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Imputation, Apportionment, and Statistical Methods in the U.S. Census: Issues Surrounding Utah v. Evans

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ABSTRACT: As in all recent censuses, the U.S. Census Bureau used statistical methods in the 2000 Census to account for missing or contradictory information concerning the number of people living in some identified housing units. These statistically corrected counts were used for Congressional apportionment and redistricting. In 2002, the Supreme Court ruled that this limited use of statistics was both lawful and constitutional. This paper provides a context for that decision, by tracing the evolution of statistical methods in the U.S. census, and the accompanying litigation. It then summarizes the statistical and legal arguments and issues raised in Utah v. Evans.

Much of the material in this report can be found in Cantwell, Hogan, and Styles (2004), "The Use of Statistical Methods in the U.S. Census: Utah v. Evans," *The American Statistician*, August 2004, Vol. 58, No. 3, 203-212. This report provides a more extensive description of many of the statistical procedures applied in the 2000 Census.

KEY WORDS: Count imputation; probability sampling; legal issues; census coverage.

1. INTRODUCTION

Census taking is both a civic ceremony and a scientific undertaking. Statistical science is used throughout the process to provide the most accurate measures of the population possible under the law and within the constraints of time, financial resources, and respondent burden. The use of statistical methods has grown steadily during the past seven censuses. While there may be limits to the role statistics can play in our civic ceremony, the available evidence indicates that the accuracy of census data has improved greatly. This increase in accuracy can be attributed both to increased Congressional support and funding, and to the power of statistical science.

The decennial census has never been a simple physical head count of inhabitants, but rather has routinely employed techniques designed to obtain and use reliable information from a variety of sources. From the very first census, enumerators have relied on information provided by a member of the household, rather than on the enumerator's direct observation. All decennial censuses have relied on responses from heads of households and other knowledgeable sources. When a member of the household could not be found, census takers have historically relied on information from proxy respondents, such as neighbors, landlords, or postal workers. Enumeration by proxy was first formally authorized for the 1880 Census. For more on the early history of the U.S. census, see Anderson (1988; 2000, pp. 55-57, 115-133).

Population counts from the census are used to determine the number of Congressional representatives allotted to each state (apportionment) and to set boundaries for Congressional districts within states (redistricting). As the census is the basis for dividing political power among the 50 states, census procedures, including statistical methods, have been challenged in the courts in recent years. After the 1980 Census, the State of Indiana sued to overturn the use of imputation that moved a seat in the U.S. House of Representatives to Florida (Orr v. Baldrige 1985). Many other plaintiffs sued to require the use of statistical procedures to correct for the differential undercount of minorities. The courts upheld the Bureau's 1980 procedures in all these cases. Since 1980 more cases have addressed the use of statistical adjustment to account for differential coverage among various racial and demographic groups in the census. Leading up to the 2000 Census, the Census Bureau proposed a plan to sample nonresponding households to reduce cost, and to measure and potentially adjust for any net undercount. This sampling plan was rejected by the Supreme Court in 1999, Dept. of Commerce v. U.S. House of Representatives (1999), as a means of obtaining the apportionment counts.

With sampling for nonresponse and adjustment prohibited for apportionment, the main legal and policy issue in the 2000 Census was expected to be whether adjusted census numbers should be used for nonapportionment purposes, such as state and local redistricting and the distribution of federal funds. Instead, while the adjustment issue was litigated extensively, the most significant lawsuit concerning the 2000 Census was brought by the State of Utah challenging the use of imputation in preparing the apportionment counts. Utah claimed that the imputation was prohibited by both the Census Act and the Constitution. The Census Act, 13 U.S.C., §1 *et seq.*, establishes the Census Bureau and sets forth the Bureau's authority to conduct its business. The Supreme Court ruled in a 2002 split decision that imputation was a permitted statistical method, Utah v. Evans (2002).

The decision in Utah v. Evans allowed the limited use of specific statistical procedures under certain circumstances in an attempt to improve census accuracy. One challenge in the years to come will be determining which statistical methods will be permitted, and which should be considered barred under the Census Act or the Constitution.

2. THE USE OF STATISTICAL METHODS IN THE CENSUS BEFORE 2000

2.1 Early Censuses

Even with the first census in 1790, the nation faced the issue of how to handle missing census information. In that year, census returns from South Carolina were incomplete and Congress began to consider apportionment without them. In 1850, the Superintendent of the Census, Joseph Kennedy, was faced with the issue of missing and incomplete data when census returns for several California counties were lost at sea. The official publication, *Abstract of the Seventh Census* (1852) makes clear that estimation was used to effect a more equitable apportionment: "Assuming the population of California to be 165,000, (which we do partly by estimate,) ..." (p. 129).

> the population of California is set down at 165,000, as an approximation to the real population, which may be essentially varied by complete returns. Should the returns vary from ou[r] estimate so far as to reduce the population of California 30,000, South Carolina will be entitled to a member additional, as being next above on the list of fractions. (p. 152)

Congress used an estimated California number for re-apportionment, choosing an estimate to account for missing information in an attempt to increase census accuracy (Anderson 1988, p. 46). The Bicentennial Edition *Historical Statistics of the United States*, however, shows the 1850 California population to be 93,000 (U.S. Census Bureau 1975, Series A 195-209, p. 25), ignoring Superintendent Kennedy's correction.

A different situation occurred in the 1920s. The 1920 Census was the first U.S. census to enumerate more people living in urban areas than in rural areas. Coincidentally or not, it is also the only census that might be called a failed census, insofar as it is the only one not used to reapportion Congress (Anderson 1988). As a consequence, the apportionment devised after the 1910 Census was used for 20 years, until after the completion of the 1930 Census. Although political considerations and a fight over the method of apportionment contributed toward the impasse, part of the Congressional discussion involved census accuracy. A major concern at the time was that Census Day had been set as January 1 rather than April 15 as in earlier censuses (or April 1, for those that followed). Congressmen from rural states alleged, with some justification, that census takers had difficulty canvassing rural areas during the winter months. In any case, discussions of census accuracy played a large role in the deliberations. See Eagles (1990).

