Correlation Bias Estimation in the Accuracy and Coverage Evaluation Revision II

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1. INTRODUCTION

Dual system estimates (DSEs) are said to contain bias if they systematically underestimate or overestimate the true population. Biases in the sample estimates of the components of the DSE formula can lead to biases in the DSEs, as discussed in Mulry (1991) and Mulry and Spencer (1991, 1993). Even in the absence of any of these biases, DSEs can still be subject to another form of bias called correlation bias, resulting from failure of the general independence assumption that underlies the DSEs. This independence assumption can fail due to:

- **causal dependence** – the act of being included in the Census makes someone more or less likely to be included in the A.C.E., or
- **heterogeneity** – Census and A.C.E. inclusion probabilities vary over persons within post-strata.

DSEs are constructed within post-strata to reduce heterogeneity in the inclusion probabilities, so heterogeneity leading to correlation bias exists only if the inclusion probabilities vary across persons *within* a post-stratum.

When heterogeneity exists it is generally suspected to be of the form in which persons (within a post-stratum) more likely to be missed in the Census are also more likely to be missed in the coverage survey (A.C.E.). Correlation bias resulting from this form of heterogeneity is negative, reflecting systematic underestimation of the true population by the DSEs. The direction of the effect of causal dependence, if it exists, is less certain. It could be that persons included in the Census are made more aware of the Census process, and hence are more likely to be included in the A.C.E., than are those missed by the Census. This type of dependence would lead to underestimation by the DSEs. Or, it could be that persons included in the Census feel they have already responded to the Census Bureau, and so are more resistant to being included in the A.C.E., than those missed by the Census. This type of dependence would lead to overestimation by the DSEs. While causal dependence can lead to either positive or negative biases in DSEs, generally the concern with correlation bias is heterogeneity leading to underestimation.

In this paper we are concerned with correlation bias in A.C.E. Revision II. The original A.C.E. was found to have problems which A.C.E. Revision II was designed to correct. A.C.E. Revision II consisted of a revised set of estimates resulting from extensive research and evaluation of the data used to produce the A.C.E. We describe evidence of correlation bias from the 1990 census. We discuss why it was important to adjust the A.C.E. Revision II dual system estimates for correlation bias. We compare Demographic Analysis (DA) sex ratios with those from A.C.E. Revision II and the 1990 Post Enumeration Survey. We present the model used in A.C.E. Revision II to conduct correlation bias adjustment and present results obtained from it for certain age/race groups. Correlation bias adjustment is compared to the adjustment for other errors identified in the March 2001 A.C.E. Undercount estimates from various models will be presented for some demographic groups, and state level undercount estimates are presented for these models.

2. CORRELATION BIAS PAST AND PRESENT

Historical evidence of correlation bias in DSEs comes from comparisons of results aggregated to the national level against DA estimates for age-race-sex groups. Comparison of DSE results against DA estimates provides an aggregate check for correlation bias whether due to causal dependence or heterogeneity. Demographic Analysis has the advantage that its estimates are constructed from administrative data sources, some of which (e.g., birth and death registration data) are quite accurate. However, DA estimates are adversely affected by errors in the administrative data, such as uncertainty about the levels of emigration and immigration. The DA sex

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ratios (number of males over number of females) are believed to be more accurate than DA totals and provide a more refined check of correlation bias for adult males (assuming negligible correlation bias for adult females).

In addition to errors in its administrative data sources, the primary limitation of DA results is a lack of detail. Because of difficulties in using administrative data to construct estimates of sub-national migration, sub-national DA estimates are significantly less accurate than are DA national estimates. Also, limited racial detail in the administrative data sources, along with differences in racial classification from the Census, limits separate DA estimates by race to Black and non-Black. This limitation was somewhat more pronounced in 2000 than in 1990 because the allowance of multiple race responses to the 2000 Census created some uncertainty about appropriate definitions of the Black and non-Black groups for comparability of DA and A.C.E. results.

