the 1990 Census, and results compared with those from existing methods.

[5] FAROOQUE, G.M. and CHEN, I.I. (1999). "Selecting Variables for Post-stratification and Raking," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 513-518.

This article applies logistic regression models to the 1990 Post-Enumeration Survey (PES) data for California and determines the important variables to form alternative post-stratification and raking matrices. The person level indicator variable for capture in the census is used as the dependent variable. This paper finds that age/sex, race/Hispanic origin, tenure, household composition, and urbanicity variables are the most important variables for forming alternative post-stratifications and raking matrices. The first order interaction terms of significant independent variables are found insignificant when they are input to the logistic regression models with their main effects.

[6] FAY, R.E. (1999). "Theory and Application of Nearest Neighbor Imputation in Census 2000," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 112-121.

The paper focuses on the nearest neighbor imputation as an estimation procedure for Sampling for Nonresponse Follow-up (NRFU) in the Census 2000 Dress Rehearsal in Sacramento and on an associated variance estimator. Thus, the paper concerns methodological aspects of an application obviated by the Supreme Court's ruling. Nonetheless, this paper, and one in preparation (Fay and Farber 1999), will focus on methodological findings from the Dress Rehearsal effort.

[7] FELDPAUSCH, R. and CHILDERS, D.R. (1999). "Erroneously Enumerated People in the Census 2000 Dress Rehearsal," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 731-736.

The number of erroneous enumerations is one of the inputs into the dual system estimator, which is a factor used to determine the final census count (Schindler, 1999). In this paper, we look at various factors which may be related to a person's probability of being erroneously enumerated.

[8] HEFTER, S.P., FAIRCHILD, L.D., and GBUR, P.M. (1999). "Missing Data in the U.S. Census 2000 Dress Rehearsal - An Overview," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 462-467.

The U.S. Census Bureau conducted the Census 2000 Dress Rehearsal (DR) in 1998 in Sacramento, CA; Menominee, WI; and Columbia, SC and surrounding counties. In the Columbia site we used components of a traditional census methodology which included a post-enumeration survey (PES). The DR PES was similar in design to the Integrated Coverage Measurement (ICM) Survey used in the Sacramento and Menominee Sites where a sampling census methodology was employed. As with any census operations or survey, missing data was encountered throughout the process. This paper gives a brief overview of census operations including the initial phase, the ICM/PES, and the estimation methodology and the levels of missing data encountered.

[9] JONES, J. and CHILDERS, D.R. (1999). "Person Duplication in the Census 2000 Dress Rehearsal," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 719-724.

Census 2000 procedures were rehearsed in three sites during 1998: Sacramento, California; the Menominee Indian Reservation in Wisconsin; and the Columbia, South Carolina area. In each location, after the Census was taken, an independent enumeration of sampled block clusters was performed for the purpose of census coverage measurement. During the Dress Rehearsal, this process was called Integrated Coverage Measurement (ICM). The people and housing units contained in this independent enumeration is known as the P-sample. People and housing units from the census that are counted in the sampled block clusters are called the E-sample. Both the P-sample and the E-sample contain within sample person and housing unit duplication. This duplication is examined with emphasis on E-sample person duplication.

[10] KEARNEY, A. and IKEDA, M. (1999). "Handling of Missing Data in the Census 2000 Dress Rehearsal Integrated Coverage Measurement Sample," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 468-473.

This paper outlines procedures used to handle missing data in the Census 2000 Dress Rehearsal Integrated Coverage Measurement (ICM) sample. It also provides a summary of the results of missing data processing.

[11] KING, B. (1999). "The Panel on Future Census Methods," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 11-15, (Discussion by B. Bailar and D. Ylvisaker, 16-18.)

The new *Panel on Future Census Methods* that I am going to discuss today is called the 2010 Panel. Our 2010 Panel held its initial and only meeting thus far on June 7-8 of this year, and it is expected to continue its activities until the spring of 2003. Phase I, picking up where the *Panel on Alternative Census Methodologies* left off, involves a review of the plans for experiments and other methodological studies to be built into the 2000 Census and recommendations for fine tuning if called for. In addition, plans for collecting and retaining data to be used in the design of the 2010 Census must be reviewed. The second phase was envisioned as running from April 1999 until March 2001 when the final results for reapportionment and redistricting will be available. Our panel will be eager to observe the outcomes of the tracking system and the experiments in the 2000 Census and to digest the findings of our sister panel in that regard. To the extent possible, we shall make recommendations concerning the best methods of analyzing the data produced by those systems in order to maximize the value of that research for the planning of the 2010 Census. Finally, in Phase III, extending from March 2001 until the end of our tenure in 2003, we shall shift into high gear and synthesize our observations and those of the 2000 Panel, producing a formal judgment concerning the overall accuracy of the 2000 Census, evaluating the results of the built-in research studies, and reporting on their implications for 2010.