2.2 Statistical Science Begins to Have a Formal Role

The period from 1940 through 1990 was one of marked change in the census, with statistical methods increasingly used in an attempt to improve quality while reducing cost and respondent burden. The 1940 Census initiated the use of sampling to simplify and reduce the cost of collecting data on personal characteristics, while maintaining accuracy. In 1940 and 1950, additional detailed questions were asked of a sample of individuals within a household. By 1960, a separate household "long form" was used to collect more detailed information from the households selected in the sample.

Except for the introduction of sampling for person characteristics, the essential nature of census field operations remained similar from 1830 through 1950. Interviewers went door to door, listing housing units and interviewing residents. The 1960 Census marked a genuine turning point, with the switch to self-enumeration. For the first time the Census Bureau mailed questionnaires to respondents, who were asked to fill them out and hold them for pick-up. This was also the first census in which the count was tabulated by computers rather than by hand.

The 1970 Census was the first in which the Census Bureau used the mail-out/mail-back procedure; the Bureau mailed out questionnaires, which were then completed and mailed back by respondents. From 1970 forward, this procedure has accounted for the largest share of the enumeration. To enable the mail-out, the Census Bureau developed a mailing list prior to Census Day; previously, enumerators had created a list of housing units as part of the interviewing process. With this address list, the Bureau could check and verify addresses prior to Census Day.

In the 1970 Census, two unusual situations prompted the Census Bureau to apply imputation techniques in conjunction with sampling to add persons to the apportionment count. Following the census, the Bureau conducted two operations to measure the number of people missed in different situations. The National Vacancy Check was designed to measure and decrease the error introduced by misclassified housing units. The goal was to estimate the difference between the number of people missed because the census interviewer had incorrectly classified their housing unit as vacant, and those erroneously included although their housing unit was, in fact, vacant on Census Day. A second operation, the Post-Enumeration Post-Office Check (PEPOC), looked for missed housing units in selected areas of 16 Southern states. These areas were selected because the Post Office had already been used to correct the address list in most of the rest of the country, but not in these states. In each operation, data were collected from a probability sample. When both studies found substantial numbers of people missed by the initial enumeration, statistical models were used to adjust the census before the numbers were reported for use in reapportionment.

The National Vacancy Check added 1,074,523 person records to the 1970 Census, constituting 0.53% of the total population count (U.S. Census Bureau 1971a). Because the operation was conducted across the nation, its differential effect on the states' population proportions was lessened. The additions by state ranged from 0.39% of the population in Minnesota and Ohio, to

1.07% in Maine. The PEPOC added 589,517 person records to the 1970 Census, 0.29% of the population. PEPOC's differential effect was greater, however, because it was used only in the 16 Southern states. The additions by state ranged from 0.32% (Maryland) to 1.65% (North Carolina) (U.S. Census Bureau 1971b). Between the two programs, North Carolina's population was adjusted upward by 123,575, or 2.4% of the total state population.

In both operations, the Census Bureau *first* used sampling techniques to estimate the number of households missed, and *then* applied imputation techniques to approximate the population count and the characteristics in those households. Neither the National Vacancy Check nor the PEPOC was repeated on a sample basis in subsequent censuses for determining the apportionment counts, though several varieties of imputation (without the use of sampling) have consistently been used.

2.3 Administrative Records

The Census Bureau has often gone beyond a simple head count by using administrative records as part of the enumeration process. In 1980, an initiative known as the Non-Household Sources Program made use of records from a variety of city, state, and Federal sources. With the goal of reducing the omission of urban minorities, the Bureau procured lists from state departments of motor vehicles and city public assistance files, as well as files from the U.S. Immigration and Naturalization Service. Records were first clerically matched to census reports for the housing unit to identify people who may have been missed. Local census enumerators conducted telephone or personal interviews at these addresses to ensure that the person lived there on census day. If the person was reported to have lived there, he or she was added to the census (U.S. Census Bureau 1984).

In the 1990 Census, administrative records played an important role in two programs again designed to reduce the omission of minorities. Both programs involved people on parole or probation (U.S. Census Bureau 1992a). In the first, corrections officers were asked to give a special census form to the parolee when he or she came into the parole office for a routine visit. The parolee was asked to fill out the form, which the corrections officer then returned to the Census Bureau. In the second program, known as the Parolee/Probationer Coverage Improvement Program Follow-Up, administrative lists of the states' departments of corrections were accepted. These lists had to contain names, addresses, and at least two demographic characteristics for each inmate. Addresses on the lists were then certified by the corrections departments as the parolees' or probationers' residences on Census Day, April 1, 1990. Direct contact with parolees and probationers was not required. In the two programs, if the parolee or probationer had not been counted at the address reported as his residence on April 1, he or she was added to the census. Unlike 1980, there was no follow-up at the reported residences.

Administrative records were used in the 1990 and 2000 Censuses to enumerate military and Federal employees living overseas, as well as their dependents. The overseas population was excluded from all tabulations except for Congressional apportionment. This practice was upheld by the Supreme Court, Franklin v. Massachusetts (1992). In 1990, the U.S. Department of

Defense originally planned to conduct an actual enumeration of its overseas personnel and their dependents. However, administrative records were used due to a lack of funds and other constraints (U.S. Census Bureau 1993, p. 5).

2.4 Considering Statistical Adjustment to Improve Coverage

After World War II, demographers and statisticians began to develop methods to estimate census coverage. These methods documented that the decennial census misses some individuals, thereby undercounting the population. This undercount was believed to be differential, with certain groups being undercounted at a higher rate than others. Price (1947) compared the 1940 Census counts for men aged 21 to 35 to totals from the First Selective Service Registration on October 16, 1940 and estimated that the census covered about 97% of this age/sex group. A similar examination restricted to Black men aged 21 to 35 yielded an estimate of only about 87% coverage by the census. By studying cohorts from the censuses of 1930, 1940, and 1950 by age, sex, and race, Coale (1955) drew similar conclusions concerning the differential coverage of the U.S. population by race. As the implications of these studies became known, they were followed by calls to apply methods to correct for the measured errors in the population count. An exposition of the issues surrounding census undercoverage and adjustment can be found in Anderson and Fienberg (1999).

