Journal of Official Statistics, Vol. 23, No. 3, 2007, pp. 345–370

Summary of Accuracy and Coverage Evaluation for the U.S. Census 2000

Mary H. Mulry[1]

The U.S. Census Bureau evaluated how well Census 2000 counted the population by conducting a coverage measurement survey known as the Accuracy and Coverage Evaluation Survey (A.C.E.). The Census Bureau considered adjusting the Census 2000 population total of 281,421,906 to correct for coverage error on three occasions, but each time decided not to adjust. The evaluations and analyses for the decisions revealed surprises about Census 2000 and leave a legacy that will influence census-taking and coverage evaluation methods for some time to come. The final estimates from A.C.E., the revision known as A.C.E. Revision II, estimated the percent net undercount to be −0.5 percent (a net overcount of 1.3 million). This article gives an overview of the methodology used to estimate the error in the coverage of Census 2000, presents the estimates, and discusses the quality of the A.C.E. Revision II estimates.

Key words: Undercount; overcount; dual system estimation.

1. Introduction

The U.S. Census Bureau evaluated how well Census 2000 counted the population by conducting a post-enumeration survey known as the Accuracy and Coverage Evaluation Survey (A.C.E.). The U.S. Census Bureau considered adjusting the Census 2000 population total of 281,421,906 to correct for coverage error on three occasions, but each time decided not to adjust. The evaluations and analyses for the decisions revealed surprises about Census 2000 and leave a legacy that will influence census-taking and coverage evaluation methods for some time to come.

The original A.C.E. estimates indicated a 1.18 percent net undercount. The U.S. Census Bureau discovered that undetected duplicate enumerations in the census were a major source of error in the A.C.E. estimates and produced the A.C.E. Revision Preliminary estimates, which indicated the net undercount was 0.06 percent (Thompson, Waite, and Fay 2001; Mule 2001; Adams and Krejsa 2001). Subsequently, the U.S. Census Bureau conducted further research to produce a more complete revision of the estimates that possibly would be used to adjust the census base used in the intercensal estimates. The

[1]U.S. Census Bureau, Washington, DC 20233, U.S.A. Email: mary.h.mulry@census.gov
Acknowledgments: The author is a Principal Researcher in the Statistical Research Division at the U. S. Census Bureau, Washington, DC 20233. This report is released to inform interested parties of research and to encourage discussion. The views expressed on statistical issues are those of the author and not necessarily those of the U.S. Census Bureau. The author thanks Bruce D. Spencer for helpful discussions. The author also thanks Florence H. Abramson, Patrick J. Cantwell, Robert E. Fay, Donna K. Kostanich, Elizabeth A. Martin, Thomas Mule, Rita J. Petroni, Tommy Wright, Mary Frances Zelenak, the referees, and the associate editor for their thoughtful and helpful comments on earlier versions.

final estimates from A.C.E., the revision known as A.C.E. Revision II, estimated the percent net undercount to be −0.5 percent (a net overcount of 1.3 million) (U.S. Census Bureau 2003b).

This article gives an overview of the methodology used to estimate the error in the coverage of Census 2000, presents the estimates, and discusses the quality of the A.C.E. Revision II estimates. A report issued by the U.S. Census Bureau (2004) contains detailed explanations of the design and methodology for A.C.E. and A.C.E. Revision II. Another source for discussion and critique of Census 2000, the A.C.E., and A.C.E. Revision II is a report from the National Research Council (Citro, Cork, and Norwood 2004).

2. Surprises

The A.C.E. Revision II estimates were the first coverage error estimates for any U. S. census that found an overcount for the nation as a whole. Although post-enumeration surveys found erroneous enumerations in previous censuses, the estimated net undercount was always positive, indicating omissions were larger. Consequently, the design of census operations focused on avoiding omissions as much as possible, with the belief that procedures for avoiding duplication were adequate.

The biggest surprise from A.C.E. Revision II was that duplicate enumerations occurred in the census much more frequently than previously observed or suspected in Census 2000 or other censuses. Studies of duplication as part of the A.C.E. Revision II program estimated 5.8 million duplicate enumerations in Census 2000 (Mule 2002; Fay 2002a). Two evaluation studies confirmed there were a large number of duplicate enumerations in the census. One found 6.7 million duplicates using only the census duplicates identified by administrative records (Mulry et al. 2006). In the other study, an expert matching team clerically examined the duplicate enumerations and agreed that about 95 percent were duplicates (Byrne, Beaghen, and Mulry 2003). Even more surprising is that this large amount of duplication remained in Census 2000 after 3.6 million enumerations were removed during the census data collection operations when the U.S. Census Bureau discovered and removed 1.4 million duplicate listings of housing units (Fay 2001). The same operation considered an additional 1.0 million addresses and their corresponding 2.4 million enumerations potentially duplicates but reinstated them in the census, although not in time for those in A.C.E. sample blocks to be included in the A.C.E. processing (U.S. Census Bureau 2003b).

Another surprise was the large number of duplicates where both enumerations were on mail-return forms. Conventional wisdom at the U.S. Census Bureau has been that questionnaires returned by mail contribute little to census error since they are self-responses. Of the 5.2 million duplicate enumerations where both were for people in housing units, 25 percent were both on mail returns while 10 percent had neither on mail returns, and the remaining 65 percent had one on a mail return and the other not on a mail return (Mule 2003). Since there were 205.3 million enumerations of people in housing units on mail returns and 64.9 million on nonmail returns (Treat 2004), the duplicate enumerations do not negate the conventional wisdom that mail returns are of higher quality. The percentage of enumerations on mail returns that have a duplicate is 2.28, with 0.64 percent having the duplicate on another mail return and 1.64 percent having a duplicate on a nonmail return. For nonmail returns, 6.01 percent have a duplicate with 0.82 percent on another nonmail return and 5.19 percent on a mail return (Mule 2003).

Interestingly, the duplicates occurred disproportionately among the population under 30 years of age. The group under 30 years of age was 42.2 percent of the census population while they were 53.6 percent of the estimated 5.8 million duplicates between enumerations in housing units and those in housing units or group quarters. The group aged 18–29 was 16.5 percent of the census population but 24.0 percent of the duplicates (Mule 2002). The duplicate enumerations within a block cluster appear to have arisen from operational errors, such as a dwelling having two different addresses on the address list. A reinterview study, limited since it was a long time after Census Day, found that the causes of duplicate enumerations in different states or counties included moving situations, people visiting family/friends, people with vacation/seasonal homes, college students, and children in shared custody situations (Smith 2004).

The technical innovation that allowed discovery of the duplicate enumerations was the scanning of census forms by optical character and mark recognition technologies that converted the names and other information on the census questionnaires into electronic format. The duplicates were identified by a computerized search of the census. The nationwide search methodology could not have been used in previous censuses because names on enumerations were not converted to an electronic format that permitted using computers.

The combination of a net overcount of 1.3 million and 5.8 million duplicates indirectly implies 4.5 million omissions (−1.3 million +5.8 million) from Census 2000. Erroneous enumerations in addition to duplications would imply more omissions. However, the methodology used for A.C.E. did not produce viable estimates of erroneous enumerations or omissions separately because the processing creates offsetting errors that preserve the net error. For example, the A.C.E. processing would not consider a person with a census enumeration that failed to meet the minimum requirements for completeness to be correctly enumerated (Hogan 2003). The processing would record offsetting errors by treating the insufficient enumeration as erroneous and the person as omitted from the census.

3. Dual System Estimator

A post-enumeration survey that measures census coverage error is composed of two samples, the enumeration sample (E-sample) and the population sample (P-sample). The E-sample is a sample of census enumerations and designed to measure erroneous enumerations. The P-sample is a sample of the population selected independently of the census and designed to measure census omissions. The members of households interviewed in the P-sample are matched to the census on a case-by-case basis to determine whether they were enumerated in the census. Both the 2000 A.C.E. and the 1990 Post-Enumeration Survey (Hogan 1992; 1993) used dual system estimation to produce estimates of the population size. The dual system estimator used by the U.S. Census Bureau for A.C.E. Revision II is shown in Equation (1) while a simpler version was used in 1990.

$$DSE_{ij} = Cen_{ij} \times r_{DD,ij} \times \frac{r_{CE,i}}{r_{M,j}} \times \phi \qquad (1)$$

where:

i and j denote the E- and P- sample poststrata used to estimate the correct enumeration and match rates, respectively.

Cen_{ij} is the census count for the cross-classification of poststrata i and j.

$r_{DD,ij}$ is the census data-defined rate for cross-classified poststratum ij, which is the percentage of enumerations with at least two characteristics reported. A name counts as one characteristic. (The reinstated enumerations are included in the denominator but not the numerator.)

$r_{CE,i}$ is the correct enumeration rate estimated by the percentage of the enumerations in the E-sample poststratum i that are correct.

$r_{M,j}$ is the census inclusion rate estimated by the percentage of individuals in the P-sample poststratum j that match a census enumeration, called the match rate.