Comparisons of 1990 Post Enumeration Survey (PES) estimates (357 post-strata) against 1990 DA estimates (totals and sex ratios) gave evidence of significant correlation bias in DSEs for adult Black males and possible correlation bias for adult non-Black males (Bell 1991). There was no evidence of correlation bias for children or adult females in the 1990 PES.

Adjustment for correlation bias was considered but ultimately not implemented for the estimates from the 1990 Post Enumeration Survey and for the March 2001 A.C.E. estimates. A major reason was uncertainty about which model was most appropriate for correlation bias adjustment. This uncertainty existed because DA provides estimates only at the national level by age, sex, and Black versus non-Black race groups, making direct estimates of correlation bias available only for certain national aggregates. Various models can be used to synthetically allocate the correlation bias estimated at the national level for adult males to post-strata within the age-race groups. The different models produced different sub-national results. Since different models provided the same fit to the available data, there was uncertainty which could not be resolved about which model was most appropriate.

Since the revised preliminary estimates of Census 2000 net undercount were close to zero, it became necessary to reconsider correlation bias adjustment for the A.C.E. Revision II estimates.

In past censuses, the census count was smaller than both the unadjusted and correlation bias adjusted DSEs. In these cases, use of the unadjusted DSEs to calculate the undercount was guaranteed to bring the estimates closer to the truth (assuming the unadjusted DSEs were smaller than the adjusted DSEs). For the Census 2000 revised estimates, however, there were poststrata for which there existed a true over-count, or a small true undercount. For these poststrata, use of the unadjusted DSEs would mean using population estimates that could be farther from the truth than were the original census counts. Whether this would happen depended on the magnitude of the differences between the unadjusted DSEs, the true counts, and the census counts. Take, for example, the case of an over-count, in which the census counts were larger than the true counts. If these true counts were close to the census counts, while the unadjusted DSEs were much lower than the true counts, then the unadjusted DSEs would be farther from the truth than were the census counts. In this case, the adjusted DSEs would probably be closer to the truth than would the unadjusted DSEs. There were a relatively large number of poststrata for which this situation or that of a small undercount existed. It was decided, therefore, to adjust the A.C.E. Revision II estimates for correlation bias, despite potential problems with doing so.

3. ADJUSTING THE DA ESTIMATES

For comparison to the 2000 A.C.E. Revision II results, we use DA estimates revised as of September 18, 2001 (Robinson 2001a). Differences in definitions between DA and A.C.E. Revision II required adjustments to the data to make the two sets of estimates comparable. Since the goal is to adjust for correlation bias in the A.C.E. Revision II estimates, adjustments for comparability were made to the DA estimates rather than to the A.C.E. Revision II estimates. The following adjustments were made to the DA totals for Blacks and non-Blacks to make them comparable to A.C.E. Revision II results. DA sex ratios could then be computed from these adjusted totals.

The Census count of the group quarters population was subtracted from the 2000 DA totals, since the group quarters population is not part of the A.C.E. Revision II universe. Next, estimates of Black Hispanics were subtracted from the DA totals for Blacks and added to the DA totals for non-Blacks. This adjustment is needed because A.C.E. Revision II assigns Black Hispanics to its Hispanic race domain (domain 3), not to its Black race domain (domain 4). The implied DA estimates of Black Hispanics for 2000 were obtained by inflating the Census counts of Black Hispanics by adjustment factors corresponding to the DA estimates of Black undercount, since separate DA estimates of Hispanic undercount are not available.

Robinson (2001b) explains how alternative Census tabulations corresponding to alternative definitions of the Black and non-Black race groups can be used in comparing the DA and Census results. He considers

two extremes for assignment of individuals to the Black and non-Black groups. Under his first model, only those persons who checked only Black for the Census race question are classified as Black. Under his second model, persons who checked Black and any other race are also classified as Black. In comparing DA and A.C.E. Revision II results, however, this choice affects only the Census group quarters population that is subtracted from the DA totals. In particular, it affects the allocation of the group quarters population to the Black and non-Black race groups. However, the effects on the DA sex ratios were negligible, and thus so were the effects on the estimates of correlation bias. We use only one set of results for sex ratio comparisons and one set for estimating correlation bias. The results are presented using Robinson's second model.