In general, there are two types of coverage errors: omissions and erroneous inclusions. The difference between the two is net coverage error. People are sometimes counted in the wrong place. For example, suppose an individual is omitted where he or she actually lives, but erroneously included in a different county in the same state. That individual would be considered an omission in one county, an erroneous enumeration in the other county, but a correct enumeration for the state total. There would be coverage error at the county level, but not at the state level. The net undercount is defined as the difference between the true population and the tabulated census count.

Undercount can also arise from misclassification error. For example, if a person who was actually 66 years of age was enumerated as 64, the person would contribute to an undercount of the number of people aged 65 and above, and an overcount of people under 65. Again, if subtotals are summarized over age, the difference disappears.

Demographic analysis is one method to estimate the net undercount. By analyzing birth records, death records, information on immigration and emigration, and selected data from the current and past censuses, it is possible to construct an estimate of the true population. Demographic analysis has been done separately by age and sex, as well as by race (Black/non-Black). Although demographic analysis estimates were first made in conjunction with the 1950 Census, reliable demographic estimates first became widely available following the 1970 Census. These early estimates clearly implied a *differential* net undercount: the net undercount for Blacks was higher than that for non-Blacks.

Since 1950, the Census Bureau has often tried to measure census coverage by conducting a post-

enumeration survey. Following the 1980 Census, the results of the survey were not available until many months after the legal deadline for completing the census and were subject to a number of limitations. Nonetheless, the possibility of applying the survey results to adjust the 1980 Census spawned extensive litigation. The Census Bureau was sued in over 50 cases following the 1980 Census. The plaintiffs in some of these cases sought to use the results of demographic analysis to adjust the census results. Essentially, the plaintiffs requested that the census totals for all areas be adjusted upward for Blacks and non-Blacks proportionally to the measured net undercount for that group, using a technique known as synthetic estimation (Wolter 1986). The Census Bureau replied that estimates from demographic analysis were too inaccurate for this use, and that a synthetic estimate based on only two groups was too crude to be useful.

Although the Census Bureau's decision not to adjust the 1980 Census was upheld by the courts, the organization began an extensive review of its coverage measurement program to determine whether it was possible to adjust the 1990 Census. The goal was to produce a more accurate measure of the net undercount, and to produce it sooner. In 1987 the Department of Commerce directed the Census Bureau not to proceed with plans to produce adjusted census counts, prompting the filing of a lawsuit against the Department. An agreement prior to the 1990 Census required the Census Bureau to undertake a post-enumeration survey after the 1990 Census and announce by July 15, 1991 whether the results of that survey would be used to adjust the previously announced results. On July 15, 1991, the Secretary of Commerce announced that the 1990 Census would not be statistically adjusted (Department of Commerce 1991). This decision culminated in a 1996 Supreme Court decision upholding the Secretary's decision against adjustment (Wisconsin v. City of New York 1996).

3. THE 2000 CENSUS: THE PLAN AND WHAT ACTUALLY TOOK PLACE

3.1 Early Planning

In planning the 2000 Census, the Census Bureau faced a great challenge. The cost of conducting the census had increased steadily throughout the century. In constant 1990 dollars, the cost per household of the four censuses from 1960 to 1990 was estimated at $9, $11, $20, and $25, respectively (National Research Council 1995, p. 48). Despite this increase, a differential net undercount across races and other demographic groups persisted.

The Census Bureau considered many options, including a sample census and a census based on administrative records. The Bureau's initial plan involved the use of sampling to control costs and to improve accuracy by supplementing--but not replacing--initial comprehensive attempts to locate and enumerate every individual and housing unit. The plan would apply sampling in three programs: the follow-up of nonrespondents, a check on units designated by the U.S. Postal Service to be vacant, and a post-enumeration survey designed to measure and adjust for under- or overcoverage (to be known as the Integrated Coverage Measurement). The latter survey was designed to deliver statistically adjusted population numbers in time for use in reapportionment. In communicating its plans, the Census Bureau stated, "In 1994 the Department of Justice (DOJ)

reviewed the Census Bureau's preliminary plans to use sampling in Census 2000 and issued a written opinion confirming that the plan was neither illegal nor unconstitutional" (U.S. Census Bureau 1997, p. 54).

The Census Bureau proposed to sample nonresponding housing units to reduce the number of follow-up visits to get an interview. Specifically, the Census Bureau would mail questionnaires to all known residential addresses. Through advertising and outreach, it would encourage all households to mail back their questionnaire. However, rather than visiting all addresses that did not return a questionnaire by mail, the Census Bureau would follow up only a scientifically selected sample in each census tract--an area averaging about 1,700 housing units--and use statistical inference to account for the others. In a similar manner, instead of verifying that every housing unit reported to be vacant by the U.S. Postal Service was indeed vacant, only a sample of such units would be checked.

The Census Bureau saw two advantages to sampling for nonresponse. The first was financial: a large fraction of the roughly 42 million nonresponding housing units would not require personal visits, appreciably reducing costs for hiring and training field workers. Second, the Bureau hoped to improve the quality of the data collected. Statistical sampling introduces a controlled, measurable random variation. The smaller workload could provide better field control, thereby possibly reducing nonsampling errors--errors caused by sources other than sampling, such as misunderstanding a census question, placing a person at the wrong address, or transferring data from the form to electronic files incorrectly. Further, census field work could be completed earlier, closer to the census reference date, April 1. The hope was that, for small areas such as tracts, the added sampling error would be offset by reduced nonsampling errors. For larger areas, the plan could provide better data because the relative sampling error decreases as the size of the area increases, while the nonsampling errors do not increase (Hogan and Waite 1998).

The Integrated Coverage Measurement also created controversy. It involved interviewing a sample of about 750,000 housing units selected to include blocks from every area in the country, representing all races and ethnic groups. Dual-system estimation, a capture-recapture technique (Sekar and Deming 1949; Hogan and Wolter 1988), would be used to produce adjusted counts of people within larger demographic groups and geographic areas. Synthetic estimation would provide adjusted counts at lower geographic levels, such as census blocks.