φ is the correlation bias adjustment factor (for adult males, distinct for a given age–race group)

The dual system estimator for the 1990 Post-Enumeration Survey had the same poststratification for the E- and P-samples. Also, there was no correlation bias adjustment, which is equivalent to $\varphi = 1$ in Equation (1) for all poststrata.

Estimation for small areas in 2000 and 1990 used the synthetic assumption that the net coverage error rate is constant within the poststratum. To produce estimates for specific areas or population subgroups first coverage correction factors (CCFs) are calculated by dividing the dual system estimates from Equation (1) by the corresponding census counts, i.e., $CCF_{ij} = DSE_{ij}/Cen_{ij}$

To produce the estimate for any area or population subgroup a, the CCFs are applied synthetically: $\sum_{ij} Cen_{a,ij} \times CCF_{ij}$ where the summation is over all the cross-classified ij poststrata and $Cen_{a,ij}$ is the census count in poststratum ij for area or subgroup a (U.S. Census Bureau 2003b).

A concern about using dual system estimation in post-enumeration surveys is that it may be subject to a bias, called correlation bias that arises because of a violation of the assumption of independence between the census and the P-sample or because of a violation of the assumption that the enumeration probabilities are equal. Correlation bias tends to be a source of downward bias in dual system estimates. The U.S. Census Bureau attempts to preserve the independence of the census and P-sample by keeping the A.C.E. data collection and processing operations completely separate from the census data collection and processing. Poststratification of the respondents by geography, sex, age, racial and ethnic groups, and population density reduces the bias by grouping together people with similar chances of being counted, as estimated by the match rate (Chandrasekar and Deming 1949). However, the poststratification may not describe all the heterogeneity of enumeration probabilities and thereby may not eliminate all correlation bias. Corrections for correlation bias in dual system estimates for adult males have been developed using Demographic Analysis estimates of the sex ratios (the ratios of the number of males to the number of females) (Bell 1993).

4. Estimates of Census Coverage Error

Table 1 shows the estimated percent net undercount for the U.S. by major population groups for Census 2000 and the 1990 Census. Table 2 shows the estimated net undercount

Table 1. Estimated percent net undercount for major groups

Characteristic	A.C.E. Revision II undercount		1990 PES undercount	
	Est. (%)	S.E. (%)	Est. (%)	S.E. (%)
Total	−0.49	0.20	1.61	0.20
Race/Hispanic origin domain				
Non-Hispanic White*	−1.13	0.20	0.68	0.22
Non-Hispanic Black	1.84	0.43	4.57	0.55
Hispanic	0.71	0.44	4.99	0.82
Non-Hispanic Asian**	−0.75	0.68	2.36	1.39
Hawaiian or Pacific Isl**	2.12	2.73	2.36	1.39
AI on Reservation	−0.88	1.53	12.22	5.29
AI off Reservation*	0.62	1.35	0.68	0.22
Tenure				
Owner	−1.25	0.20	0.04	0.21
Nonowner	1.14	0.36	4.51	0.43
Age/Sex				
0–9***	−0.46	0.33	3.18	0.29
10–17***	−1.32	0.41	3.18	0.29
18–29 Male	1.12	0.63	3.30	0.54
18–29 Female	−1.39	0.52	2.83	0.47
30–49 Male	2.01	0.25	1.89	0.32
30–49 Female	−0.60	0.25	0.88	0.25
50+ Male	−0.80	0.27	−0.59	0.34
50+ Female	−2.53	0.27	−1.24	0.29

Source: U.S. Census Bureau 2003b.
The A.C.E. Revision II is for the household population.
The 1990 net undercount is for the PES universe which included noninstitutional, nonmilitary group quarters in addition to the household population.
* For 1990, AI off Reservation was included in the Non-Hispanic White Race/Hispanic Origin Domain. Therefore, the net undercount and standard error for these domains are identical.
** For 1990, Asian or Pacific Isl. was a single Race/Hispanic Origin Domain. Therefore, for Non-Hispanic Asian and for Hawaiian or Pacific Isl. the net undercount and standard error are repeated.
*** For the 1990 PES, the "0–17" Age/Sex group was a single group. Therefore, the net undercount and standard error for children "0–9" and "10–17" are identical.
A negative net undercount denotes a net overcount.

for the U.S. by the major population groups for Census 2000 and the 1990 Census. Table 3 shows the estimated percent net undercount for owners and renters within the major groups for the last two censuses. The estimates in these tables correspond to aggregates of poststrata.

The percent net undercount estimates for the 1990 Census provide some context for viewing the percent net undercount estimates for Census 2000. The 1990 Census was evaluated using the 1990 Post-Enumeration Survey (PES). However, differences in methodology have to be weighed when viewing the two sets of estimates. The A.C.E. Revision II estimates are only for the population living in housing units while the 1990 Post-Enumeration Survey included the population living in noninstitutional group quarters along with the population living in housing units. The race/Hispanic ethnicity groups are

Table 2. Net undercount estimates for major groups (in thousands)

Characteristic	Census 2000	A.C.E. Revision II		1990 PES	
		Est.	S.E.	Est.	S.E.
Total	273,587	−1,332	542	3,994	488
Race/Hispanic origin domain					
Non-Hispanic White*	192,924	−2,151	382	1,277	417
Non-Hispanic Black	33,470	628	146	1,389	168
Hispanic	34,538	248	152	1,102	181
Non-Hispanic Asian**	9,960	−74	67	174	103
Hawaiian or Pacific Isl**	590	13	16		
AI on Reservation	540	−5	8	52	22
AI off Reservation*	1,565	10	21		
Tenure					
Owner	187,925	−2,320	372	71	334
Nonowner	85,662	988	310	3,871	368
Age/Sex					
0–9***	39,642	−180	130	2,084	191
10–17***	32,307	−422	129		
18–29 Male	21,594	245	138	792	130
18–29 Female	21,576	−295	111	687	113
30–49 Male	41,297	848	104	685	114
30–49 Female	42,783	−257	105	326	95
50+ Male	33,798	−270	90	−160	93
50+ Female	40,590	−1,001	107	−419	98

Source: U.S. Census Bureau 2003b.
The Census count is for the household population.
The A.C.E. Revision II net undercount is for the household population.
The 1990 net undercount is for the PES universe, which included noninstitutional, nonmilitary group quarters in addition to the household population.
* For 1990, AI off Reservation was included in the Non-Hispanic White Race/Hispanic Origin Domain.
** For 1990, Asian or Pacific Isl. was a single Race/Hispanic Origin Domain. Therefore, the net undercount and standard error displayed is for the Asian or Pacific Isl. Domain.
*** For the 1990 PES, the "0–17" Age/Sex group was a single group. Therefore, the net undercount and standard error displayed are for the "0–17" Age/Sex group.
A negative net undercount denotes a net overcount.

not exactly the same in the two sets of estimates.[2] In addition, the A.C.E. Revision II estimates for adult males included a correction for correlation bias while the 1990 Post-Enumeration Survey estimates did not. If the 1990 estimates had contained a correction for correlation bias, the net undercount rates would have been larger, particularly for Black males (Bell 1993). Estimates of bias for individual error components for the 1990 Post-Enumeration Survey from an evaluation program that included reinterviews and expert recoding are contained in Mulry and Spencer (1993).

[2] In the 1990 PES estimates, the Hispanic group excluded Blacks, Asian or Pacific Islanders, and American Indians on Reservation, while the Hispanic group for A.C.E. Revision II included members of all groups who said they were Hispanic. See the footnotes for Table 1 for more information about differences in the race/Hispanic ethnicity groupings.

Table 3. Estimated percent net undercount: Race/Hispanic origin domain by tenure

A.C.E. Revision II			1990 PES		
Characteristic	Est. (%)	S.E. (%)	Characteristic	Est. (%)	S.E. (%)
Total	−0.49	0.20	Total*	1.59	0.19
Owner	−1.25	0.20	Owner	0.04	0.21
Nonowner	1.14	0.36	Nonowner	4.51	0.41
Non-Hispanic White	−1.13	0.20	Non-Hispanic White	0.68	0.22
Owner	−1.46	0.20	Owner	−0.26	0.23
Nonowner	−0.07	0.41	Nonowner	3.06	0.50
American Indian off reservation	0.62	1.35			
Owner	−1.53	1.77			
Nonowner	3.54	2.18			
Non-Hispanic Black	1.84	0.43	Black	4.57	0.53
Owner	0.56	0.49	Owner	2.26	0.56
Nonowner	3.06	0.60	Nonowner	6.48	0.83
Hispanic	0.71	0.44	Hispanic	4.99	0.78
Owner	−1.08	0.50	Owner	1.82	0.68
Nonowner	2.35	0.62	Nonowner	7.43	1.18
Non-Hispanic Asian	−0.75	0.68	Asian or Pacific Isl.	2.36	1.36
Owner	−1.71	0.85	Owner	−1.45	1.47
Nonowner	0.68	0.98	Nonowner	6.96	2.50
Hawaiian or Pacific Isl	2.12	2.73			
Owner	0.67	3.87			
Nonowner	3.64	3.60			
American Indian on reservation	−0.88	1.53			
Owner	−0.74	1.74			
Nonowner	−1.17	1.71			

Source: U.S. Census Bureau 2003b.
*Excludes American Indians on Reservations.
A negative net undercount denotes a net overcount.
The 1990 Hispanic domain excludes Blacks, Asian or Pacific Islanders, and American Indians on Reservation. The1990 net undercount is for the PES universe which included noninstitutional, nonmilitary group quarters in addition to the household population.

