Variance Estimation Issues in the 2010 NSCG Two-Phase Sample Design

Michael White[1], Jean Opsomer[2]
[1]U.S. Census Bureau[3], 4700 Silver Hill Road, Suitland, MD 20746
[2]Colorado State University, Fort Collins, CO 80523

Abstract

The 2010 National Survey of College Graduates (NSCG) selected its sample using respondents to the 2009 American Community Survey (ACS) as the sampling frame. The sample design was two-phase which creates variance estimation complexities. This paper discusses the issues with two-phase variance estimation and describes a proposed estimator to produce approximately unbiased variance estimates.

The American Community Survey uses Successive Difference Replication (SDR) to estimate variances. This paper also discusses an evaluation plan to determine whether or not SDR best meets the NSCG estimation needs by comparing SDR variance estimates against delete-a-group jackknife (JKR) and balanced-repeated replication (BRR) variance estimates. Preliminary results of this comparison will be discussed and the plan for a simulation study will be described.

Key Words: variance estimation, two-phase, NSCG, ACS

1. Introduction

The National Survey of College Graduates (NSCG) is a longitudinal survey that collects information on employment, educational, and demographic characteristics of the college-educated science and engineering (S&E) workforce in the United States. The U.S. Census Bureau conducts the NSCG on behalf of the National Science Foundation (NSF). The 2010 NSCG selected its sample using a dual frame design. One frame included respondents to the 2008 NSCG and 2008 National Survey of Recent College Graduates (NSRCG) and is referred to as the "old" cohort and the other frame included respondents to the 2009 American Community Survey (ACS) and is referred to as the "new" cohort[4]. Cases were eligible for the "new" cohort sampling frame if they had responded to the

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[3] This report is released to inform interested parties of ongoing research and to encourage discussion of work in progress. Any views expressed on statistical, methodological, technical, or operational issues are those of the authors and not necessarily of the U.S. Census Bureau or the Colorado State University.

[4] Historically, the NSCG sample was selected once a decade from the decennial census long form respondents. In 2010, the Census Bureau discontinued the long form, so the NSF switched to using the American Community Survey (ACS) as a sampling frame for the NSCG.

2009 ACS, reported obtaining at least a Bachelor's degree, were less than 76 years of age, and were noninstitutionalized[5]. From a frame of 855,402 eligible cases, 65,195 "new" cohort sample cases were selected. This paper will only discuss variance estimation for the "new" cohort portion of the 2010 NSCG as this is where the two-phase sample design concerns arise.

It is common to use two-phase sampling to observe auxiliary variables in the first-phase sample and then use those auxiliary variables to stratify the second-phase sample. This was the case with the 2010 NSCG as the sampling frame was stratified using occupation field, educational attainment, and demographic variables obtained in the 2009 ACS. An issue arises with variance estimation in this two-phase sample setting because the usual replication-based variance estimation methods cannot be directly applied in the two-phase context. In fact, the literature on replication methods for two-phase sampling is surprisingly sparse, with only a small number of authors attempting to tackle this issue. Even though unbiased linearized variance estimators exist, the conditional probabilities of selection and asymptotic conditions of the two samples make the theory messy in developing replicate variance estimators. In other words, it is difficult to create replicates that can account for both the first and second-phase sample and so proposed replicate variance estimators are biased. We will describe some of the existing results and outline our proposed approach in the next section.

2. Background

In practice, two common estimators are used in two-phase sampling: the double expansion estimator (DEE) and reweighted expansion estimator (REE) (Kott and Stukel (1997)). These estimators are defined under ideal conditions, i.e. full response, no frame errors, etc. The DEE is defined as

$$\hat{t}_{ys} = \sum_{s} \frac{y_k}{\pi_{ak}\pi_{k|s_a}} \tag{1}$$

where s includes the second-phase sample cases, y_k is the estimate of interest, π_{ak} is the first-phase inclusion probability, and $\pi_{k|s_a}$ is the conditional second-phase inclusion probability. The REE is defined as

$$\hat{t}_{ys,ratio} = \sum_{g=1}^{G} \sum_{s_{ag}} \frac{1}{\pi_{ak}} \frac{\sum_{s_g} \frac{y_k}{\pi_{ak}\pi_{k|s_a}}}{\sum_{s_g} \frac{1}{\pi_{ak}\pi_{k|s_a}}} \tag{2}$$

where g is the second-phase sampling strata, s_{ag} are the first-phase cases in stratum g, s_g are the second-phase sample cases in stratum g, and the other terms are as defined previously. Unlike the DEE, this estimator post-stratifies the weights back to the estimated totals within each stratum. It should be noted that when the second-phase