Another facet of the original design for the 2000 Census was the Census Bureau's plan for counting people without a usual residence--a population that is difficult to enumerate as it includes many of those considered to be homeless--through an operation called the Service Based Enumeration (U.S. Census Bureau 2000a). Special procedures were planned at homeless shelters, soup kitchens, mobile food vans, and certain outdoor locations. Because the procedures could only account for people at these facilities on the day of enumeration, the Bureau planned to apply a technique called multiplicity estimation to account for people who sometimes use these facilities, but did not use them on the day of enumeration.

Respondents were asked how many times in the week leading up to the enumeration they had

used the facility. For example, a person who said he or she used the facility only two nights out of seven would be given a weighting factor of 7/2. The idea behind multiplicity estimation was that, under specified assumptions, such a person had only two chances in seven to be found at the facility on the date selected for enumeration. Conversely, a person who used a service all seven nights that week would be given a weighting factor of 7/7 or 1, as he or she would have been enumerated no matter what day had been selected for enumeration. By applying the appropriate weight, those who are found at the service facilities on the evening of enumeration are weighted upwards to account for people who sometimes use services, but did not on that day.

Serious problems afflicted the multiplicity estimator in 2000. The usage question suffered a high level of nonresponse, and worse, apparently a very high level of response error. The Census Bureau judged that the improved coverage obtained by applying multiplicity estimation was outweighed by the bias induced by inaccurate answers, as well as the added variance. Thus, a decision was made not to apply multiplicity estimation in the Service Based Enumeration (U.S. Census Bureau 2001a). The census count for this population thus included only those people enumerated (after removing duplicates) at these service locations on the one day.

In January 1999, the Supreme Court ruled that the Census Act precluded the use of sampling to arrive at the apportionment count, "[w]hether used as a 'supplement' or as a 'substitute,' " Dept. of Commerce v. U.S. House of Representatives (1999, Opinion of the Court, p. 24). As a result, the Census Bureau eliminated sampling for nonresponse and in the postal vacancy check, as well as the Integrated Coverage Measurement, from the 2000 Census. As these operations had formed the backbone of the original census plan, the Bureau had to prepare a new design. Because the Court's decision did not appear to bar the use of multiplicity estimation, plans for applying the procedure were not changed, nor were they challenged in court. However, as noted above, multiplicity estimation was not actually applied. For a more detailed account of the plan for the 2000 Census and how it evolved, see Wright and Hogan (1999).

3.2 The Accuracy and Coverage Evaluation

The Census Bureau quickly redesigned the post-enumeration survey following the Supreme Court's 1999 decision. The revised survey, renamed the Accuracy and Coverage Evaluation (A.C.E.), was reduced to about 300,000 housing units. It was redesigned to produce adjusted population numbers in time for their possible use for redistricting and the distribution of federal funds. Redistricting refers to the division of each state or local government area into voting districts and is distinguishable from apportionment, by which the 435 seats in the United States Congress are allotted to the 50 states according to the states' total population counts.

Based on results of the A.C.E. and through the use of dual-system estimation, the Census Bureau estimated the net coverage error in the 2000 Census. By applying synthetic estimation, the Bureau estimated adjusted counts for census blocks and higher geographic levels. The Department of Commerce had only a brief period of time before making a decision to release unadjusted or adjusted numbers to the states for redistricting. A committee of senior Census Bureau executives assessed the relative accuracy of the adjusted and unadjusted numbers, as well

as the various component activities and errors that contributed to these numbers. The reports describing these findings are available at http://www.census.gov/dmd/www/ReportRec.htm. On March 1, 2001, the Census Bureau's Deputy Director recommended to the Department of Commerce that "the unadjusted census data be released as the Census Bureau's official redistricting data." The chief reason stated was that there was no conclusive information implying that either set--the unadjusted or the adjusted data--was more accurate for redistricting. The committee was concerned about inexplicable differences between estimates derived from demographic analysis and the A.C.E., as well as potential errors arising in the operations leading into the estimation (U.S. Census Bureau 2001b, Recommendation).

Subsequent months provided the Census Bureau additional time to study and compare the unadjusted and adjusted data sets. After reviewing various evaluations and analyses, the executive committee reported that new evidence suggested that the A.C.E. "overstated the net undercount by at least 3 million persons, and that the cause of this error was the A.C.E.'s failure to measure a significant number of census erroneous enumerations, many of which were duplicates" (U.S. Census Bureau 2001c, p. i). For more information, see http://www.census.gov/dmd/www/EscapRep2.html.

In March, 2003, the Census Bureau released the final adjusted population estimates as the Accuracy and Coverage Evaluation Revision II. These numbers incorporate various procedures to eliminate duplication and other errors as estimated in the 2000 census. The estimated net coverage error was quite small, a net *overcount* of about 0.5% (U.S. Census Bureau 2003a, p. ii). For comparison, the revised demographic analysis measured a 0.1% net undercount.

3.3 The Use of Statistical and Other Methods in the 2000 Census

Statistical methods underlay every aspect of the 2000 Census, from building the list of addresses and removing duplicate responses, to quality assurance and measuring coverage. Statistical processes applied in 2000 included the primary selection algorithm, disclosure avoidance, the duplicate housing-unit operation, characteristic imputation, count imputation (discussed in detail in Section 4), and the A.C.E. Other activities that did not involve the use of statistical methods also helped to accurately enumerate the U.S. population. Some of these are described in what follows.

In 2000, the Census Bureau went to great lengths to obtain a census response from every household. The Bureau designed and implemented marketing and partnership programs to increase awareness of the decennial census and the need for public cooperation. The marketing program, the first-ever paid advertising program, included a national media campaign to increase mail response, advertising directed at historically undercounted populations, and special messages aimed at hard-to-enumerate people. In the partnership program, the Census Bureau worked with state and local groups nationwide to encourage everyone to respond to the census.

Further, in the 2000 Census for the first time people were allowed to respond to the census in a variety of ways. Filling out and returning the paper questionnaire continued to be the most

common method. But, if they wished, respondents could use the telephone, the Internet, or special blank forms available at various public locations.