As mentioned earlier, a computerized search of the 1990 Census for duplicates was not possible at the time.

The A.C.E. for Census 2000 and the 1990 Post-Enumeration Survey had different treatments of people who move between Census Day and the P-sample interview. The match rate for movers is important to measure because it tends to be lower than the match rate for those who do not move (Mulry 2000). For the 1990 PES, the members of the P-sample are the residents of the housing unit when the P-sample interview is conducted. However, the A.C.E. used the number of movers into the sampled housing units to estimate the number of movers and the match rate for the people who have moved out to estimate the match rate for movers. The A.C.E. relied on proxy interviews with landlords, neighbors, or others to gather information for those who moved out of the sample blocks, and did not attempt tracing outmovers. An evaluation in the Census 2000 Dress Rehearsal compared match rates from data for outmovers obtained from proxy interviews and from self-interviews after tracing and found little difference (Raglin and Bean 1999).

A.C.E. Revision II estimates a negative percent net undercount of the Census 2000 household population. The estimated percent net undercount of −0.49 with a standard error of 0.20 is significantly different from zero at the 10-percent significance level. In contrast, the 1990 PES estimated a 1.61 percent net undercount (standard error of 0.20) in the 1990 census (U.S. Census Bureau 2003b). The estimates of standard error used in the significance tests account for sampling error only and do not include non-sampling error.

Among the A.C.E. Revision II coverage estimates by race and Hispanic ethnicity, only those for the Non-Hispanic White and Non-Hispanic Black domains are significantly different from zero. The estimated percent net undercount for Non-Hispanic Whites was −1.13, reflecting an overcount, while the estimate for Non-Hispanic Blacks was a percent net undercount of 1.84 (U.S. Census Bureau 2003b).

The A.C.E. Revision II estimate for Hispanics was a percent net undercount of 0.71. The 1990 Post-Enumeration Survey estimated very similar net undercount rates for the Non-Hispanic Blacks and Hispanics but the estimates from A.C.E. Revision II were not as close. The change in pattern may partly be due to sampling error. However, a comparison is difficult because the estimates for Hispanic adult males contained the correlation bias correction based on all non-Blacks while Black adult males had correlation bias correction based only on Blacks. The data used in formulating the correction for correlation bias came from Demographic Analysis estimates, which are available only by Black and non-Black (Robinson and Adlakha 2002). The correction was made only for adult males and is discussed in more detail in Section 7.4. Regardless, the A.C.E. Revision II net undercount estimates for the Non-Hispanic Black and Hispanic domains are not significantly different from one another (U.S. Census Bureau 2003b).

A comparison between the A.C.E. Revision II and the 1990 PES net undercount estimates for the American Indian and Alaska Native on Reservation population is difficult because of the large standard errors for the estimates. A.C.E. Revision II estimated a percent net undercount of −0.88 percent for the American Indian and Alaska Native on Reservation population in Census 2000 with a standard error of 1.53. The 1990 PES estimated a percent net undercount of 12.22 for the American Indian and Alaska Native on Reservation population with a standard error of 5.29. (U.S. Census Bureau 2003b.)

Table 3 shows differences in coverage error estimates with respect to tenure, determined by whether a person's household owns or rents their dwelling. Nationally, A.C.E. Revision II estimates a net undercount of −1.25 percent for owners and 1.14 percent for nonowners. These estimated net undercount rates are statistically different from zero, and their difference is also statistically significant. The 1990 PES estimated an even more dramatic difference in coverage between owners and nonowners, though in the same direction (higher estimated undercount for nonowners) (U.S. Census Bureau 2003b).

The A.C.E. Revision II estimates show coverage differences by age and sex. In particular, statistically significant net overcounts were estimated for children age 10–17 and for adult females 18–29, 30–49, and 50 and over, as well as for males 50 and over. In contrast, statistically significant percent net undercounts were estimated for males 18–29 and 30–49, and the percent net undercount estimate for children 0–9 was not significantly different from zero. The coverage differences by sex are affected by the correlation bias adjustments that increase the undercount estimates for adult males (U.S. Census Bureau 2003b).

5. Comparisons with Demographic Analysis

Demographic Analysis provides alternative estimates of census coverage. It also is a tool for examining the relative error between the census and A.C.E. Revision II even though the correction for correlation bias used information from Demographic Analysis. Robinson (2001) describes the construction of the Demographic Analysis estimates. Demographic Analysis uses vital records to form an estimate of the size of the population. The basic approach is to start with births, subtract deaths, and add the net migration, the difference between immigrants and emigrants. Demographic Analysis uses administrative statistics on births, deaths, authorized international migration, and Medicare enrollments, as well as estimates of legal emigration and net unauthorized immigration (Robinson and Adlakha 2002).

Table 4 shows that Demographic Analysis, known as the Revised Demographic Analysis, produced an estimate of 0.12 percent net undercount in Census 2000. Overall, the Demographic Analysis estimates indicate that the net census undercount is small except for the two groups, adult Black males and young children ages 0–9. For age subgroups within adult Black males and racial subgroups within young children, the percent net undercount is disproportionately high in that their percent net undercount rate is at least 2 percentage points higher than the percent net undercount rate for the total population. Table 5 shows that when the adult Black men are divided into three age groups of 18–29 years, 30–49 years, and 50 and over, percent net undercount rates are 5.71 percent, 9.87 percent, and 3.87 percent, respectively. Also, the net undercount rates for children ages 0–9 are 3.26 percent for Black males, 3.60 percent for Black females, 2.18 percent for non-Black males and 2.59 percent for non-Black females (U.S. Census Bureau 2003b).

Although Demographic Analysis and A.C.E. Revision II estimates of percent net undercount were in opposite directions, they both showed that the net coverage error for the population overall was small. The A.C.E. Revision II estimate implies a net overcount of 1.3 million, or 0.48 percent,[3] as compared to the Demographic Analysis estimated net undercount of 0.12 percent. The consistency between Demographic Analysis and A.C.E. Revision II displayed in Table 5 is basically a consequence of using the Demographic Analysis sex ratios to correct for correlation bias. The A.C.E. Revision II estimates for females (especially non-Black females) show patterns similar to the Demographic Analysis estimates for ages 10 and over, even though they did not receive an adjustment for correlation bias (U.S. Census Bureau 2003b).

For ages 50 and over, a small but systematic gap appears between the Demographic Analysis and A.C.E. Revision II estimates. The Demographic Analysis estimate of percent net undercount is consistently higher by at least 1.2 percent for each race–sex group.

[3] This estimated net undercount from A.C.E. Revision II is slightly different from the −0.49 estimate cited earlier because it is relative to the entire resident population including persons in group quarters.

Table 4. Census count, Demographic Analysis (DA) estimate and A.C.E. Revision II estimate for the U.S. resident population: April 1, 2000. Standard errors are in parentheses

	Count or estimate
1. Census count	281,421,906
2. DA estimate	281,759,858
3. A.C.E. Revision II estimate	280,090,250 (541,631)
Net Census undercount	
4. DA estimate (= 2–1)	337,952
5. A.C.E. Revision II estimate (= 3–1)	− 1,331,656 (541,631)
Percent Net Census undercount	
6. DA estimate (= 4/2*100)	0.12%
7. A.C.E. Revision II estimate (= 5/3)	− 0.48% (0.20%)

Source: Robinson and Adlakha 2002.
Note: 1) A.C.E. Revision II estimate includes an adjustment for correlation bias, based on the DA sex ratios for adult males.
2) DA reflects revised estimate published in Robinson (2001).

For Black males, both methodologies estimate a net undercount while for Black females and non-Black females, both measure a net overcount. For non-Black males Demographic Analysis estimates a small net undercount and the A.C.E. Revision II estimates a small net overcount (U.S. Census Bureau 2003b).

Figures 1 and 2 provide a historical perspective. Figure 1 shows estimates of percent net undercount at the national level from the 1980, 1990, and 2000 implementations of post-enumeration surveys and Demographic Analysis. The estimated net undercount from the two methods has been comparable for the past three censuses.

Figure 2 shows Demographic Analysis estimates of the percent net undercount for the U.S. as well as separately for Blacks and non-Blacks for censuses from 1940 to 2000 (Long, Robinson, and Gibson 2003). Census 2000 was able to lower the difference between the percent net undercounts for Blacks and the U.S., called the percent differential undercount for Blacks, substantially to 2.7 (2.8 − 0.1). From 1940 through 1990, the percent differential undercount for Blacks ranged from 3.0 to 3.9 percent. Reduction in the differential undercount for a group improves the accuracy of the group's proportion of the population, called its population share. The accuracy of an area's share is important in determining the number of representatives or the amount of funds it receives (Citro and Cohen 1985; Spencer 1980).