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[5] There are other minor eligibility criteria for the "new" cohort sampling frame. For details on all the eligibility criteria, see Finamore and Hall (2010).

sampling is equal probability within strata, the $\pi_{k|s_a}$terms cancel out with each other leaving only the first-phase inclusion probabilities.

Kott and Stukel (1997) examined using jackknife replication with the DEE and REE. They note that the DEE is an unbiased estimator while the REE is in general not unbiased but is instead a design consistent estimator. The sample design they used was a stratified with-replacement probability cluster sample in the first-phase, with elements from the sample clusters restratified and simple random subsamples drawn from second-phase stratum in the second-phase. They proposed two different versions of a replicate DEE estimator and one version of a replicate REE estimator. Conducting a simulation study the authors found that, using jackknife replication, the REE estimator was more efficient than either of the proposed DEE estimators in the two-phase sample. However, their sample design does not match the ACS and NSCG sample design and the NSCG might not use jackknife replication so it is unclear if their results are applicable to the 2010 NSCG.

Kim, Navarro, and Fuller (2006) theoretically discuss the use of the DEE and REE with replication variance methods. In particular, they propose a consistent variance estimator that is applicable for both the DEE and REE given a consistent first-phase replication variance estimator. The difficulty with directly applying their approach to the NSCG is that they assume stratified simple random sampling (SRS) in the second-phase, while the 2010 NSCG selected some of its sample using stratified systematic SRS and some of its sample using stratified systematic probability proportional to size (PPS) sampling.

Since there was no literature that directly addressed the 2010 NSCG two-phase sample design with unequal probabilities of selection in the second-phase, we needed to find an appropriate estimator to use. We decided to examine a modified version of the replicate DEE or REE proposed by Kim et al. (2006) that explicitly accounts for unequal selection probabilities in the second-phase (Opsomer (2010a)).

Our proposed replicate variance estimator for the DEE estimator is

$$\hat{V} = \sum_{r=1}^{R} c_r (\hat{t}_{ys}^{(r)} - \hat{t}_{ys})^2 \qquad (3)$$

where c_r is a constant that depends on the replication method, R is the number of replicates, and the DEE replicate estimator $\hat{t}_{ys}^{(r)}$ is defined as

$$t_{ys}^{(r)} = \sum_{g=1}^{G} \sum_{s_{ag}} \pi_{ak} w_{ak}^{(r)} \frac{\sum_{s_g} \frac{w_{ak}^{(r)} y_k}{\pi_{k|s_a}}}{\sum_{s_g} \frac{w_{ak}^{(r)} \pi_{ak}}{\pi_{k|s_a}}} \qquad (4)$$

where $w_{ak}^{(r)}$ is the first-phase replicate weight and the other terms are as defined previously.

Our proposed replicate variance estimator for the REE estimator is

$$\hat{V}_{ratio} = \sum_{r=1}^{R} c_r (\hat{t}_{ys,ratio}^{(r)} - \hat{t}_{ys,ratio})^2 \qquad (5)$$

where the REE replicate estimator $\hat{t}_{ys,ratio}^{(r)}$ is defined as

$$t_{ys,ratio}^{(r)} = \sum_{g=1}^{G} \sum_{s_{ag}} w_{ak}^{(r)} \frac{\sum_{s_g} \frac{w_{ak}^{(r)} y_k}{\pi_{k|s_a}}}{\sum_{s_g} \frac{w_{ak}^{(r)}}{\pi_{k|s_a}}} \qquad (6)$$

with terms defined as above.