The several programs, however, increased the likelihood of multiple responses from the same household. For example, one spouse might mail back the questionnaire, while the other called the Census Bureau. To make sure individuals were not counted more than once, the Bureau used statistical procedures to match households and individuals, and then remove duplicate responses. Through a procedure called the primary selection algorithm, based on a set of pre-defined criteria, one of the several matched responding households was designated as the "primary," the response to be included in the apportionment count. Individuals in the duplicated responses who were not identified in the primary might be added to the primary to enhance the coverage. All others were removed or "unduplicated." The greater variety of options for responding to the Census were not possible before 2000 because the statistical matching procedures were not adequate to permit the proper unduplication of responses, and the names of residents were generally not captured for computer searching and matching.

Formal control procedures, used to review and insure quality, were introduced in the 1960 Census (U.S. Census Bureau 1967). Since that time, the role of statistical quality control--based on sound statistical theory, including sampling and estimation--continued to grow and evolve, expanding to include listing, interviewing, keying, coding, procurement, and especially printing. The goal was to detect and correct errors before they affected accuracy or data quality. For example, quality control procedures were applied to detect possible problems with census enumerators and to target problem cases for re-evaluation.

Other operations were implemented to ensure as complete coverage as possible in the census enumeration. Computer edits were performed on mail-return questionnaires to identify returns that contained missing persons, missing personal information, or large housing units (more than six persons). Interviewers then conducted telephone interviews with those housing units during the Coverage Edit Follow-Up operation. Another procedure, the Coverage *Improvement* Follow-Up, was conducted after the nonresponse follow-up. This operation required that an interviewer recheck housing units classified as vacant or nonexistent during the follow-up to ensure that no units were misclassified, as well as to check on new construction, lost or blank forms, and other coverage problems. Through this operation, 2.3 million occupied housing units were enumerated. Finally, after data collection efforts were completed, the data were processed through a sequence of computer routines to edit inconsistent or missing responses.

The Census Bureau created and conducted another program, the Housing Unit Duplication Operation, during the census, after the Bureau discovered that its address list contained a relatively large number of duplicate addresses (U.S. Census Bureau 2000b). The Bureau designed a computer procedure to identify and remove from the housing-unit list duplicate addresses likely to contain duplicated person records. This operation used statistical methods to remove 1.4 million addresses from the census, together with the corresponding 3.6 million person records (U.S. Census Bureau 2000c).

4. THE USE OF IMPUTATION IN THE CENSUS

The Census Bureau has long used both characteristic and count imputation to account for missing data in the census. The phrase "missing data" refers to a wide variety of situations. In 2000, situations that resulted in missing data included incomplete or unavailable responses from housing units with previously confirmed addresses, conflicting data from the same housing unit, and failures in the data-capture process. The various types of missing data included characteristic data (information about an enumerated person, such as sex, race, age) and population count data (information about the number of occupants in an identified housing unit). In the 2000 Census, the Census Bureau processed data for over 120 million households, including over 147 million paper questionnaires and 1.5 billion pages of printed material. The workload during peak operations was about 3.3 million forms per day. Given the size of this undertaking, some amount of missing data was unavoidable.

The categories of missing data and the processes that lead to them have changed over the decades as the census has become increasingly computerized and centralized. In the 1940 Census, the Census Bureau introduced characteristic imputation simply to impute missing ages; the population count was not affected. Characteristic imputation has been used in every census since 1940 and its use has not been challenged in the courts.

Count imputation, in contrast, assigns a population count to a housing unit. The Census Bureau uses this technique when it is unable to secure any information regarding a given address, or when it has limited or contradictory information about the address and does not definitively know the number of occupants. As in prior censuses, the Census Bureau used count imputation in three instances in the 2000 Census:

- *Household Size Imputation.* When Census Bureau records indicated that a housing unit was occupied, but did not show the number of residents, a population count for the unit was imputed.

- *Occupancy Imputation.* When Census Bureau records indicated that a housing unit existed, but not whether it was occupied or vacant, occupancy status (occupied or vacant) was imputed; then, if the unit was imputed to be occupied, a household size was imputed.

- *Status Imputation* (referring to housing-unit status). When Census Bureau records demonstrated evidence of the physical existence of a unit, but conflicting or insufficient information about whether the address represented a valid, non-duplicated housing unit, the unit's status (occupied, vacant, or nonexistent) was imputed; then, if the unit was imputed to be occupied, household size was imputed.

The housing-unit status "nonexistent" includes more than simply a vacant lot. Other possibilities include buildings used only for business purposes and structures that are not (or not yet) fit for habitation.

Since the 1960 Census, the Census Bureau has typically used hot-deck methods to impute counts. Hot-deck procedures use contemporaneous data, often from neighboring housing units, and preserve a realistic distribution of data. In contrast, cold-deck imputation uses information from a prior census or some other outside source (Ford 1983).

4.1 Count Imputation in Prior Censuses

The 1960 Census was the first to use computers to produce the apportionment count. Not surprisingly, it was also the first census to use count imputation to resolve occasional discrepancies between expected and actual numbers of computer records. Some of the missing data resolved through count imputation in the 1960 Census appear to have been the result of mechanical difficulties, specifically problems with FOSDIC (Film Optical Sensing Device for Input to Computers), the device used to read filled-in circles on questionnaires. In general, a sequential hot-deck method was used: the missing data were taken from the previously processed census form, which usually represented a neighboring housing unit.

After the 1960 Census, the Census Bureau reported that "[p]ersons substituted" due to "noninterview" or "mechanical failure" were responsible for 0.5% of the total U.S. census count (U.S. Census Bureau 1965, p. 83). Because the Bureau's term "substitution" has at various times referred to imputation of a full set of characteristics (age, sex, etc.) for a known, enumerated individual, as well as to count imputation, it is unclear whether the numbers in the cited table refer just to the number of count imputations or include other forms. Moreover, the Bureau's records do not reveal the exact numbers in this category but only the percentage.

When processing data from the 1970 Census, the Census Bureau used imputation techniques similar to those applied in 1960, except that the Bureau made greater use of hot-deck imputation. It appears that the Bureau performed both household size and occupancy imputation in the 1970 Census. The 1970 apportionment count included about 900,000 imputed persons (Hogan 2001, par. 44). See Table 1.

Table 1. Count Imputation in the Census, 1960 - 2000

Year	Resident Population	Total Count Imputations	Percent Count Imputation
1960	179,323,175	(unknown)	(unknown)
1970	203,211,926	900,000[a]	0.44%
1980	226,545,805	761,000[a]	0.34%
1990	248,709,873	53,655	0.02%
2000	281,421,906	1,172,144	0.42%

NOTE: [a] Only approximate count imputation figures are available for 1970 and 1980.