6. Survey Design for Evaluating Census 2000

A.C.E. Revision II used data collected for the A.C.E. along with additional data collected and processed in subsequent evaluations and research. The A.C.E. evaluated the coverage of Census 2000 only for individuals living in housing units. The A.C.E. did not assess the coverage of individuals living in group quarters such as college dormitories, nursing homes, and prisons.

The design of the A.C.E. applied the basic concepts of a post-enumeration survey (Hogan 2003; Childers 2001). The E- and P-samples for the A.C.E. used the same sample of block clusters, which may be one block or several smaller blocks grouped together.

Table 5. Estimates of percent net undercount for Census 2000 by race, sex, and age based on Demographic Analysis (DA) and A.C.E. Revision II

Category	DA	A.C.E. Revision II	A.C.E. Revision II standard error
Black male			
All ages	5.15	4.19	0.43
0–9	3.26	0.72	0.73
10–17	−1.88	−0.59	0.68
18–29	5.71	6.14	0.94
30–49	9.87	8.29	0.53
50 +	3.87	2.43	0.62
Black female			
All ages	0.52	−0.61	0.43
0–9	3.60	0.70	0.73
10–17	−1.20	−0.55	0.68
18–29	−0.66	0.00	0.94
30–49	1.28	−0.40	0.53
50 +	−1.03	−2.51	0.62
Non-black male			
All ages	0.21	−0.19	0.22
0–9	2.18	−0.68	0.33
10–17	−2.01	−1.46	0.42
18–29	−0.63	0.19	0.70
30–49	0.63	1.05	0.25
50 +	0.14	−1.10	0.27
Non-black female			
All ages	−0.78	−1.41	0.20
0–9	2.59	−0.68	0.33
10–17	−1.55	−1.44	0.42
18–29	−1.94	−1.54	0.53
30–49	−1.01	−0.63	0.25
50 +	−1.18	−2.42	0.27

Source: Robinson and Adlakha 2002.
Note: See Table 4.

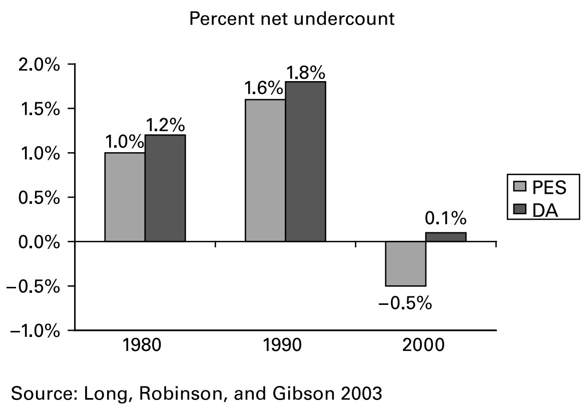
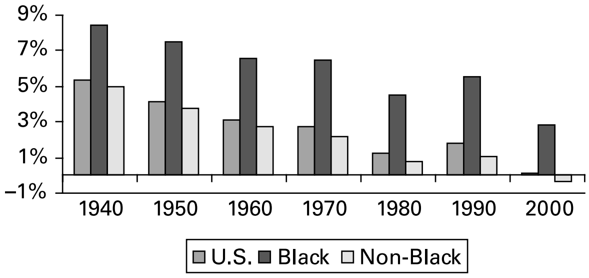


Fig. 1. Percent net undercount estimates from post-enumeration surveys and demographic analysis for the 1980–2000 censuses



Source: Long, Robinson, and Gibson 2003

Fig. 2. Demographic analysis estimates of percent net undercount for the U.S., blacks, and non-blacks for the 1940–2000 censuses

A sample of 11,303 block clusters was selected from all block clusters in the 50 states and the District of Columbia. In the very large block clusters, a subsample was selected. The E-sample had 311,029 housing units, and the P-sample had 300,913 housing units (U.S. Census Bureau 2004). All the enumerations geocoded to the sample block clusters, or subsampled portion, were in the E-sample. An independent listing of housing units that did not rely on any of the Census 2000 addresses was constructed in the sample block clusters. Interviewers listed all people living in the housing units in the sample block clusters, or subsampled portion, for the P-sample and did not use any information from the census regarding the block cluster or household.

The A.C.E. design had several basic steps, which are explained in more detail in the following sections. First, interviewers created a list of all the housing units in the sample block clusters. Next, P-sample interviews were conducted at all the housing units. With the data collected, cases were matched to the census on a case-by-case basis. When there was uncertainty about whether a P-sample person was actually enumerated in the census (or should have been) or whether an E-sample enumeration should have been included at all or in the sample block, a follow-up interview was conducted. With the additional information, a final matching operation was conducted.

6.1. Data Collection for A.C.E

Prior to the A.C.E. interviewing, interviewers listed all the addresses in the sample blocks. The operation was designed to create a list independent from the census. No information from the census address list was used. The interviewers could not work on the A.C.E. address list in any area where they had worked on the census. Then the A.C.E. list of addresses was matched to the census list of addresses for the sample blocks. When there were discrepancies or uncertainty as to whether an address on the A.C.E. list was the same as an address on the census list, these cases were sent to the field for interviewers to collect additional information.

The A.C.E. interviewers used laptop computers to collect data from respondents. After the resolution of discrepancies in the address lists, a merged list of addresses for each sample block cluster was loaded into the laptop computer for the interviewer assigned to the area. The laptop had the advantage of containing the entire questionnaire and could automatically do the branching when different answers required different subsequent questions.

After the interviews were completed, the interviewers transmitted the data electronically to the A.C.E. processing center. Having the data in electronic format enabled the processing to proceed faster than it would have if the interview had been conducted with a paper questionnaire that required a keying operation to convert the answers to electronic format.

For the A.C.E. treatment for movers, the interviewers collected information about the residents on the day of the interview and the residents on Census Day, who may or may not have been the same people. The interviewing operation obtained interviews about the residents of 97 percent of the 261,969 housing units in the P-sample that were occupied on Census Day and 98.9 percent of the 267,155 P-sample housing units that were occupied on the day of the interview (Cantwell and Ikeda 2003). The estimation included an adjustment for the housing units not interviewed (Cantwell and Ikeda 2003).

6.2. Matching Operation and Follow-up for A.C.E

The A.C.E. for Census 2000 considered a person to be correctly enumerated only if the person was enumerated at the person's "usual residence," defined as the place where the person lives and sleeps most of the time surrounding April 1, 2000, Census Day. Therefore, the matching operation searched for an enumeration only in the vicinity of a person's usual residence. Also, the interviewers asked questions designed to determine a person's usual residence. The 1990 Post-Enumeration Survey used the same definition for correctly enumerated.

After the data collected in the A.C.E. interviews were transmitted to a processing center, a computer-assisted clerical operation matched the P-sample people to the census enumerations in the sample blocks. The search was expanded to the surrounding blocks for a subsample of the enumerations where there was a possibility that the housing unit was geographically coded to the wrong block. The easier cases were matched by computer before the matchers received the data. The matchers used an automated system to view the census data and the P-sample data. For the E-sample enumerations, the matchers determined whether they were correct, erroneous, or unresolved. For the P-sample people, the matchers determined whether they were residents of the sample block and whether they matched a census enumeration, did not match, or were unresolved. The matchers used the P-sample person's name and other characteristics to decide if the person matched a census enumeration. Other information collected on the questionnaires aided the matchers in determining if the P-sample people were residents of the sample block cluster on Census Day. The matchers entered the codes that they assigned to cases reflecting their conclusions into the automated system.

When the matchers could not resolve whether an E-sample enumeration was correct or erroneous or whether a P-sample person was a resident of the sample block on Census Day or matched a census enumeration, the case was sent for further data collection, called a follow-up. In the field the interviewers conducted interviews with paper questionnaires that sometimes had special questions tailored to resolve the ambiguity. With the additional data, the matchers made final determinations for the cases sent to follow-up.

Sometimes the ambiguity was not clarified. These cases retained a final status of unresolved, and an imputation of their final status was entered. In the E-sample, 3 percent of the enumerations were unresolved and received imputed probabilities of being a correct enumeration. For 2 percent of the P-sample people, the operation could not determine whether they were a resident of the sample block on Census Day and a probability of being a resident was imputed. The match status was unresolved for 1 percent of the P-sample people, and a probability of being included in the census was imputed. Those whose match status was unresolved also had an unresolved residence status, so no one received an imputed match status without receiving an imputed residence status (Cantwell and Ikeda 2003).

6.3. Lessons About A.C.E. Design

The evaluations of the original A.C.E. and the A.C.E. Revision II estimates of census coverage error proved to be very important because they provided valuable information about the quality of the census as well as the post-enumeration survey operation and estimates. The evaluations of the original A.C.E. estimates detected erroneous enumerations that the A.C.E. failed to detect. The evaluations of the A.C.E. Revision II estimates confirmed the presence of duplicate enumerations in the census and provided insight into the quality of the A.C.E. Revision II estimates themselves, as discussed further in Section 8 (Mulry and Petroni 2003; Mulry 2004). The evaluations also provided information about the design of the data collection and processing for A.C.E.