4. COMPARING DA AND A.C.E. REVISION II ESTIMATED SEX RATIOS

Comparisons of DA and A.C.E. Revision II sex ratios, prior to the correlation bias adjustment, are given in Tables 1.a and 1.b. Some highlights from these tables include:

- The 2000 DA sex ratios for adult Blacks significantly exceed those for A.C.E. Revision II, strongly suggesting correlation bias in DSEs for adult Black males.
- The DA sex ratios for non-Blacks 30-49 and 50 and over only slightly exceed those from A.C.E. Revision II, suggesting at most small amounts of correlation bias for persons in these groups.
- The DA sex ratio for non-Blacks 18-29 is slightly lower than that from A.C.E. Revision II. This probably reflects other errors in the DA and revised estimates for this group, rather than saying anything about correlation bias. Because of this anomaly, A.C.E. Revision II did not adjust for correlation bias for non-Blacks 18-29.
- The sex ratio comparisons between DA and A.C.E. Revision II are broadly similar to the corresponding comparisons for 1990. Group quarters populations were treated differently between A.C.E. Revision II and the 1990 PES, and this may explain the higher sex ratios for non-Blacks 50 and over observed for both the 2000 DA and revised estimates in comparison to the corresponding 1990 sex ratios.

Table 1.a Sex Ratios from DA and A.C.E. Revision II

Age	Black A.C.E. Rev II	Black DA	Non-Black A.C.E. Rev II	Non-Black DA
18-29	.83	.90	**1.05**	**1.04**
30-49	.81	.89	.99	1.01
50+	.72	.76	.85	.86

Table 1.b Sex Ratios from DA and the 1990 PES

Age	Black PES	Black DA	Non-Black PES	Non-Black DA
18-29	.83	.90	1.02	1.02
30-49	.84	.91	.99	1.01
50+	.72	.78	.81	.82

Notes to Table 1:

1. The sex ratios for A.C.E. Revision II are those before any adjustments are made to correct for correlation bias.
2. For 2000, DA estimates revised as of September 18, 2001 are used. Before computing the DA sex ratios, the DA totals were adjusted for comparability with A.C.E. Revision II and PES estimates as discussed in the text.
3. Sex ratios for DA in 2000 with race assignment of the group quarters population using Robinson's first model are the same as those with his second model to the accuracy shown in the table.

5. THE CONSTANT RELATIVE BIAS MODEL

A model known as the Constant Relative Bias Model was selected for correlation bias adjustment in A.C.E. Revision II. It assumes that relative correlation bias (percent bias) is constant over male post-strata within adult age groups for Blacks and non-Blacks. This model was selected because it is relatively simple and the variances of the estimates calculated from it are believed to be at least as small as those from any other model that might have been used. It has also been called the Two-Group Model because it can be derived by postulating two groups of people within each male post-stratum (e.g., hard-to-count and easy-to-count), and assuming a parameter relating the two groups is constant across post-strata.

To calculate estimates under this model within each age-race group, we solve the equation

$$\phi \sum DSE\ males = r_{DA} \sum DSE\ females$$

for ϕ by summing over the poststrata in the age-race group, where r_{DA} is the adjusted DA sex ratio for the age-race group, and the right hand side of the equation is a "control total" consisting of the adjusted DA sex ratio for the group multiplied by the summed female DSEs within the group. The control total is accepted as the best estimate of the total count of males in the age-race group. The estimate of ϕ provides a multiplicative correction factor to adjust each male DSE in the age/race group for correlation bias. The parameter ϕ is therefore the ratio of the true population over the expected value of the aggregated male DSEs.