Around the same time we were trying to determine an appropriate estimator to use in the 2010 NSCG, Kim and Yu (2010) came out with a paper discussing theoretical support for a replication-based variance estimator for use in two-phase sampling with unequal probabilities of selection in the second-phase. In particular, the authors extended the method of Kim et al. (2006) for when the second-phase selection uses Poisson sampling. They show that the variance estimators (3) and (5) we propose, when using Poisson sampling in the second-phase, have negligible bias when the first-phase sampling rate is negligible but that the bias can become arbitrarily large if the first-phase sampling rate is not negligible. It is not clear if these results extend to the systematic PPS sampling used by the 2010 NSCG. Also, it is unclear whether the ACS's sampling rate of about 1 in 40 is negligible. Therefore, we developed a research plan to determine whether the DEE or the REE replicate estimator, as defined in (4) and (6), was best for the 2010 NSCG.

In addition to investigating an appropriate estimator to use for the 2010 NSCG, we also decided to evaluate different variance replication methods. The ACS uses the Successive Difference Replication (SDR) method (Fay and Train (1995)). The sample design for the ACS is an unequal-probability, stratified systematic sample of U.S. households with independent samples of households selected within each county in the U.S. and Puerto Rico. The systematic sample selection is made after sorting census blocks geographically within each county. SDR replicates are assigned within counties using this sort order.

The SDR method was designed to be used with systematic samples for which the sort order of the sample is informative which is the case with ACS's geographic sort. However, it is unclear whether the ACS's SDR replicate weights are suitable for the 2010 NSCG since the 2010 NSCG stratifies by demographics, not geography. Additionally, it is unclear how robust SDR is to large sample reductions that occur in the 2010 NSCG two-phase sample design. Therefore, it is possible the Balanced Repeated Replication (BRR) or delete-a-group Jackknife Replication (JKR) method may be more appropriate for the 2010 NSCG.

The next section will describe a plan we developed in consultation with the NSF to empirically evaluate which estimator and replication method best meets the 2010 NSCG estimation needs. Some initial results will be discussed.

3. Plan for Empirical Evaluation of Estimators and Replication Methods, Plus Some Results

The two issues that are attempting to be addressed through the research described in this paper are determining which replication method is most robust to the restratification and large subsampling that occur in the 2010 NSCG and which estimator (DEE or REE) best accounts for the two-phase sample design. The steps of the research plan developed to arrive at this determination will now be described.

The first step in the evaluation process is to create new first-phase replicates in addition to the SDR replicates already created for the ACS. In particular, the plan is to create Balanced Repeated Replicates (BRR) and delete-a-group Jackknife Replicates (JKR), assigning the pseudo-strata for each of these methods in different ways to create four additional replicate methods. Next, each of the sets of replicates will go through the ACS weighting process to produce final first-phase replicate weights. At this point, first-phase variance estimates of several ACS variables will be compared amongst the replication methods, for the entire ACS population as well as for the NSCG eligible population, to see if there is any early indication of which replication method performs best. Poorly performing replication methods may possibly be dropped at this point from further evaluation. Finally, a simulation study will be conducted to evaluate different properties of the replication methods and estimators, such as bias, confidence interval coverage, and stability. Comparisons of these metrics will lead to a determination of which replication method and estimator best meet the 2010 NSCG's estimation needs.

All of the steps of this evaluation, except for the simulation study, have been completed and will be described in detail below.

3.1 Creation of the Alternative Replicate Weights

Since it is unclear whether SDR best meets the 2010 NSCG's estimation needs, we decided to compare SDR against other replication methods. In particular, we created a number of variants of BRR and JKR replicates, assigning the pseudo-strata for each of these methods in different ways to create four additional replicate methods. BRR is a natural comparison for the SDR method since the variance estimates are also created using paired differences. For the BRR methods, the same Hadamard matrix used to assign the SDR replicate factors was used to assign the BRR replicate factors to keep comparisons with the SDR as similar as possible. JKR is a common replication method that is also used to create replicates for the National Survey of Recent College Graduates (NSRCG), a companion survey to the NSCG, and therefore is also an appropriate method to evaluate. Since the ACS staff produced 80 replicate weights for SDR, 80 replicate weights were also created for each of the alternative replication methods.