Several evaluation studies indicated weaknesses in the collection of Census Day residence. Previously, the assumption for post-enumeration surveys had been that the combination of questionnaire probes about usual residence and moves asked by high-quality interviewers could obtain accurate information. However, there was evidence to the contrary from a computerized search for P-sample people among the census enumerations outside the area where the A.C.E. matching operation searched, which was the sample block cluster. The search of the entire census was able to link 6.08 million P-sample people who reported they were not movers and their usual residence was in the A.C.E. sample blocks on Census Day, to census enumerations outside the A.C.E. search area. Of the 6.08 million, 3.24 million also matched to enumerations within the A.C.E. search area and 2.84 million were nonmatches (Mule 2002). These links raised doubts about whether the P-sample persons actually were Census Day residents at the address they reported (U.S. Census Bureau 2003b). Reviews of the questionnaires found unreliable identification of moves, second homes, and stays in group quarters residences. These reviews concluded that there were fundamental problems with how the questionnaires asked about the usual residence of a person and that improving the quality of data collected would require intensive questionnaire design and testing (Martin, Fay, and Krejsa 2002). Interviewers had to use notes to describe more complicated cases (Adams and Krejsa 2002a; Martin, Fay, and Krejsa 2002). Also, in a reinterview, 37 percent of the people who originally stated they had moved into the sample block between Census Day and the A.C.E. interview reported they had not moved. Of those, 40 percent matched to census enumerations and 10 percent were duplicates of other nonmovers (Krejsa and Raglin 2001).

Another discovery was that the selection keys for laptop data entry can contribute to errors. The degree of inconsistency in reporting the sex of E- and P-sample cases that matched was higher than expected (Farber 2001). Further investigation found that the inconsistency might have been related to laptop data entry design. The keys for entering sex were "1" and "2," which by their close proximity led to errors. A better choice would have used keys further apart on the keyboard, such as "1" and "5," or with meaning, such as "M" and "F" (Love and Byrne 2004).

A.C.E. Revision II demonstrated that automated coding with the data collected on the follow-up questionnaire is possible for a large number of cases. The recoding operation assigned some of the E- and P-sample codes by a computer algorithm using keyed data from the follow-up form, with the rest assigned clerically by the U.S. Census Bureau's elite matching team (Adams and Krejsa 2002a). Concerns arose that the automated assignment of enumeration and residence status for some of the cases increased the possibility of error in the estimates. An evaluation based on a subsample of cases coded both ways indicated that the error from the automated coding was very small (Adams and Krejsa 2002b).

Using clerical searching to augment automated searching within block clusters increases the number of duplicates found. Within the A.C.E. block clusters, the A.C.E. Revision II computerized matching found 1.2 million duplicates, but the combination of A.C.E. computer and clerical matching found 1.9 million duplicates (Mule 2002). However, when clerical matchers looked for additional duplicates in households where a member linked to someone outside the A.C.E. sample block cluster, they found very few (Byrne, Beaghen, and Mulry 2003).

The clerical matching operation used a computerized system, which proved very effective in keeping coding error at a low level. An evaluation of the error in the E-sample processing used the expert matching team to reprocess the same data in the block clusters in a subsample of the A.C.E. block clusters. Then the evaluation calculated two measures to compare the original and reprocessed codes: (1) the gross difference rate, the proportion of cases whose classification changed, and (2) the net difference rate, the sum of the absolute difference for each coding category divided by the population total. The evaluation found a P-sample gross difference rate of 0.46 percent and a net rate of 0.41 percent. For the E-sample the evaluation found a gross difference rate of 0.62 percent and a net rate of 0.20 percent (Bean 2001).

7. A.C.E. Revision II Estimation

Since A.C.E. evaluations found erroneous enumerations the A.C.E. did not detect, the U.S. Census Bureau pursued a complete revision, the A.C.E. Revision II, to provide census coverage estimates for geographic areas and possible use in the Intercensal Population Estimates Program. No new data were collected for the revision, but data were extensively reanalyzed and additional data sources were tapped. Preparations for the revision included research with the census data, the development of improved methods for processing data collected for evaluations of the A.C.E., and the development of an estimator that incorporated corrections based on the results (U.S. Census Bureau 2003b).

7.1. Different E- and P-sample Poststratification

For the first time, the A.C.E. Revision II poststratification reflected one set of variables related to erroneous inclusions and a different set of variables related to omissions. Previous estimates of census coverage error used the same variables for poststratification of the E- and P-samples. Having separate post-stratifications permitted the use of census operations variables for the E-sample since there were no requirement for the variables to be defined for people in the P-sample that the census missed. The E-sample poststratification included census proxy response and a variable for timing of the return of the census questionnaire (U.S. Census Bureau 2003b)

The use of separate poststratification variables and the choice of the variables, particularly those concerning census operations, appears to have been problematic for some of the smaller areas (Mulry et al. 2005). Some small places, which are cities and towns, received estimates of extreme overcounts. For example, undercount rates lower than −10 percent (i.e., overcount rates larger than 10 percent) were estimated for 107 of the 19,269 places in the U. S.; all 107 had populations under 10,000 and 76 had populations under 100. Undercount rates larger than 5 percent were estimated for 15 places; all had populations under 10,000 and 9 had populations under 100 (U.S. Census Bureau 2003b).

7.2. Corrections to the Correct Enumeration Rate

The corrections to the correct enumeration rate were based on the results of the computerized search for duplicates and a recoding of a subsample of the A.C.E. sample. Since the evaluations of the A.C.E. found errors in the assignment of enumeration and residence status codes for the E- and P-samples, respectively, the A.C.E. Revision II methodology included recoding the subsample of the A.C.E. sample that were interviewed in the Evaluation Follow-up and using the results in the estimation. The recoding for A.C.E. Revision II had to reprocess 69,318 E-sample enumerations and 52,671 P-sample people. The operation assigned some of the E- and P-sample codes by a computer algorithm, with the rest assigned clerically by the U.S. Census Bureau's elite matching team. The clerical matchers assigned codes to 23,988 people (Adams and Krejsa 2002b). The strategy of combining automated and clerical coding permitted recoding of a larger sample in the time available and most likely reduced the variance of the A.C.E. Revision II.

Corrections were applied to the numerators of the correct enumeration rates, $r_{CE,i}$, in Equation (1). The denominators of the correct enumeration rates were not affected. The E-sample enumerations were divided into two groups, based on whether or not the computerized search linked them to another enumeration outside the A.C.E. search area. For those with a duplicate enumeration identified by the computerized search, the basic principle followed was that each detected duplicate pair would contribute one correct enumeration in the A.C.E. Revision II estimation (Bell 2003) and on the average, the probability of being a correct enumeration for the member of the pair in the E-sample was $\frac{1}{2}$. This principle was used in the construction of the A.C.E. Preliminary Revised Estimates (Fay 2002b). An additional feature for A.C.E. Revision II was that for some situations, one of the pair was designated correct and the other erroneous, so that when, for example, one was in a group quarters and the other in a housing unit, the group quarters enumeration was considered correct. For the E-sample enumerations without duplicates, an adjustment based on the results of the re-coding of a subsample was applied to their total number of correct enumerations estimated from the original A.C.E.

7.3. Corrections to Match Rate

The corrections used data from the computerized search to find P-sample people who linked to census enumerations outside the A.C.E. search area and a recoding of a subsample that combined the results of two A.C.E evaluations with the recoding for A.C.E. Revision II. The recoding for A.C.E. Revision II produced improved coding for residence status for the subsample of the A.C.E. sample that went to follow-up. However, the recoding of match status for the P-sample came from a combination of the codes assigned in the A.C.E. evaluations of measurement error (Krejsa and Raglin 2001) along with the additional matches in the surrounding block discovered by the A.C.E. evaluation of matching error (Bean 2001). Drawing from the results of these evaluations appeared to provide the best coding available, and any further recoding probably would not provide better codes (U.S. Census Bureau 2003b).

Corrections were applied to both the estimates of matches and the estimates of P-sample residents that are the numerators and denominators of the match rates, $r_{M,j}$, in Equation (1). The P-sample enumerations were divided into two groups, based on whether or not they linked to an enumeration outside the A.C.E. search area. For the P-sample people that had such a link, there was no symmetry argument for estimating the probability of being a resident of the sample block that was analogous to that used for estimating correct enumeration probabilities for E-sample people with duplicates. Therefore, the P-sample matches and nonmatches linking to enumerations outside the search area were assigned probabilities of being a resident equal to the probabilities of being a correct enumeration derived for corresponding E-sample matches and nonmatches with duplicates. The recoding of a subsample for A.C.E. Revision II suggested, but did not prove, that the probability of being a resident of the sample block on Census Day for a P-sample person who linked to a census enumeration outside the A.C.E. search area was similar to the probability of being correct for an E-sample enumeration with a link to another enumeration outside the A.C.E. search area. The recoding operation coded 76.9 percent of the E-sample enumerations with a link as correct and 76.2 percent of the P-sample people with a link as residents of the sample block on Census Day (U.S. Census Bureau 2003b). The error due to the choice of the model for estimating the probability of being a Census Day resident for P-sample people with a link was assessed through a sensitivity analysis embedded in the loss function analysis discussed in Section 8.2 (Mulry, ZuWallack, and Spencer 2003, p. 7) For this analysis, the estimation of the variance of the percent net undercount estimate included a nonsampling component due to the choice of the model based on the model selected and three reasonable alternative models. Table 6 shows the variance components for the percent net undercount for the U.S., owners, and renters.