Table 2 gives the estimates of ϕ calculated for A.C.E. Revision II under the Two-Group Model.

Table 2: Estimates of Adjustment Factor for A.C.E. Revision II

Age	Black	Non-Black
18-29	1.08	1.00
30-49	1.10	1.02
50+	1.05	1.01

Table 3.a gives percentage correlation bias estimates for the Constant Relative Bias model for A.C.E. Revision II. These are functions of the above adjustment factors in that they show the percentage by which correlation bias adjusted values are greater than the corresponding unadjusted values. Table 3.b gives similar results for the 1990 PES. Some results:

- The Two-Group Model estimate of relative correlation bias for Black males 18-29 for A.C.E. Revision II is similar to that in 1990, at about eight percent underestimation.

- The estimate of relative correlation bias for Black males 30-49 was slightly higher for A.C.E. Revision II compared to the estimate from 1990 , while the estimate for Black males 50 and over in A.C.E. Revision II was slightly lower than the estimate from 1990.

- A.C.E. Revision II estimates of relative correlation bias for non-Black Males 30-49 and 50 and over are negative and small in magnitude, similar to results from 1990.

- The relative correlation bias estimate for non-Blacks 18-29, 0.4 percent, is probably not due to correlation bias. This result may reflect other errors in the A.C.E. Revision II and DA estimates.

Because the correlation bias estimate for non-Blacks 18-29 is probably not an accurate estimate of correlation bias, it was assumed that there was no correlation bias for this group. This assumption was acceptable because estimates of relative correlation bias for older (30-49 and 50+) non-Black males were small in 2000, and the estimate of relative correlation bias for non-Black males 18-29 in 1990 was small. Therefore, the adjustment factor for this group was set equal to one, as given in Table 2.

Table 3.a Relative Correlation Bias Estimates for A.C.E. Revision II*

Age	Black males	Non-Black males
18-29	–7.4	0
30-49	–9.1	–2.0
50+	–4.8	–1.0

Table 3.b Relative Correlation Bias Estimates for the 1990 PES*

Age	Black males	Non-Black males
18-29	–8.0	0
30-49	–7.7	–1.6
50+	–8.2	–1.2

* The entries in Tables 3.a are related to those in Table 2 by the following formula: Correlation bias = $(1 / \phi) - 1$. The entries in Table 3.b are related to the 1990 adjustment factors in a similar manner.

Table 4 shows totals for the DSEs in A.C.E. Revision II for males in the different age-race categories. The first column gives the totals for the original DSEs not adjusted for correlation bias. The second column gives totals for the DSEs after adjusting for correlation bias. The third column shows the change that adjustment gives in each category, and the final column expresses this change in terms of percentages. The results for this column can be easily compared with the results from table 3.a. Table 4 shows the amount by which the unadjusted counts are increased to bring them to the level of the adjusted counts, while the results from Table 3.a show the amount by which the adjusted counts would need to be reduced to equal those of the unadjusted counts.

Table 4 Effect of Correlation Bias Adjustment for A.C.E. Revision II

Race/Age Categories	DSE Totals Without Corr Bias Adj	DSE Totals With Corr Bias Adj	Difference Between DSE Totals	Percent Increase
Black males				
18 - 29	2,582,683	2,790,833	208,150	8.1
30 - 49	4,385,308	4,832,212	446,904	10.2
50+	2,746,088	2,895,811	149,723	5.5
Non-Black males				
18 - 29	19,047,719	19,047,719	0	0
30 - 49	36,735,919	37,312,620	576,701	1.6
50+	30,311,508	30,632,206	320,698	1.1

Note that for non-Black males 18-29 the correlation bias adjustment is forced to have the value zero. Also, the correlation bias adjustment factor for females and persons age 17 and younger is set equal to 1, so the correlation-bias adjusted DSEs are equal to the original DSEs for persons in these groups. Adjustment added about 800,000 to the total estimate for Blacks, and about 900,000 to the estimate for non-Blacks.