The pseudo-strata were first assigned in a way to mimic the original assignment of SDR replicate factors. The SDR replicate factors were assigned using the systematic geographic sort of the sample, which implicitly creates 'pseudo-strata' of pairs of sampling units. Using the sort order of the original SDR replicate factors, consecutive pairs of cases were therefore assigned to the BRR two-per-stratum pseudo-strata. Because the number of pseudo-strata greatly exceeded the dimension of the Hadamard matrix, *partial balancing* was used to create the replicates (see Wolter, 2007, Ch. 3.6). This means that each row of the Hadamard was assigned to a large number of pairs of cases, which can be thought of as creating 'pseudo-PSUs' within larger pseudo-strata that contain repeated pairs of cases. See Figure 1 for an illustration of how the pseudo-strata and 'pseudo-PSUs' were assigned. For the JKR replicates, the cases in each of these larger pseudo-strata were randomly assigned to 80 groups. By balancing the jackknife groups across the SDR sort order in this manner, the replication method is expected to more closely reflect the geographic balancing of the original ACS sampling design. The replicates created with these pseudo-strata will be referred to as BRR-1 and JKR-1 throughout this paper.

Figure 1. Example of Assignment of Pseudo-Strata and PSUs

SDR Sort Order	BRR-1 and JKR-1 Pseudo-Strata	BRR-1 'Pseudo-PSU'
1	1	1
2	1	2
3	2	3
4	2	4
…	…	…
155	78	155
156	78	156
157	1	1
158	1	2
…	…	…

The first method for assigning pseudo-strata mimicked the SDR replicate factor assignment to create an apples-to-apples comparison amongst the methods and paid particular attention to the systematic geographic sort of the sample. However, if the SDR replicates did not exist then it would make more sense for the BRR and JKR replicates to be constructed in a way that more closely reflects the ACS's overall geographic stratification. Therefore, the pseudo-strata were next assigned using geography in two ways. For the BRR replicates, most states were assigned their own pseudo-stratum but the larger states were broken down into two or more pseudo-strata with similar sized counties in each pseudo-stratum. Within these pseudo-strata, the cases were sorted the same way used to assign the SDR replicates and the cases were then systematically assigned to two 'pseudo-PSUs'. The first case in each consecutive pair of cases was assigned to the first 'pseudo-PSU' and the second case was assigned to the second 'pseudo-PSU'. The 'pseudo-PSU' assignment was randomly switched in about half of the pairs of cases to prevent issues that could arise if there were cycles in the sort order. The effect of this 'pseudo-PSU' assignment is that each 'pseudo-PSU' is geographically representative of each pseudo-stratum. For the JKR replicates, each county was assigned to its own strata, reflecting the actual strata used by the ACS. The cases in each stratum were then randomly assigned to 80 groups. Since some counties contained less than 80 sample cases, an adjusted delete-a-group Jackknife method was used to assign replicate factors (Kott (2001)). These replicates created using geography as pseudo-strata/strata will be referred to as BRR-2 and JKR-2 throughout this paper.

After creating base replicate weights, all the replicates went through a simplified version of the ACS weighting process to produce final first-phase replicate weights. The ACS production weighting process used small geographic domains for its nonresponse and post-stratification adjustments. Since the NSCG only produces estimates at the national level, a simplified weighting process that used high level geographic areas was used instead so as to not introduce unnecessary weight variation. See Finamore, Hall, and Walker (2011) for more details.

3.2 Comparison of First-Phase Replicate Weights

The five sets of replicate weights created for the first-phase sample were used to estimate variances for a variety of ACS variables. Variance estimate comparisons using the five sets of replicate weights were evaluated both for the entire ACS population and for the NSCG eligible population. The first metric evaluated was the coefficient of variation (CV) for the replicate variances. The results are presented in Tables 1 and 2.