[12] KOHN, F. and GRIFFIN, R. (1999). "Service Based Enumeration Estimation," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 519-522.

The Census Bureau established the Service Based Enumeration (SBE) program as the statistical program designed to include persons without usual residence that use service facilities (shelter, soup kitchen or mobile food vans). Those persons are not covered by regular Census Bureau procedures for households or persons in group quarters. The proposed methodology for the SBE estimation for the 2000 Census is the Multiplicity estimator that is based on the number of times the respondent uses the service facilities. In this paper, the authors present several multiplicity estimators based on the usage question for service facilities.

[13] MULE, Jr. V,T. (1999). "Accounting for Changes from the 1990 Post-Enumeration Survey Methodology in the 2000 Accuracy and Coverage Evaluation Sample Design," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 507-512.

The Accuracy and Coverage Evaluation (A.C.E.) Survey will have a different methodology than the 1990 Post-Enumeration Survey (PES). This research was done prior to the Supreme Court ruling when the Integrated Coverage Measurement (ICM) survey was being designed. Since the A.C.E. sample will be a subsample of the ICM design, studying differences between the ICM and PES will address differences between the ICM and the PES and provide information for the A.C.E. survey design. Previous ICM sample design research used data from the PES while not considering these differences. This research focused on accounting for the changes in methodology when simulating coefficients of variation. The sample design and operational differences between the ICM and the PES were the primary changes investigated. While some differences could be accounted, other 1990 conditions are identified that could not. While this design will not be used in 2000, this research investigated how different variance estimations might have affected the simulated reliability. The effect of this design on minority and non-minority estimates is also discussed.

[14] NASH, F.F., MOYER, L.H., and STACKHOUSE, H.F. (1999). "Census 2000: Developing a Traditional Census Plan," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 158-162.

In the spring of 1998, the United States Census Bureau embarked upon an intensive planning process to develop an alternative approach to conducting Census 2000 without the use of statistical sampling. This plan was publicly released in January 1999. Later that month, the US Supreme Court held that the Census Bureau could not use statistical sampling for reapportionment purposes, but left open the issue of using statistical sampling techniques for other purposes, such as state redistricting, allocation of federal funds and the Bureau's intercensal population estimates program. In response to that decision, the Census Bureau modified the plan for taking the census by using a more traditional approach, and it is now implementing that modified plan. This paper first describes the planning process and then discusses the current plan for conducting a traditional census.

[15] RAGLIN, D.A. and BEAN, S.L. (1999). "Outmover Tracing for the Census 2000 Dress Rehearsal," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 456-461.

This evaluation provided information to help us determine if outmover tracing needs to be done as part of the Accuracy and Coverage Evaluation (A.C.E.) in Census 2000. Based on the results described here, the decision was made not to conduct outmover tracing in Census 2000. To aid in that determination, this evaluation answered the following questions: a) How many cases did we try to trace and what were the results? b) For households where a traced interview was obtained, how do the proxy and traced data compare? c) What is the person match rate to the census for the proxy data compared to the traced data? d) How are the estimates affected by replacing the outmovers provided by the proxies with the people provided by tracing outmovers?

[16] RUST, K. (1999). "The Activities and Findings of the Panel on Alternative Census Methodologies," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 1-10. (Discussion by B. Bailar and D. Ylvisaker, 16-18.)

In April 1995 the Bureau of the Census asked the National Research Council's Committee on National Statistics (CNSTAT) to form a study panel to review plans and research and make recommendations regarding the design of the 2000 Census. The panel's charge was to review the Census Bureau's plans for the 2000 Census, and to make recommendations regarding the census design. Specifically, we were asked to review the results of the 1995 and 1996 Census Tests, particularly with respect to the sample design for the nonresponse follow-up and the planned integrated coverage measurement sample design, to evaluate the statistical estimation procedures for the 2000 Census, to recommend additional field tests and research to carry out before finalizing plans for the 2000 census, and to review the potential use of administrative records in the 2000 census. The panel last met in June 1998, and released its final report in February 1999, following two interim reports and a letter report. The report is titled *Measuring a Changing Nation: Modern Methods for the 2000 Census*, and is available from National Academy Press (www.nap.edu; 800-624-6242). In this paper, the author will discuss the scope of the panel's work, and its findings and recommendations, particularly those included in the final report.

[17] SCHINDLER, E. (1999). "Iterative Proportional Fitting in the Census 2000 Dress Rehearsal," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 450-455.