The 1980 Census used count imputation for household size and occupancy. As in prior censuses, the procedure was based on geographic proximity. The specific procedures are described in Bailar (1982, pp. 7-9). As in 1960, count imputation appears to have been used in instances of mechanical failure of questionnaire readers. On the other hand, the sampling techniques used in

1970 in the National Vacancy Check and Post-Enumeration Post-Office Check (see Section 2) were not continued. In 1980, approximately 761,000 persons were added to the final count through imputation (U.S. Census Bureau 2001d). After the 1980 Census, the State of Indiana unsuccessfully sued the Census Bureau as the use of count imputation shifted a seat from Indiana to Florida (Orr v. Baldrige 1985).

Count imputation in the 1990 Census differed from 1980 in two major ways. First, the level of count imputation was much lower, practically nonexistent. Only about 53,600 individuals were imputed in 1990 (U.S. Census Bureau 1992b). The Census Bureau instituted better questionnaire control methods and more clerical edit procedures. Further, incomplete questionnaires went through additional rounds of recycling to the field, where census workers were strongly encouraged to determine a count in the field. The result was a large drop in the number of housing units eligible for imputation.

Second, the Bureau introduced status imputation, to go along with imputation for household size and occupancy. Status imputation was required in 1990 because of the introduction of a computerized address list, called the Address Control File (ACF). For prior censuses, address registers had been maintained by hand in local census offices for each separate enumeration district. The 1990 ACF, in contrast, was a centralized, automated list of all housing units, prepared in advance of the census. Its existence required reconciliation of each address having incomplete or conflicting information. If one source indicated that a housing unit was a valid, nonduplicated unit, while the ACF indicated the unit should be removed from the list (deleted), this discrepancy had to be resolved. The 1990 procedures, therefore, allowed for the imputation of a status of "delete" (nonexistent), rather than only "occupied" or "vacant," to resolve discrepancies.

The Census Bureau's review of count imputation after the 1990 Census was less intense than the more comprehensive review that followed the 1980 Census. In 1990, the Bureau reasoned that further study was probably not warranted because count imputation had such a minimal effect on census accuracy (Hogan 2001). Additionally, further study of count imputation in past censuses appeared to become less relevant. As mentioned in Section 3, from the early 1990s the Bureau intended to take a sample of nonresponding housing units following the 2000 Census; such a plan would have obviated the need to conduct a separate count imputation process.

4.2 Count Imputation in the 2000 Census

In the 2000 Census, a total of approximately 1.2 million persons, or 0.4% of the population, were added through count imputation (U.S. Census Bureau 2001e). Although the number and percentage of count imputations were much higher in 2000 than in 1990, the percentage was similar to those in earlier censuses, as shown in Table 1. With several exceptions noted below, the imputation procedures in 2000 were similar to earlier ones. As in 1960, 1970, and 1980, the Census Bureau used imputation for household size and occupancy. Further, as in 1990, status imputation allowed the Bureau to impute the existence or nonexistence of a separate, non-duplicated housing unit in instances where records were not conclusive about the unit. See

Table 2. Again, all count imputation was performed using a variant of the hot-deck method.

Table 2. Count Imputation in the 2000 Census

Type of Count Imputation	Count Imputations	Percent of Total Count Imputations	Percent of Total Resident Population Imputed
Total	1,172,144	100.0%	0.42%
Household Size	495,600	42.3%	0.18%
Occupancy	260,652	22.2%	0.09%
Status	415,892	35.5%	0.15%

Status imputation was applied only to addresses included in the Census Bureau's Decennial Master Address File. Addresses in this file originated from official sources such as the 1990 Census, the U.S. Postal Service, local governments, tribal governments, and Census Bureau enumerators. These addresses were validated and updated according to specific, predetermined procedures. *All counts*--whether based on an actual enumeration or on imputation--were attributed to housing units that originated through these procedures (Hogan 2001, par. 15).

Several consistency criteria had to be satisfied before deleting a household from the address file when the Census Bureau had information indicating an address was a duplicate or was not valid. Under the Bureau's double-delete policy, a housing unit could be labeled a “vacant” or “delete” (nonexistent) only following two independent verifications. Alternatively, if the Bureau had not received a mail return from a unit and the enumerator response indicated that the unit was nonexistent, the housing unit was given a final status of delete (Hogan 2001, par. 70). Still, evidence tends to confirm that most of the count imputations performed in the 2000 Census were attributable to existing housing units whose data were not captured because of a variety of processing errors (U.S. Census Bureau 2003b). These cases appear to have been appropriately included in the census. Without the use of count imputation, some individuals who had tried to be enumerated in the census would have been left out simply through processing errors.

5. UTAH CHALLENGES THE USE OF COUNT IMPUTATION

As required by the Constitution, the U.S. House of Representatives is re-apportioned after each decennial census. The Method of Equal Proportions (Ernst 1994) is used to determine how many seats are allotted to each state. Based on state apportionment totals from the 2000 Census, the State of Utah would have needed fewer than 1,000 additional residents to qualify for the 435^{th} and final seat in the House of Representatives. In 2001, Utah challenged the census numbers. In its first suit, Utah alleged that its population total should have included Mormon missionaries temporarily living abroad. This claim was later rejected by the District Court. For a summary of the issues of the case and the strategy deployed by Utah, see Wolfson and Lee (2003).

The State of Utah then brought a second complaint. Noting that without count imputation it

would be entitled to the final House seat, Utah claimed that the use of count imputation violated both the Census Act and the Constitution, being merely a back-door method to implement sampling for nonresponse, a procedure that the Supreme Court had already held could not be used to produce the apportionment count. Utah sought an injunction compelling Census Bureau officials to change the official census counts. North Carolina, the state that would lose the contested seat if imputation counts were removed, intervened. After extensive briefing, the District Court found in favor of the Federal Government in a 2-1 decision, Utah v. Evans (2001, Lower Court Opinion), and Utah appealed directly to the Supreme Court.