There are two main takeaways from the results shown in Tables 1 and 2. First, the CVs are all very small. For estimates on the ACS population, all CVs are less than 1.5% with the largest CV coming for estimates of Native Hawaiians/Pacific Islanders, a very small domain. Across all the estimates for the ACS population, the average CV for each replicate method was less than two-tenths of a percent. The CVs are larger when the estimates are restricted to the NSCG eligible population but are all less than 5%. The average CV for each replicate method was less than half a percent.

The second takeaway from Tables 1 and 2 is the similar performance of all replicate methods. There is some variation on individual estimates, but on the ACS population the average CV ranged from a low of 0.164% for the SDR replicates to a high of 0.177% for the JKR-2 replicates, a very small range. For the NSCG population the average CV ranged from 0.450% for BRR-1 replicates to 0.476% for JKR-1 replicates. These results do not show any one replicate method strongly outperforming the others. This is an expected result since asymptotic results indicate that all the replicate methods perform well on large samples. It is expected that examining the replicate variances on the second-phase sample, where there are fewer cases, is more likely to reveal differences amongst the methods.

The other metric evaluated is the relative difference in standard errors amongst the replication methods, with the SDR standard errors used as the benchmark. SDR is used as the benchmark since this is the production method used for the ACS. The statistic is calculated as $\frac{\text{SDR\_std\_err} - \text{Alternate\_replicate\_method\_std\_err}}{\text{SDR\_std\_err}}$. Therefore, positive values indicate the SDR standard errors are larger while negative values indicate the SDR standard errors are smaller. The results are presented in Tables 3 and 4.

Most of the alternative replication methods' estimates of standard errors are within 15% of the SDR estimate. However, for the ACS population there is one variable where the SDR estimates of standard errors are much smaller than the alternative methods: the 'in poverty' variable. This is a characteristic where there is strong evidence that those in poverty are highly clustered in small geographies, even at the sub-county level. The superior performance of SDR for this variable is to be expected since one of the main attractions in using SDR is its strong performance in small geographic area estimation, particularly in comparison with the JKR-1 and JKR-2 replication methods which do not pay attention to the geographic sort order. It is interesting to note that SDR's advantage goes away on standard error estimates of the 'in poverty' variable for the NSCG population. This is likely due to the NSCG being more spread out geographically and may be early evidence that for some estimates of the NSCG population, SDR is not necessarily the best replication method.

None of the results presented in Tables 1, 2, 3, or 4 provide strong evidence that one replication method is superior to another. Likewise, no replication method at this point appears to perform poorly. Therefore, all replication methods will be evaluated in the proposed simulation study. The plan for the simulation study will now be presented in section 3.3.

3.3 Simulation Study Plan

Timing did not allow for the completion of the simulation study at this time. Instead, the plan for the simulation study will be described.

Two-phase samples potentially induce bias in replication-based variance estimators; therefore, the primary metric of interest in the simulation study is the bias of the variance estimators. Because we only have a single realization of ACS, the first-phase sample, we cannot directly compare the bias of variance estimators with full simulation-based variances. Instead, we derived an equation that uses simulation of the second-phase sample from a fixed first-phase to provide insight on the bias of the variance estimators.

The following equations will consider the DEE estimator, but work the same for the REE estimator. The variance estimate obtained by using any of the five replication methods will be generically denoted by $\hat{V}$.. The ACS sample is denoted by s_a.

The true variance of $\hat{t}_{ys}$ is

$$\mathrm{Var}(\hat{t}_{ys}) = \mathrm{E}(\mathrm{Var}(\hat{t}_{ys}|s_a)) + \mathrm{Var}(\mathrm{E}(\hat{t}_{ys}|s_a)) \qquad (7)$$

and $\hat{V}$ is a proposed estimator of Var($\hat{t}_{ys}$). We are interested in evaluating whether Bias($\hat{V}$)=E($\hat{V}$)-Var($\hat{t}_{ys}$) is sufficiently close to 0. To evaluate the bias of $\hat{V}$ using a single realization of the ACS, we plan to use the "conditional estimator"[6]

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[6] See Opsomer (2010b) for a derivation and justification for this formula.

$$\hat{B}_{s_a} = \mathrm{E}^*\left(\hat{V} \middle| s_a\right) - \mathrm{Var}^*\left(\hat{t}_{ys} \middle| s_a\right) - \hat{V}_\mathrm{a} \qquad (8)$$

where E* and Var* denote the moments are approximated via simulation, and $\hat{V}_\mathrm{a}$ is the chosen replication variance estimator (SDR, BRR-1, BRR-2, JKR-1, JKR-2) applied to the first-phase.