Iterative proportional fitting, or raking, was employed in addition to the dual system estimation methodology to measure the undercoverage for the Census 2000 Dress Rehearsal conducted during 1998 in three sites. The raking procedure was used to adjust the initial phase estimates for poststrata defined by race/origin/age/sex/tenure to two sets of marginals defined by race/origin/age/sex and tenure estimated by taking the sums of direct dual system estimates for the same poststrata. This procedure was designed specifically to improve reliability and preserve the race/origin/age/sex cells required for congressional and state redistricting and to induce approximately the same coverage differences between owners and renters for each demographic group. This paper discusses the results of the procedure and several alternative raking matrices with a view towards Census 2000.

[18] SHORES, R., CANTWELL, P.J., and KOHN, F. (1999). "Variance Estimation for the Multiplicity Estimator in The Service Based Enumeration Program," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 523-528.

Service Based Enumeration (SBE) is the statistical program that the Census Bureau uses to estimate the population of persons without usual residence who use services. The methodology selected to measure this population is a multiplicity estimate of the number of times they use service facilities. This paper first presents the justification of the estimator and a derivation of its variance. The estimator of this variance then follows in a straightforward fashion. We examine the behavior of the multiplicity estimator and its variance. An important specific case is the one in which usage is assumed to follow a Bernoulli distribution. Results are presented that show what happens to the variance when the probability parameter for the Bernoulli distribution is varied.

[19] SINGH, R.P., CANTWELL, P.J., and KOSTANICH, D.L. (1999). "Census 2000 Dress Rehearsal Methodology and Initial Results," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 444-449.

In 1998 the Census Bureau conducted a dress rehearsal in three sites. According to an agreement between the Congress and the Department of Commerce, we applied the planned sampling techniques in two of the sites–Sacramento, California, and Menominee County, Wisconsin. In the third site, the city of Columbia, South Carolina and eleven surrounding counties, sampling procedures were not used. However, a post-enumeration survey was conducted there to measure the net undercount. This paper discusses the methodology used in the Dress Rehearsal and presents a brief summary of selected results in the three dress rehearsal sites.

[20] STARSINIC, M.D. and TOWN, M.K. (1999). "Analysis of Generalized Variance Estimation for the Census 2000 Dress Rehearsal," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 474-479.

It is the policy of the U.S. Census Bureau to provide measures of how reliable its published estimates are. Due to the very large number of published estimates for Census 2000, it is not feasible to report a standard error for each estimate. Instead, it was decided to compute generalized variance parameters for a set of general characteristics for data product users to compute an estimate of the variance for any desired estimate at any desired geographic level. Computing a generalized variance model also eases the problem of instability associated with estimating standard errors for very small populations, such as the census's redistricting (Public Law 94-171) data released at the block and tract level, crosstabulated by race, Hispanic origin, and age. A method of computing the generalized variances using a weighted least-squares regression (Wolter 1985) was implemented in the 1995 Census Test (Krenzke and Navarro 1996). Basing our efforts on that work, the model was used again to calculate the generalized variances for the Census 2000 Dress Rehearsal, and it is planned to be the method used in production for Census 2000. This paper analyzes the results of the modeling from the Census 2000 Dress Rehearsal. Section two and three give brief overviews of the sampling, estimation, and direct variance estimation processes, and results of the variance generalization are found in section four.

[21] WOLFGANG, G. and CHILDERS, D. (1999). "Integrated Coverage Measurement Persons Not Matched in the Census 2000 Dress Rehearsal," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 725-730.

The focus of this paper is on P-sample nonmatches, persons who were not found to be enumerated in the Census 2000 Dress Rehearsal. The aim is to identify characteristics that may be related to their being missed in census enumeration. The statistic used in this study is the nonmatch rate, the proportion of nonmatches among P-sample persons, computed within age, race, and other descriptive categories. The nonmatch rate is well related to (but less refined and more inflated than) the dual system adjustment factor used in census coverage evaluation. Errors and incomplete data estimated from the E-sample, as well as matches that may exist among census enumerations beyond areas searched, are refinements taken into account by dual system estimates but not nonmatch rates. Nonmatch rates are worthy of study independent of the effects of false or ambiguous enumerations, which are investigated by Feldpausch and Childers (1999) and by Jones and Childers (1999). Beaghen (1999) modeled both E-sample and P-sample data to gain insight into misses.

[22] WRIGHT, T. (1999). "A One-Number Census: Some Related History, " *Science, Vol. 283,* 491-492.

The U.S. Census Bureau plans to produce one best set of official counts of the population of the United States in the year 2000—a one-number census—by integrating the results of conventional counting techniques with results from probability sampling techniques. The plan will help lead to a result that includes more of the overall population, especially for certain subpopulations, and it will help control costs. It is instructive to reflect briefly on the need for and origins of the one-number census concept in this article.