To put the results from Table 4 into context, we can compare them to other error adjustments made to the March 2001 A.C.E. estimates. The following table is taken from Mule (2003). It shows the effect that duplication and coding corrections for the E and P Samples have on the March 2001 estimates. It also gives the adjustment for correlation bias correction. The value for the correlation bias adjustment of 1,702,176 is equal to the sum of the entries in Table 4 in the column labeled "Difference Between DSE Totals". The results presented in Table 5 show that adjustment for correlation bias represents a significant portion of the change in the estimated net undercount from the March 2001 to the A.C.E. Revision II estimates.

Table 5: Change in Estimated Net Undercount of the Household Population

		Estimated Net Undercount	Change*	Cumulative
March 2001 A.C.E. Estimate		3,261,876		
New Post-Stratification			+38,618	3,300,493
E sample	Person Duplication Corrections		-2,814,355	486,138
	Coding Corrections		-2,427,198	-1,941,060
P sample	Person Duplication Corrections		-1,103,805	-3,044,865
	Coding Corrections		+11,032	-3,033,833
Correlation Bias			+1,702,176	-1,331,656
A.C.E. Revision II Estimate		-1,331,656	-4,593,532	

* Shows the effect of adding in one revision at a time. A different ordering of the revisions would result in slightly different intermediate effects, but yield the same overall net undercount estimate. Estimated changes in the net undercount are not the same as estimated additional census erroneous enumerations or additional census omissions.

6. UNDERCOUNT ESTIMATES

In this section, undercount rates and undercount estimates (number of persons) are presented for the Two-Group and three other models, organized by tenure and the age/sex and major race categories used in A.C.E. Revision II.

The other models are called the Modified Two-Group, Fixed Relative Risk (FRR), and Prithwis (see Shores (2003) for a description of these models). All three assume there exists a parameter related to correlation bias that is constant across male post-strata within age-race groups, and that there is no correlation bias for females.

The modified Two-Group Model is similar to the Two-Group Model. In this model, correlation bias for Hispanics is assumed to be equal to that of Blacks. The correlation-bias adjusted dual system estimates for Blacks do not change, but for non-Black non-Hispanics the adjustment is reduced to compensate for the larger adjustment for Hispanics. The correlation-bias adjusted DSEs for Hispanics are quite different under this model compared to the DSEs calculated in the Two-Group and other models.

The parameter in the FRR model is the ratio of the probability of inclusion in A.C.E. given capture in the census to the probability of inclusion in A.C.E. given lack of capture in the census. For the Prithwis Model, the parameter is the ratio of the probability of inclusion in the A.C.E. or census for males to the probability of inclusion in the A.C.E. or census for females.

The undercount rate estimate for a particular group in the table (e.g., non-Hispanic Blacks) under any of the models was calculated by the formula

$$UC = \left(\frac{\sum DSE - \sum Census}{\sum DSE} \right) \times 100 \ ,$$

where the summation is taken over all of the poststrata in the group.