The simulated estimates will be calculated by taking 1,000 second-phase samples of the 2010 NSCG from the first-phase ACS sample. The first term in (8) will be calculated by creating a set of replicate weights for each simulated second-phase sample, calculating a replicate variance estimate for each second-phase sample, and then averaging the replicate variance estimates across all second-phase samples. The second term in (8) will be calculated by taking the variance of the simulated estimate across all 1,000 second-phase samples. The third term in (8) will be calculated as the replicate variance of the estimate using the single realization of the first-phase sample.

Because of the large size of the ACS relative to the NSCG, it is expected that using $\hat{B}_{s_a}$ instead of the true bias is reasonable as a way to evaluate the replication methods. However, because it is not the true bias, it is still subject to variability and interpretation of the estimated bias needs to take this into consideration. Therefore, we will look for large and consistent differences between the estimators across different variables and domains.

In addition to an evaluation of bias, the simulations will be used to evaluate the confidence interval coverage, mean confidence interval length, and stability of the replicate variances. All the variables shown in Table 1 will be included in this evaluation. The confidence interval evaluation will assume a t-distribution with 79 degrees of freedom and will examine the 90% confidence level, the U.S. Census Bureau standard. Stability will be evaluated by comparing the variance of the 1,000 simulated replicate variances amongst the methods.

The evaluation will initially focus on determining which replication method performs best using the DEE as the estimator. After determining the best replication method for the NSCG, the REE estimator using the best replication method will then be evaluated to determine whether the DEE or REE is most appropriate for the 2010 NSCG.

4. Future Research

The results presented in section 3.2 show that all replication methods should be evaluated in the simulation study. The proposed simulation study should show which combination of replicate method and estimator performs best with the 2010 NSCG two-phase sample design. If all the replication methods and estimators produce unacceptable levels of bias, then alternatives proposed by Kim and Yu (2010), such as perturbing the replicate weights or creating additional replicates, will be explored. Future research will also focus on which replication method and estimator perform best after conducting nonresponse and post-stratification weighting adjustments.

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Table 1. Coefficients of Variation of ACS Estimates Using Five Replication Methods - ACS Population