Table 6. Estimated variance components due to sampling and to the choice of the model for the probability of being Census Day resident for P-sample people with a link to a census enumeration outside the A.C.E. search area

Group	Census count	Net undercount (%)	SE sampling	SE model for P-sample links
Total	273,586,997	−0.49	0.20	0.18
Owner	187,924,850	−1.25	0.20	0.16
Renter	85,662,147	1.14	0.36	0.21

Source: Mulry, ZuWallack, and Spencer 2003 and U.S. Census Bureau 2003b.

For these groups, the estimated standard error due to the model was comparable to the estimated standard error due to sampling. However, as the size of the groups defined by race/Hispanic ethnicity and tenure decreased, the error due to the model became less prominent relative to the standard error due to sampling. When the groups Asians, Pacific Islanders, and American Indians On and Off Reservations were divided by tenure, the ratio of the standard error due to the model to the standard error due to sampling ranged from 3 to 37 percent (Mulry, ZuWallack, and Spencer 2002).

For P-sample people without a link to an enumeration outside the search area, adjustments based on the results of the recoding of a subsample were applied separately to their population total and number of matches estimated from the original A.C.E (U.S. Census Bureau 2003b).

7.4. Correction for Correlation Bias

The U.S. Census Bureau decided to include a correction for correlation bias in the A.C.E. Revision II estimator. In previous post-enumeration surveys, the erroneous inclusions appeared to be much smaller in numbers than the omissions. In this setting not adjusting estimates for correlation bias had the effect of understating the net undercount, which resulted in population estimates that were in the right direction but not large enough. In the presence of overcounts, it is possible that the estimated net error without including correlation bias might not even be in the right direction, and the population estimate could have relative errors larger than the census (U.S. Census Bureau 2003b).

Estimates of correlation bias used the sex ratios from Demographic Analysis estimates (Robinson and Adlakha 2002). The simple model used for the correlation bias adjustment in the A.C.E. Revision II estimates assumed that relative correlation bias was constant for adult males within the age-race groups. The correlation bias estimates were made only for adult males under the assumption of no correlation bias for adult females. Also, correlation bias was not estimated for children. The correlation bias adjustments were done separately for Blacks and non-Blacks to the poststrata within three age categories: 18–29, 30–49, and 50 and over, with the exception of non-Black males 18 to 29 years of age, a group for which the data would not support estimation of correlation bias for males (U.S. Census Bureau 2003b). For Blacks, the correlation bias adjustment rates were 8 percent for 18–29, 10 percent for 30–49, and 5 percent for 50+. For non-Blacks, the correlation bias adjustment rates were 2 percent for 30–49 and 1 percent for 50+ (Shores 2002). The assumptions and model underlying the measurement of correlation bias are discussed in detail in an article by Bell (2001).

8. Evaluations of A.C.E. Revision II Estimates

The evaluations of the A.C.E Revision II estimates were relatively limited because data that previously were used to evaluate the A.C.E. estimates were used to produce the A.C.E. Revision II estimates to correct for the major biases. The limited volume of data available for evaluation does not itself reflect negatively on the A.C.E. Revision II estimates. Rather, the U.S. Census Bureau believes that because of the corrections for these major biases, the A.C.E. Revision II estimates are of much higher quality than the original A.C.E. estimates (U.S. Census Bureau 2003b). The evaluations of the estimates of census duplicates, relative error in the census and A.C.E. estimates, and synthetic error are discussed in this section.

Other evaluations examined the potential for bias in the match rate due to inconsistent reporting in the census and the P-sample of the variables used in the poststratification as well as the violation of assumptions about movers and missing data in the estimation. Evaluations found that these potential sources of error had very little effect on the A.C.E. Revision II estimates or their estimated variances (U.S. Census Bureau 2003b).

8.1. Evaluation of Estimates of Duplication

Two evaluation studies examined the A.C.E. Revision II estimates of census duplications. One evaluation formed an alternative estimate of duplicates using administrative records, and the other was a clerical review of a subsample of the A.C.E. Revision II duplicates and the administrative records duplicates. The administrative records came from the Statistical Administrative Records System, created with newly developed administrative records database methodology (Leggieri, Pistiner, and Farber 2002; Judson 2000). The clerical review offered a validation of the estimates of duplicate enumerations based on only census information but raised questions about the accuracy of some types of duplicates identified only with administrative records. The results pointed to areas for refinements in evaluating census duplicates with administrative records. The validation of the presence of duplicate enumerations through the use of administrative records demonstrated that administrative records provided a viable tool for the evaluation of census duplication (Mulry et al. 2006).

8.2. Evaluation of Relative Error

An evaluation examined the relative error in the census and the A.C.E. Revision II estimates by using the data from the other evaluations to estimate bias (systematic error) and variance (random error). The estimated bias and variance were then used to construct bias-corrected confidence intervals and perform a loss function analysis (Mulry, ZuWallack, and Spencer 2003). The loss function analysis examined the relative accuracy by using the estimates of sampling variance and nonsampling bias and variance to estimate the aggregate expected loss for the census and the A.C.E. Revision II for population levels and shares for counties and places across the nation and within state. The measure of accuracy used by the loss functions was the weighted mean squared error with the weights set to the reciprocal of the census count for levels and the reciprocal of census share for shares. If the estimates for small areas were problematic, the weighting by population size minimizes the influence of these small areas on the results of the loss function analyses.

The evaluations of bias were relatively limited because data that previously were used to estimate bias were incorporated into the A.C.E. Revision II estimates in order to correct for major errors discovered in the original A.C.E. estimates. Although the evaluations did account for the variance arising from the corrections for bias, the corrections for bias in the A.C.E. Revision II estimates may themselves have been subject to bias, the magnitude of which was not quantified. This was particularly true for the corrections for correlation bias and for P-sample cases that linked to census enumerations outside the A.C.E. search area since several models fit the data, and no information was available to enable selecting among the models on the basis of bias. Other criteria, such as variance, had to be used (U.S. Census Bureau 2003b).

The loss function analysis accounted for some but not all error components that could be identified in the A.C.E. Revision II estimates. More specifically, the bias estimate included components for error from inconsistency of poststratification assignments based on census versus A.C.E. data, for error from estimating the numbers of outmovers by the numbers of inmovers, and most importantly, for error in the estimates of census duplicates, although evaluations indicate that this error may have been misestimated. The variance estimate included sampling error components from both phases of sampling in A.C.E. Revision II estimates, and also random nonsampling error components from choice of imputation models and for models used to account for P-sample cases that matched census enumerations outside the search area. On the other hand, the loss function analysis did not account for the following errors: synthetic estimation error; bias from response error and coding error in P-sample residency status, match status, and mover status; bias from response error and coding error in E-sample correct enumeration status; bias in correlation bias adjustments to the estimates due to error in the Demographic Analysis sex ratios and to the choice of model used to implement the adjustments; and bias due to the choice of model used to adjust the DSE for E-sample cases with duplicate links; bias from the use of separate poststratification variables for the E- and P-samples (Mulry, ZuWallack, and Spencer 2003). Though not included in the loss functions, a partial evaluation of synthetic error is described in the next section.

The synthesis of the available evaluation data detected a small amount of bias in the A.C.E. Revision II estimate of the net undercount rate at the national level, only -0.16 percent. Based on the bias-corrected 95-percent confidence intervals, both the census and the A.C.E. Revision II estimates were too low for Non-Hispanic Blacks and both Non-Hispanic Black Owners and Renters. The intervals showed the census was too high for Non-Hispanic Whites, Owners, Non-Hispanic White Owners, and Hispanic Owners. All other census and A.C.E. Revision II estimates were covered by their bias-corrected 95-percent confidence intervals. The source of most of the bias estimate was based on the evaluation of the identification of duplicates using administrative records (Mulry, ZuWallack, and Spencer 2003).

The loss function analyses indicated that A.C.E. Revision II was more accurate than the census for every loss function considered, with the exception of levels for places with a population of at least 100,000. The bulk of the error in A.C.E. Revision II for places with a population of at least 100,000 appeared to lie in the nine places with a population of at least 1 million. More research is needed to understand the one exceptional result. The validity of the loss function analysis depended on the quality of the estimates of components of error in A.C.E. Revision II, and some of those components were not accurately quantified. The synthetic error, in particular, was not addressed adequately but is discussed further in Section 8.3 (Mulry, ZuWallack, and Spencer 2003.