Utah was not the first state to challenge the Census Bureau's use of count imputation. The State of Indiana sued the Census Bureau after the 1980 Census; without the use of count imputation, a seat would have shifted from Florida to Indiana, Orr v. Baldrige (1985). The parties stipulated that imputation was not sampling and the District Court upheld the use of imputation, holding that "the Bureau's use of hot deck imputation was an entirely reasonable means of dealing with the problem of incomplete data ..." The case was heard in District Court; the decision was not appealed.

5.1 Is Imputation Distinguishable From Sampling?

Witnesses testifying for Utah contended that the count imputation used in the 2000 Census was a prohibited form of sampling. Lara Wolfson, Utah's principal expert witness, argued that "... [count] imputation ... is a form of statistical sampling, both because it involves (a) the process of selecting a particular housing unit (one whose occupants were actually enumerated in the 2000 census) to be used as the sample from which inferences could be drawn to a non-responding unit, and (b) the process of drawing that inference" (Wolfson 2001, par. 46). In Wolfson and Lee (2003), the authors write, "... hot-deck imputation has the same practical effect as the random sampling method [for nonresponse follow-up] at issue in *House of Representatives* ... [A]s a practical matter, the only difference between the two procedures is that the random sampling procedure is used to estimate a larger percentage of the population. But ... that difference is as legally irrelevant as it is practically fortuitous, because even scaled-down sampling is sampling."

Expert witness Donald Rubin, in a declaration for Utah, argued that the use of sampling includes imputation, "since imputation involves the process by which characteristics of the non-sampled units (*e.g.*, the non-enumerated segments of the population) are estimated from the characteristics of the sampled units (the enumerated segments of the population)." He stated that the definition of sampling included both probability and nonprobability samples (Rubin 2001, par. 21, 23).

The lead witness for the Census Bureau, Howard Hogan, claimed that the definitions provided by Utah's expert witnesses were too broad. He stated that, "Under their definitions, all censuses in this or probably any other country have been 'samples,' as none to my knowledge has ever included each and every person in the population" (Hogan 2001, par. 27).

Dr. Hogan continued: "... when used in the context of statistical, demographic, and population

survey applications, the term ‘sampling’ generally refers to probability sampling” (Hogan 2001, par. 30). He cited testimony from Barbara Bailar, formerly the Associate Director for Statistical Standards and Methodology at the Census Bureau, in Orr v. Baldrige in arguing that sampling is "the selection of a subset of units from a larger population in such a way that each unit of the population has a known chance of selection. Sampling is used where a scientifically selected set of units can be used to represent the entire population from which they are drawn and inferences to the entire population can be based on sample results" (Bailar 1982, p. 5). The count imputation procedure applied in the 2000 Census does not fit into this definition of sampling. First, the Census Bureau attempted in numerous ways to contact every resident, making no "selection" of a subset of units in designing the census. Further, the chance that a unit would later be used to provide data for imputation was not specified nor ever known.

In its declarations, the Census Bureau argued that (i) various methodologies used in the census are statistical, including editing, imputation, weighting, quality control, etc.; and (ii) imputation is one of many statistical methodologies--but it is not sampling. To produce data describing a target population or subgroup, two stages of activities are conducted: (1) *collecting the data*: developing a frame, determining a sample (for surveys), developing a questionnaire, contacting units or people, addressing nonresponse through personal visits or telephone follow-up, etc.; and (2) *processing the data*: creating a database, processing, editing, imputing, weighting (for surveys), tabulating, etc. Dr. Hogan contended that the term sampling refers to one strategy of data collection and can be said to encompass some or all of the activities in the data collection stage. By contrast, imputation--count imputation or other types--is a statistical procedure applied only in the data processing stage (par. 19-23). He again quoted Dr. Bailar from the *Orr* case, that sampling and imputation "are two completely different procedures, based upon totally distinct principles and serving equally distinct purposes" (Bailar 1982, p. 5).

Joseph Waksberg, an expert witness writing for the Census Bureau, also made the point that (1) research topics in surveys and censuses are very often classified into two categories--sampling and nonsampling; and (2) “[m]ost survey researchers and practitioners consider nonresponse and methods of adjusting for nonresponse either by imputation, as it has been done in recent decennial censuses, or through weighting, which is applied more commonly in sample surveys, as nonsampling issues and treat them as separate and distinct from sampling issues” (Waksberg 2001, par. 7). Mr. Waksberg provided a variety of supporting examples, including a short pamphlet, *What is a Survey?*, printed by the American Statistical Association (ASA 1980); a three-volume report published by the Committee on National Statistics (Madow, Nisselson, and Olkin 1983; Madow, Olkin, and Rubin 1983; Madow and Olkin 1983); and a book on nonsampling errors in surveys (Lessler and Kalsbeek 1992).

5.2 Does Imputation Improve Accuracy?

Utah also questioned whether imputation improves accuracy, arguing that the Census Bureau’s count imputation procedure was less accurate than probability sampling. Dr. Wolfson wrote that count imputation “relies on a more questionable, non-random, non-representative sample to estimate the number of persons in unenumerated households,” and that it is “even less

statistically valid" than the sampling procedures barred by the *House of Representatives* decision (Wolfson 2001, par. 48-49). Dr. Rubin also wrote that "the imputation methodology ... was based on a non-probability sampling design ...; [t]herefore, population estimates produced using the Census Bureau's imputation procedure rest on generally less reliable statistical assumptions than those produced using probability sampling ..." (Rubin 2001, par. 22, 25).

For the Census Bureau, Dr. Hogan argued that, in the decennial census the "alternatives for handling missing data for an identified address are either ... to assign no value to the empty data fields, or to assign [impute] plausible values for the missing data. The first alternative is the equivalent of imputing a value of 0, i.e., of deciding that all returns with questionable or incomplete data represent vacant or nonexistent housing units" (Hogan 2001, par. 10). He contended that this conclusion is untrue, as studies have shown that a significant proportion of such returns are actually valid, occupied housing units (U.S. Census Bureau 2001f); without imputation, data from such returns would be excluded from the census, possibly ignoring the intentions of some people who responded.