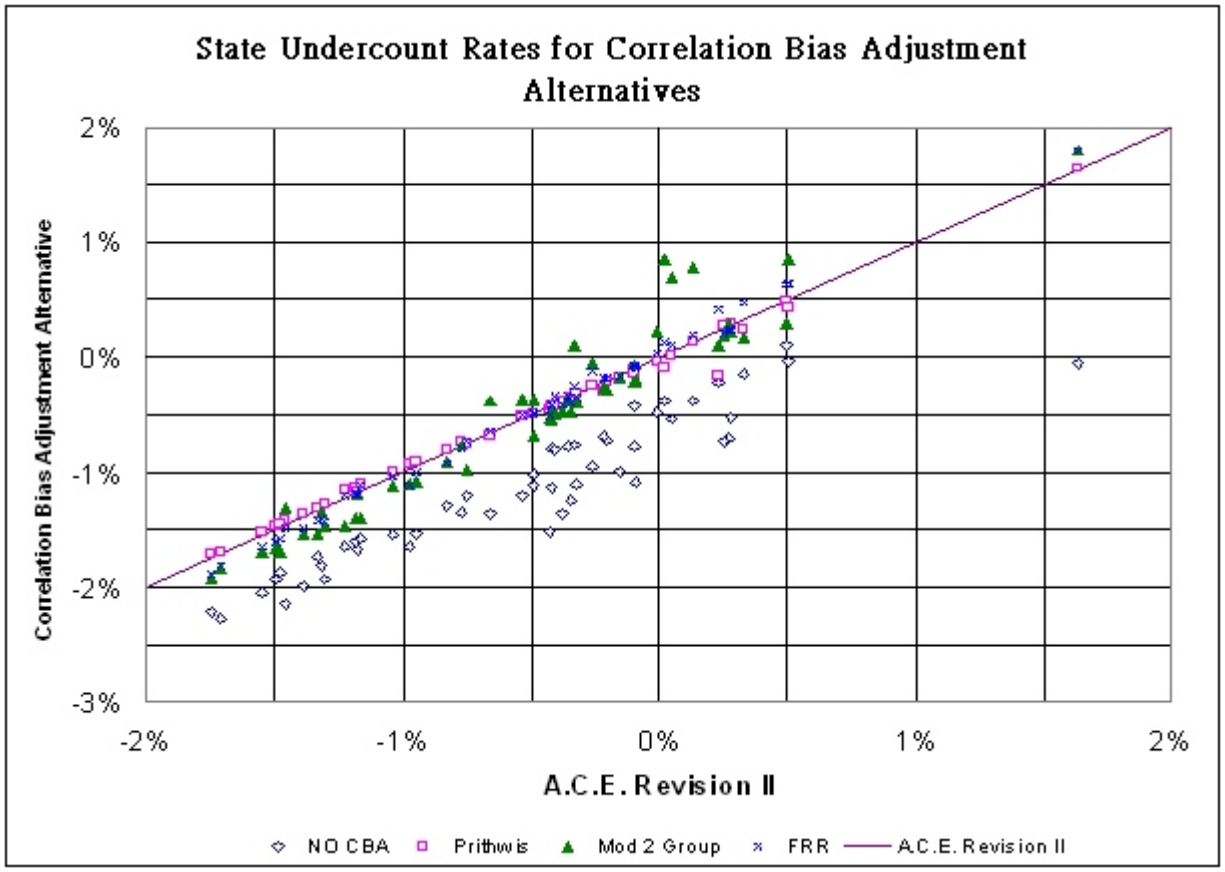
Table 6: Percent Net Undercount Rates for Major Groups

Characteristic	If No Corr. Bias Adjustment Estimate (%) (S.E.)	**A.C.E. Revision II (Two-Group)** Estimate (%) (S.E.)	If Fixed Relative Risk Model Estimate (%) (S.E.)	If Prithwis Model Estimate (%) (S.E.)	If Modified Two-Group Model Estimate (%) (S.E.)
Race/Origin Domain					
Non-Hispanic White	-1.53 (0.20)	-1.13 (0.20)	-1.17 (0.20)	-1.10 (0.20)	-1.39 (0.20)
Non-Hispanic Black	-0.53 (0.41)	1.84 (0.43)	1.84 (0.43)	1.84 (0.43)	1.84 (0.43)
Hispanic	0.42 (0.44)	0.71 (0.44)	0.89 (0.44)	0.58 (0.43)	3.17 (0.49)
Non-Hispanic Asian	-1.12 (0.68)	-0.75 (0.68)	-0.64 (0.70)	-0.72 (0.68)	-1.01 (0.68)
Hawaiian or Pacific Islander	1.81 (2.73)	2.12 (2.73)	2.47 (2.90)	0.53 (2.26)	1.90 (2.73)
AIAN on Reservation	-1.16 (1.53)	-0.88 (1.53)	-0.63 (1.57)	-0.97 (1.52)	-1.08 (1.53)
AIAN off Reservation	0.30 (1.35)	0.62 (1.35)	0.71 (1.38)	0.64 (1.37)	0.39 (1.35)
Tenure					
Owner	-1.85 (0.20)	-1.25 (0.20)	-1.40 (0.20)	-1.21 (0.20)	-1.26 (0.20)
Non-Owner	0.45 (0.36)	1.14 (0.36)	1.46 (0.37)	1.06 (0.36)	1.56 (0.37)