In general, one cannot be certain whether omitted biases tend to make any given loss function analysis overstate or understate the comparative accuracy of the A.C.E. Revision II estimates relative to the census. Whether omitted biases caused the loss function to favor the census or A.C.E. Revision II depended on the signs of the correlations between the omitted biases and the expected undercount rate for the areas considered (Mulry and Spencer 2001). Therefore, the nature of omitted biases, not just their mere existence, affects the direction of error in the loss function analysis. While the loss function evaluations suggested the superiority of the A.C.E. Revision II estimates, concerns did remain about whether the bias estimates used in the loss function analysis were of sufficient quality to assure the correctness of the results (Mulry, ZuWallack, and Spencer 2003).

8.3. Evaluation of Synthetic Error

Synthetic assumptions were used in the construction of the A.C.E. Revision II estimates. One type of synthetic assumption involved correcting the individual poststratum estimates for errors estimated at more aggregate levels, such as the corrections for correlation bias, duplicates, and measurement coding error. All involve estimates at a very aggregate level with little or no information available about how the effects being estimated truly affect correct enumeration rates and census inclusion probabilities for individual poststrata. For example, the correction for correlation bias relies on a synthetic assumption that correlation bias for adult males is constant over persons within the age-race groups (U.S. Census Bureau 2003b).

Another synthetic assumption is used in the application of poststratum coverage correction factors to specific areas within the poststratum. An evaluation focused on the synthetic estimation bias that arises when the census data from different areas but in the same poststratum have different coverage error rates but have the same coverage correction factors. The evaluation attempted to estimate synthetic estimation bias in undercount estimates from analysis of "artificial populations" or "surrogate" variables that are correlated with coverage error whose geographic distributions are known. These surrogate variables were constructed to be related to net coverage error as well as possible by using the difference between one variable that was correlated with erroneous enumerations in the E-sample and another variable that was correlated with nonmatches in the P-sample. Sensitivity analyses of four artificial populations generally did not change the overall loss function findings (Griffin 2002), though the analyses were not considered conclusive. Any limitations of the loss functions regarding synthetic error are expected to be more important when comparing small places or counties than when comparing large places or counties. Since the correction factors were extreme for some poststrata, violations of the synthetic assumption of a uniform coverage error rate within poststrata could produce inaccurate estimates in the areas with population concentrations in such poststrata. As mentioned in Section 7.1, some small areas had overcount estimates that were considered extreme.

9. Epilogue

The U.S. Census Bureau did not use the A.C.E. Revision II estimates in an adjustment of the census base for the intercensal population estimates program because of the technical limitations. The concern about the A.C.E. Revision II estimates focused on the correlation bias adjustment, the estimation methodology for small areas, and inconsistencies with demographic analysis. Data limitations forced the adjustment to correct for correlation bias to use only two race categories, Black/non-Black, although correlation bias was not expected to occur at the same rate within the non-Black category. The estimates of extreme overcounts for some small places could not be validated or explained and created a concern that a systematic problem existed in the estimates for all small areas. While the A.C.E. Revision II estimates and the Demographic Analysis estimates for the whole U.S. were reasonably consistent, A.C.E. Revision II estimated a small net overcount (not statistically significant) for children aged 0–9 while Demographic Analysis estimated a net undercount of 2.56 percent. Demographic Analysis estimates for this group are believed to be highly accurate because they rely primarily on recent birth registration data (U.S. Census Bureau 2003c).

Although concerns about some of the technical limitations of A.C.E. Revision II estimates led to the U.S. Census Bureau's decision not to adjust the population base for the intercensal estimates, the results are influencing the planning and research for the 2010 Census and the evaluation of the coverage of the 2010 Census. The large number of duplicate enumerations found in Census 2000 illuminated the need to develop improved methodology for identifying and resolving potential duplicates. Another thing that became apparent was the need to improve how the census and the coverage evaluation ascertain usual residence on Census Day. The 2004 and 2006 Census Tests (U.S. Census Bureau 2003a; Kostanich, Whitford, and Bell 2004) include examining methodology for detecting and removing duplicate enumerations before the census is completed in addition to methodology designed to reduce the number of people missed by the census. Also underway are investigations of methods to improve the design of questions that ask a person's Census Day residence for the census and for the measurement of coverage error.

The A.C.E. Revision II results showed that a very small net overcount was a result of a large number of erroneous census inclusions that would have had to be offset by an almost equally large number of census omissions. These results have prompted an expansion of the coverage measurement goals for 2010 beyond estimating net error to include estimating individual components of coverage error, meaning viable separate estimates of erroneous enumerations and omissions. Testing of methodology and operations for estimating components of coverage error and net coverage error are included in the 2006 Census Test (Kostanich, Whitford, and Bell 2004). The design of the program is drawing on the methodological and operational lessons learned from the A.C.E. (Childers and Petroni 2004) and the A.C.E. Revision II as well as the results of continuing research on estimation methodology.

10. References

Adams, T. and Krejsa, E.A. (2001). ESCAP II: Results of the Person Follow-up and the Evaluation Follow-up Forms Review. Executive Steering Committee for A.C.E. Policy II, Report No. 24, October 12. U.S. Census Bureau, Washington, DC. http://www.census.gov/dmd/www/pdf/Report24.PDF

Adams, T. and Krejsa, E. (2002a). A.C.E. Revision II Measurement Subgroup Documentation. DSSD A.C.E. Revision II Memorandum Series #PP- 6. U.S. Census Bureau, Washington, DC. http://www.census.gov/dmd/www/pdf/pp-06r.pdf

Adams, T. and Krejsa, E. (2002b). Evaluation of At-Risk Codes. DSSD A.C.E. Revision II Memorandum Series #PP- 45. U.S. Census Bureau, Washington, DC. http://www.census.gov/dmd/www/pdf/pp-45r.pdf

Bean, S.L. (2001). ESCAP II: Accuracy and Coverage Evaluation Matching Error. Executive Steering Committee for A.C.E. Policy II, Report No. 7, October 12. U.S. Census Bureau, Washington, DC. http://www.census.gov/dmd/www/pdf/Report7.PDF

Bell, W.R. (1993). Using Information from Demographic Analysis in Post-Enumeration Survey Estimation. Journal of the American Statistical Association, 88, 1106–1118.

Bell, W.R. (2001). ESCAP II: Estimation of Correlation Bias in 2000 A.C.E. Using Revised Demographic Analysis Results. Executive Steering Committee for A.C.E. Policy II, Report No. 10, October 13. U.S. Census Bureau. http://www.census.gov/dmd/www/pdf/Report10.PDF

Bell, W.R. (2003). Alternative Options for Tabulating Estimates of Census Correct Enumerations Allowing for Duplicate Links. DSSD A.C.E. Revision II Memorandum Series #PP- 3. U.S. Census Bureau, Washington, DC. http://www.census.gov/dmd/www/pdf/pp-03.pdf

Byrne, R., Beaghen, M., and Mulry, M.H. (2003). Clerical Review of Census Duplicates. Proceedings of the American Statistical Association, Section on Survey Research Methods [CD-ROM]. American Statistical Association, Alexandria, VA, 769–771.

Cantwell, P. and Ikeda, M. (2003). Handling Missing Data in the 2000 Accuracy and Coverage Evaluation Survey. Survey Methodology, 29, 139–145.

Chandrasekar, 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, 44, 101–115.

Childers, D.R. (2001). Accuracy and Coverage Evaluation: The Design Document. DSSD Census 2000 Procedures and Operations Memorandum Series, Chapter S-DT-1, Revised. Decennial Statistical Studies Division, January 26. U.S. Census Bureau, Washington, DC. http://www.census.gov/dmd/www/pdf/S-DT-1R.pdf

Childers, D.R. and Petroni, R.J. (2004). Coverage Measurement from the Perspective of March 2001 A.C.E. Census Testing, Experimentation, and Evaluation Program, Topic Report Series, No. 4, TR-4. U.S. Census Bureau, Washington, DC. http://www.census.gov/pred/www/rpts/TR4.pdf

Citro, C.F. and Cohen, M.L. (1985). The Bicentennial Census: New Directions for Methodology in 1990. National Academy of Science Press, Washington, DC.

Citro, C.F., Cork, D.L., and Norwood, J.L. (2004). The 2000 Census: Counting Under Adversity. Panel to Review the 2000 Census. Committee on National Statistics, Division of Behavioral and Social Sciences and Education. The National Academies Press, Washington, DC.

Farber, J. (2001). Accuracy and Coverage Evaluation: Consistency of Post-Stratification Variables. DSSD Census 2000 Procedures and Operations Memorandum Series B-10*. U.S. Census Bureau, Washington, DC. http://www.census.gov/dmd/www/pdf/Fr10.pdf

Fay, R.E. (2001). The 2000 Housing Unit Duplication Operations and Their Effect on the Accuracy of the Population Count. Proceedings of the American Statistical Association [CD-ROM]. American Statistical Association, Alexandria, VA.