[23] WRIGHT, T. and HOGAN, H. (1999). "Census 2000: Evolution of the Revised Plan," *Chance, Vol. 12, No. 4,* 11-19.

In planning for Census 2000, the Census Bureau sought to improve upon the 1990 Census in several ways. It sought to control the rising costs of census taking by using modern survey methods and questionnaire design to increase the mailback of census questionnaires. It also planned to follow up only a sample of the households that had not returned their questionnaires by mail, and use probability sampling to account for the remainder. It sought to improve accuracy for the smallest areas (towns, neighborhoods, blocks) by working with the post office and local officials to build a complete address list and to assign units to correct locations. It also planned to overcome a historic pattern of undercount by using a quality-check sample. In this article, we discuss how the Census Bureau's plans evolved through a series of field tests, court cases, and legislative agreements into the current design.

[24] ZUWALLACK, R., SALGANIK, M., and MULE, Jr., V.J. (1999). "Sample Design for the Census 2000 Accuracy and Coverage Evaluation," *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 501-506.

In the tradition of improving census evaluations, the Census Bureau is conducting the Accuracy and Coverage Evaluation (A.C.E.) following the Census 2000 enumeration. This paper discusses all phases of the A.C.E. sample design, how the design was effected by the recent Supreme Court decision on sampling for the census, and changes made to the design based on a evaluation of the Census 2000 Dress Rehearsal design.

[1] ELLIOTT, M.R. and LITTLE, R.J.A. (2000). "A Bayesian Approach to Combining Information from a Census, a Coverage Measurement Survey, and Demographic Analysis," *Journal of the American Statistical Association, Vol. 95, No. 450,* 351-362.

Demographic analysis of data on births, deaths, and migration and coverage measurement surveys that use capture-recapture methods have both been used to assess U.S. Census counts. These approaches have established that unadjusted census counts are seriously flawed for groups such as young and middle-aged African-American men. There is considerable interest in methods that combine information from the census, coverage measurement surveys, and demographic information to improve census estimates of the population. This article describes a number of models that have been proposed to accomplish this synthesis when the demographic information is in the form of sex ratios stratified by age and race. A key difficulty is that methods for combining information require modeling assumptions that are difficult to assess based on fit to the data. We propose some general principles for aiding the choice among alternative models. We then pick a particular model based on these principles and imbed it within a more comprehensive Bayesian model for counts in poststrata of the population. Our Bayesian approach provides a principled solution to the existence of negative estimated counts in some subpopulations; provides for smoothing of estimates across poststrata, reducing the problem of isolated outlying adjustments; allows a test of whether negative cell counts are due to sampling variability or more egregious problems such as bias in Census or coverage measurement survey counts; and can be easily extended to provide estimates of precision that incorporate uncertainty in the estimates from demographic analysis and other sources. The model is applied to data for African-Americans ages 30-49 from the 1990 Census, and results are compared with those from existing methods.

[2] POLLOCK, K.H. (2000). "Capture-Recapture Models," *Journal of the American Statistical Association, Vol. 95, No. 449,* 293-296.

Here, I briefly review capture-recapture models as they apply to estimation of demographic parameters (e.g., population size, survival, recruitment, emigration, and immigration) for wild animal populations. These models are now also widely used in a variety of other applications, such as the census undercount, incidence of disease, criminality, homelessness, and computer bugs (see Pollock 1991 for many references). Although they have their historical roots in the sixteenth century, capture-recapture models are basically a twentieth century phenomenon. These papers by Petersen and Lincoln (Seber 1982) from late last century and early this century represent early attempts by biologists to use capture-recapture methods. Later, as statistical inference took its modern form and provided powerful tools such as maximum likelihood methods, biometricians became involved. There has been an explosion of research that still seems to be accelerating at the century's end. Fortunately, most of the research is still rooted in the need to solve biological questions. Section 2 reviews closed models; Section 3, open models; and Section 4, combined models. I conclude the article with my views on fruitful current and future research thrusts and how the pace of change is affecting them.

[3] WRIGHT, T. (2000). "Census 2000: Who Says Counting is Easy as 1-2-3?," *Government Information Quarterly, Vol. 17, No. 2,* 121-136.

The Census Bureau's originally announced Census 2000 plan called for the use of probability sampling methods to supplement the conventional counting methods of attempts at direct contact with every household in producing the population count. Just how sampling might improve results from counting alone seems to remain unclear to many. The first part of this article shares the lessons learned in a 1997 experience with eleven youth concerning the benefits of using sampling methods to improve counting results. The second part of the paper draws on a publication and gives details of the role of sampling in the Census Bureau's current Census 2000 plan for producing the population count for purposes other than apportionment of the U.S. House of Representatives.