The Census Bureau further contended that, under the second alternative, a value other than 0 may be inserted into an empty data field. Because incomplete information may distort census results, producing an accurate census dictates that the issue is not whether to impute, but what type of imputation will be the most accurate. Although the effects of imputation in general have been studied for decades, hot-deck imputation, particularly sequential or nearest-neighbor hot-deck imputation--used by the Bureau in the census--has received less attention; much of that work has focused on variance estimation. Earlier studies found that hot-deck imputation on discrete data, while possibly increasing the variance of the survey estimates, can reduce their nonresponse bias (Cox and Folsom 1978, Ford 1983). Kalton and Kasprzyk (1986) mention possible advantages to a sequential hot-deck imputation. Results in Chen and Shao (2000) demonstrate that nearest-neighbor imputation in general works well under minor assumptions; its bias is asymptotically negligible, and it is more efficient than random hot-deck imputation.

The State of Utah also claimed that applying count imputation in the census violated Article 1 of the Constitution, arguing that the requirement of an "actual Enumeration" compelled the Census Bureau to seek out each individual. The Census Bureau could rely on documentary or eyewitness evidence that an individual existed, and it could rely on proxy respondents. But, Utah contended, the Census Bureau could not rely on count imputation to fill in missing data. Thomas Lee, Utah's lead counsel, has argued "the Framers required that representation in Congress be apportioned on the basis of an 'actual enumeration' ... not out of naïveté or unfamiliarity with alternative methods of estimation, but to minimize the risk of political manipulation" in the apportionment (Lee 2002). The Census Bureau disputed this contention in Utah v. Evans.

6. THE DECISION OF THE SUPREME COURT

In a split decision, the Court agreed with the Census Bureau that imputation was not sampling, and found that it did not violate the Census Clause of the Constitution. The majority held that

"imputation differs from sampling in respect to the nature of the enterprise, the methodology used, and the immediate objective sought." The Court further noted that the differences were "of both kind and degree." Justice O'Connor dissented from the holding, concluding that imputation did constitute a form of sampling and was thus barred by the Census Act. Justices Thomas and Kennedy agreed that imputation was distinguishable from sampling, but found its use a violation of the Constitution. Justice Scalia dissented on the grounds that the Court did not have jurisdiction to hear the case.

Justice Breyer, writing for the majority, summarized the distinction between sampling and imputation, citing with approval an illustrative example offered in oral argument:

> Imagine a librarian who wishes to determine the total number of books in a library. If the librarian finds a statistically sound way to select a sample (*e.g*., the books contained on every 10th shelf) and if the librarian then uses a statistically sound method of extrapolating from the part to the whole (*e.g*., multiplying by 10), then the librarian has determined the total number of books by using the statistical method known as "sampling." If, however, the librarian simply tries to count every book one by one, the librarian has not used sampling. Nor does the latter process suddenly become "sampling" simply because the librarian, finding empty shelf spaces, "imputes" to that empty shelf space the number of books (currently in use) that likely filled them ... *[citations omitted]* (Utah v. Evans 2002, Opinion of the Court, p. 10)

The Court stated that sampling and imputation differ in three critical respects:

> (1) In respect to the *nature of the enterprise*, the librarian's sampling represents an overall approach to the counting problem that from the beginning relies on data that will be collected from only a part of the total population; ... (2) in respect to *methodology*, the librarian's sampling focuses on using statistically valid sample-selection techniques to determine what data to collect; ... and (3) in respect to *the immediate objective*, the librarian's sampling seeks immediately to extrapolate the sample's relevant population characteristics to the whole population. ...
>
> By way of contrast, the librarian's imputation (1) does not represent an overall approach to the counting problem that will rely on data collected from only a subset of the total population, since it is a method of *processing* data (giving a value to missing data), not its collection; ... it (2) does not rely upon the same statistical methodology generally used for sample selection; ... and it (3) has as its immediate objective determining the characteristics of missing individual books, not extrapolating characteristics from the sample to the entire book population. ... *[citations omitted]* (pp. 10-11)

The majority agreed that count imputation was not used for "the extrapolation of the features of a large population from a small one, but the filling in of missing data as part of an effort to count individuals one by one" (p. 11). The Court further examined the legislative history and wording

of the Census Act, as well as the definition of "sampling" at the time the Act was amended, to conclude that Congress did not intend to bar the use of all statistical methods, just sampling.

Justice O'Connor dissented from the majority, stating "the Bureau's use of imputation was a form of sampling. The Bureau used a pre-defined deterministic method to select a portion of the population and then used that portion of the population to estimate unknown information about the overall population. ... [T]he majority contends that imputation is not sampling because it occurs after all data have been collected. ... But sampling from collected data is a recognized form of sampling, even when the collected data result from an attempt to survey the entire population" (Utah v. Evans 2002, Opinion of Justice O'Connor, pp. 4, 6).

Regarding an "actual Enumeration," the majority of the Court held that the use of count imputation did not violate the Constitution. Justice Breyer wrote for the majority: "We do not believe the Constitution makes the distinction that Utah seeks to draw. The Constitution's text does not specify any such limitation. Rather the text uses a general word, 'enumeration,' that refers to a counting process without describing the count's methodological details" (p. 19). Justices Thomas and Kennedy found imputation unconstitutional. They concluded that the Framers of the Constitution had experience with various statistical techniques and purposefully disallowed them in the census (Utah v. Evans 2002, Opinion of Justice Thomas, pp. 11-12).

The Supreme Court upheld the use of count imputation, noting, among other factors, that the interest in accuracy favored the Census Bureau. In summary, the majority said, "... we need not decide here the precise methodological limits foreseen by the Census Clause. We need say only that in this instance, where all efforts have been made to reach every household, where the methods used consist not of statistical sampling but of inference, where that inference involves a tiny percent of the population, where the alternative is to make a far less accurate assessment of the population, and where consequently manipulation of the method is highly unlikely, those limits are not exceeded" (p. 24).

7. CONCLUSION

The Court's decision in Utah v. Evans is a recognition that the Constitution can accommodate changes in census methodology that are consistent with the goals of accuracy and equal representation, and that the use of statistical methods can be consistent with the requirement of an "actual Enumeration." Future statistical improvements to census methodology must be judged by the procedures used, the kind and degree of statistical inference, and the immediate objective of the procedures, consistent with Congressional intent.

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