Fay, R.E. (2002a). Probabilistic Models for Detecting Census Person Duplication. Proceedings of the American Statistical Association, Section on Survey Research Methods [CD-ROM]. American Statistical Association, Alexandria, VA. 969–974.

Fay, R.E. (2002b). Evidence of Additional Erroneous Enumerations from the Person Duplication Study. Executive Steering Committee for A.C.E. Policy II, Report No. 9. Revised March. U.S. Census Bureau, Washington, DC. http://www.census.gov/dmd/www/pdf/report9revised.pdf

Griffin, R.A. (2002). Analysis of Synthetic Assumption. DSSD A.C.E. Revision II Memorandum Series #PP-49. U.S. Census Bureau, Washington, DC. http://www.census.gov/dmd/www/pdf/pp-49r.pdf

Hogan, H. (1992). The 1990 Post-Enumeration Survey: An Overview. The American Statistician, Alexandria, VA, 261–269.

Hogan, H. (1993). The 1990 Post-Enumeration Survey: Operations and Results. Journal of the American Statistical Association, 88, 1047–1060.

Hogan, H. (2003). The Accuracy and Coverage Evaluation: Theory and Design. Survey Methodology, 29, 129–138.

Judson, D.H. (2000). The Statistical Administrative Records System: System Design and Challenges. Paper presented at the NISS/Telcordia Data Quality Conference, November.

Kostanich, D., Whitford, D., and Bell, W.R. (2004). Plans for Measuring Coverage of the 2010 Census. Proceedings of the American Statistical Association, Section on Government Statistics [CD-ROM]. American Statistical Association, Alexandria, VA, 1626–1635.

Krejsa, E.A. and Raglin, D.A. (2001). ESCAP II: Evaluation Results for Changes in A.C.E. Enumeration Status. Executive Steering Committee for A.C.E. Policy II, Report No. 16, October 15. U.S. Census Bureau, Washington, DC. http://www.census.gov/dmd/www/pdf/Report3.PDF

Leggieri, C., Pistiner, A., and Farber, J. (2002). Methods for Conducting an Administrative Records Experiment in Census 2000. Proceedings of the American Statistical Association, Section on Survey Research Methods [CD-ROM]. American Statistical Association, Alexandria, VA, 2709–2713.

Long, J.F., Robinson, J., and Gibson, C. (2003). Setting the Standard for Comparison: Census Accuracy from 1940 to 2000. Proceedings of the American Statistical Association, Section on Government Statistics [CD-ROM]. American Statistical Association, Alexandria, VA, 2515–2524.

Love, K. and Byrne, R. (2005). Investigation Measurement Errors Due to Interviewer Misclassification and Mode. Decennial Statistical Support Division. U.S. Census Bureau, Washington, DC.

Martin, E.A, Fay, R.E., and Krejsa, E.A. (2002). Analysis of Questionnaire Errors in Survey Measurements of Census Coverage. Proceedings of the American Statistical Association Section on Survey Research Methods [CD-ROM]. American Statistical Association, Alexandria, VA, 2260–2265.

Mule, T. (2001). Person Duplication in Census 2000. Executive Steering Committee for A.C.E. Policy II, Report No. 20. October 11. U.S. Census Bureau, Washington, DC. http://www.census.gov/dmd/www/pdf/Report20.pdf

Mule, T. (2002). Further Study of Person Duplication in Census 2000. DSSD A.C.E. Revision II Memorandum Series #PP- 51. U.S. Census Bureau, Washington, DC. http://www.census.gov/dmd/www/pdf/pp-51r.pdf

Mule, T. (2003). Estimate of Census 2000 Person Duplication by Type of Returns 2004. Census Test Memorandum Series # G-5. June 27. U.S. Census Bureau, Washington, DC.

Mulry, M.H. (2000). Post-enumeration Survey. In Encyclopedia of the U.S. Census, Margo Anderson (ed.). Congressional Quarterly, Inc., Washington, DC, 303–306.

Mulry, M.H. (2004). Methodological Lessons from Census 2000 Coverage Error Measurement. Proceedings of the American Statistical Association, Section on Survey Research Methods [CD-ROM]. American Statistical Association, Alexandria, VA, 4066–4071.

Mulry, M.H. and Petroni, R.J. (2003). Evaluation of the A.C.E. Revision II Estimates of Census 2000 Coverage Error. Proceedings of the American Statistical Association, Section on Survey Research Methods [CD-ROM]. American Statistical Association, Alexandria, VA, 2960–2965.

Mulry, M.H. and Spencer, B.D. (1993). Accuracy of the 1990 Census and Undercount Adjustments. Journal of the American Statistical Association, 88, 1080–1091.

Mulry, M.H. and Spencer, B.D. (2001). Overview of Total Error Modeling and Loss Function Analysis. DSSD Census 2000 Procedures and Operations Memorandum Series, Number B-19*. Decennial Statistical Studies Division, February 28. U.S. Census Bureau, Washington, DC. http://www.census.gov/dmd/www/pdf/Fr19.pdf

Mulry, M.H., ZuWallack, R.S., and Spencer, B.D. (2002). Confidence Intervals and Loss Functions. DSSD A.C.E. Revision II Memorandum Series #PP- 42. U.S. Census Bureau, Washington, DC. http://www.census.gov/dmd/www/pdf/pp-42r.pdf

Mulry, M.H., ZuWallack, R.S., and Spencer, B.D. (2003). Loss Function Analysis for A.C.E. Revision II Estimates of Census 2000 Coverage Error. Proceedings of the American Statistical Association, Section on Survey Research Methods [CD-ROM]. American Statistical Association, Alexandria, VA, 2966–2971.

Mulry, M.H., Bean, S.L., Bauder, D.M., Wagner, D., Mule, T., and Petroni, R.J. (2006). Evaluation of Estimates of Census Duplication Using Administrative Records Information. Journal of Official Statistics, 22, 655–679.

Mulry, M.H., Schindler, E., Mule, T., Nguyen, N., and Spencer, B.D. (2005). Investigation of Extreme Estimates of Census Coverage Error for Small Areas. Proceedings of the American Statistical Association, Section on Survey Research Methods [CD-ROM]. American Statistical Association, Alexandria, VA, 3414–3421.

Raglin, D.A. and Bean, S.L. (1999). Outmover Tracing for the Census 2000 Dress Rehearsal. Proceedings of the American Statistical Association, Section on Survey Research Methods. Alexandria, VA, 456–461.

Robinson, J.G. (2001). Demographic Analysis. Executive Steering Committee for A.C.E. Policy II, Report No. 1, October 13. U.S. Census Bureau, Washington, DC. http://www.census.gov/dmd/www/pdf/Report1.PDF

Robinson, J.G. and Adlakha, A. (2002). Comparison of A.C.E. Revision II Results with Demographic Analysis. DSSD A.C.E. Revision II Memorandum Series #PP- 41. U.S. Census Bureau, Washington, DC. http://www.census.gov/dmd/www/pdf/pp-41r.pdf

Shores, R. (2002). Adjustment for Correlation Bias. DSSD A.C.E. Revision II Memorandum Series #PP- 53. U.S. Census Bureau, Washington, DC. http://www.census.gov/dmd/www/pdf/pp-53r.pdf

Smith, D.R. (2004). Long Distance Duplicate Telephone Follow-up Operation. DSSD 2003 Memorandum Series Chapter #A-03, July 8. U.S. Census Bureau, Washington, DC.

Spencer, B.D. (1980). Benefit-Cost Analysis of Data Used to Allocate Funds. New York: Springer Verlag.

Thompson, J., Waite, P., and Fay, R. (2001). Basis of "Revised Early Approximations" of Undercounts, Released Oct. 17. Executive Steering Committee for A.C.E. Policy II, Report 9a. U.S. Census Bureau, Washington, DC. http://www.census.gov/dmd/www/pdf/report9a.pdf

Treat, J.B. (2004). Response Rates and Behavior Analysis. Census 2000 Testing, Experimentation, and Evaluation Program, Topic Report Series, No. 11, TR-11. U.S. Census Bureau, Washington, DC. http://www.census.gov/pred/www/rpts/TR11.pdf

U.S. Census Bureau (2003a). 2004 Census Test Operational Plan. Dated September 29. Decennial Management Division. U.S. Census Bureau, Washington, DC. http://www.census.gov/procur/www/fdca/library/2004-test/2004-Operational-Plan-v2-9-29-03.pdf

U.S. Census Bureau (2003b). Technical Assessment of A.C.E. Revision II, March 12. U.S. Census Bureau, Washington, DC. http://www.census.gov/dmd/www/pdf/ACETechAssess.pdf

U.S. Census Bureau (2003c). Decision on Intercensal Population Estimates. March 12. U.S. Census Bureau, Washington, DC. http://www.census.gov/dmd/www/dipe.html

U.S. Census Bureau (2004). Accuracy and Coverage Evaluation of Census 2000: Design and Methodology. DSSD/03-DM, issued September. U.S. Census Bureau, Washington, DC. http://www.census.gov/prod/2004pubs/dssd03-dm.pdf

Received March 2005
Revised November 2006