For some groups, adjustment from the models had only a moderate effect. For non-Hispanic Blacks, however the effect was dramatic; the undercount rate estimate changed from a one-half percent overcount estimate to a nearly two-percent undercount estimate. Correlation bias adjustment increases the dual system estimates and thereby increases the undercount rates. For non-Hispanic Whites, for example, the undercount rate did increase, but it still remained an overcount (that is, a negative undercount). Overall, the undercount rate changed from 1.18 percent under the March 2001 A.C.E. estimates to -0.49 under A.C.E. Revision II.

7. COMPARISONS BY STATE

Synthetic estimates for the fifty states and the District of Columbia are calculated by multiplying the state census count in each post-stratum by the post-stratum coverage correction factor adjusted for correlation bias and then adding these results over post-strata. The graph below compares the undercount rates at the state level for three alternative approaches to correlation bias adjustment to those from the Two-Group Model estimates. The graph also shows the estimated undercount rates if no correlation bias adjustment is performed. The horizontal axis gives the A.C.E. Revision II estimated undercount rates (that is, estimates from the Two-Group Model) . The vertical axis gives estimated undercount rates for all of the models, including those from the Two-Group Model. The estimates from the Two-Group Model are represented by the diagonal line, making it easy to compare results from the other models to those obtained for A.C.E. Revision II. As an example, the District of Columbia is represented by the symbols in the upper right corner of the graph. The estimated undercount resulting from use of the Two-Group Model is approximately 1.6 percent. The estimated undercount from the Prithwis Model is the same. The estimated undercount from the Modified Two-Group and FRR models is slightly higher. If no correlation bias adjustment is performed, the estimated undercount is around zero percent.



Some highlights from the graph:

- The estimated undercount rates calculated without correlation bias adjustment (the diamonds in the graph) are always smaller than those from the Two-Group Model or any of the other models. The reason for this is that all of the models increase the count of males, leading to larger dual system estimates and therefore larger undercount rates compared to the rates based on estimates which have not been adjusted.

- Estimated undercount rates from the Prithwis and Fixed Relative Risk models (the squares and crosses, respectively) are very similar to those obtained from the Two-Group Model.

- Estimated undercount rates from the Modified Two-Group Model (the triangles) are often similar to the estimates from the Two-Group Model, but for some states the estimates are noticeably different. Overall, this model is less similar to the other three models than those models are to one another. For states with a high percentage of Hispanics, the undercount rate is larger than that of the Two-Group Model because the count of a relatively large number of Hispanic males is adjusted by the high adjustment factor for Black males. For states with a small percentage of Hispanics, the undercount rate is lower than that of the Two-Group Model because fewer non-Black non-Hispanic males are added.

8. CONCLUSION

Correlation bias adjustment had a very significant impact on the dual system estimates for Black males in A.C.E. Revision II. For non-Black males correlation bias was less pronounced, and the consequent effect for adjusting their estimates for correlation bias was smaller. Overall, correlation bias adjustment was an important part of A.C.E. Revision II. It is apparent, however, that the choice of model to adjust for correlation bias is not critical for some purposes. All of the models discussed in this paper, with the possible exception of the Modified Two-Group Model, produce rather similar correlation bias adjusted state estimates. Therefore, for this purpose, the model selected to do correlation bias adjustment is of less importance than the decision of whether or not to do correlation bias adjustment in the first place.

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