Variable	Value	n	Estimate	Coefficients of Variation				
				SDR	BRR-1	BRR-2	JKR-1	JKR-2
Covered by health	Yes	3,857,344	84.887%	0.037%	0.034%	0.038%	0.037%	0.035%
	No	530,003	15.113%	0.205%	0.192%	0.211%	0.209%	0.198%
In poverty	Yes	538,878	14.476%	0.215%	0.257%	0.295%	0.244%	
	No	3,836,771	85.524%	0.036%	0.043%	0.050%	0.041%	0.049%
Unemployed	Yes	203,237	6.569%	0.256%	0.271%	0.278%	0.289%	0.298%
	No	3,282,884	93.431%	0.018%	0.019%	0.020%	0.020%	0.021%
Urban/Rural	Urban	2,988,502	76.646%	0.054%	0.050%	0.057%	0.054%	0.053%
	Rural	1,398,845	23.354%	0.178%	0.164%	0.186%	0.177%	0.173%
Marital status	Married	1,966,981	39.787%	0.084%	0.073%	0.085%	0.096%	0.083%
	Widowed	234,300	4.680%	0.224%	0.214%	0.215%	0.220%	0.209%
	Divorced	364,267	8.540%	0.169%	0.224%	0.206%	0.195%	0.205%
	Separated	63,327	1.760%	0.448%	0.425%	0.481%	0.547%	0.456%
	Never married	1,758,472	45.232%	0.060%	0.043%	0.051%	0.056%	0.049%
Eligible for NSCG	Yes	855,402	18.516%	0.135%	0.142%	0.141%	0.114%	0.122%
	No	3,531,945	81.484%	0.031%	0.032%	0.032%	0.026%	0.028%
Highest degree	Bachelor/Professional	638,539	14.542%	0.162%	0.165%	0.152%	0.141%	0.134%
	Master's	234,133	5.064%	0.248%	0.250%	0.205%	0.254%	0.244%
	Doctorate	37,286	0.805%	0.623%	0.719%	0.535%	0.698%	0.625%
	Less than bachelor's	3,319,916	79.590%	0.033%	0.035%	0.035%	0.029%	0.029%
Disabled	Yes	566,409	14.971%	0.165%	0.157%	0.171%	0.153%	0.141%
	No	3,012,546	85.029%	0.029%	0.028%	0.030%	0.027%	0.025%
Hispanic	Yes	576,565	16.975%	0.006%	0.006%	0.006%	0.005%	0.005%
	No	3,810,782	83.025%	0.001%	0.001%	0.001%	0.001%	0.001%
Race	White	3,487,397	75.008%	0.035%	0.033%	0.038%	0.032%	0.039%
	Black	436,943	12.940%	0.061%	0.063%	0.066%	0.075%	0.065%
	Asian	204,798	4.956%	0.087%	0.090%	0.088%	0.094%	0.100%
	AIAN[1]	75,381	1.560%	0.494%	0.540%	0.518%	0.463%	0.589%
	NHPI[2]	11,135	0.290%	1.040%	1.019%	0.796%	1.378%	1.133%
	Other	171,693	5.245%	0.513%	0.519%	0.511%	0.399%	0.483%
U.S. citizen at birth	Yes	3,936,170	87.425%	0.023%	0.025%	0.028%	0.027%	0.023%
	No	451,177	12.575%	0.161%	0.173%	0.192%	0.185%	0.158%
S&E[3] Degree	Yes	415,280	8.941%	0.187%	0.168%	0.214%	0.186%	0.199%
	No	3,972,067	91.059%	0.018%	0.016%	0.021%	0.018%	0.020%
Gender	Male	2,117,585	49.042%	0.001%	0.001%	0.001%	0.001%	0.001%
	Female	2,269,762	50.958%	0.001%	0.001%	0.001%	0.001%	0.001%
Age group	0-39	2,059,756	52.493%	0.020%	0.017%	0.020%	0.022%	0.024%
	40+	2,327,591	47.507%	0.022%	0.019%	0.022%	0.024%	0.026%
	Average coefficient of variation:			0.164%	0.168%	0.162%	0.177%	0.171%

1-AIAN- American Indian/Alaskan Native

2-NHPI-Native Hawaiian/Pacific Islander

3-S&E-Science and Engineering

Table 2. Coefficients of Variation of ACS Estimates Using Five Replication Methods - NSCG Population

Variable	Value	n	Estimate	Coefficients of Variation				
				SDR	BRR-1	BRR-2	JKR-1	JKR-2
Covered by health	Yes	806,877	92.845%	0.046%	0.043%	0.043%	0.041%	0.044%
	No	48,525	7.155%	0.594%	0.564%	0.552%	0.532%	0.569%
In poverty	Yes	33,279	4.550%	0.807%	0.727%	0.810%	0.714%	0.795%
	No	822,123	95.450%	0.038%	0.035%	0.039%	0.034%	0.038%
Unemployed	Yes	31,095	3.957%	0.521%	0.704%	0.647%	0.705%	0.643%
	No	824,307	96.043%	0.021%	0.029%	0.027%	0.029%	0.027%
Urban/Rural	Urban	648,278	81.345%	0.067%	0.061%	0.059%	0.071%	0.077%
	Rural	207,124	18.655%	0.293%	0.264%	0.258%	0.309%	0.335%
Marital status	Married	589,424	64.367%	0.113%	0.119%	0.114%	0.104%	0.111%
	Widowed	15,845	1.749%	0.975%	0.941%	1.057%	0.950%	0.842%
	Divorced	76,748	9.462%	0.438%	0.385%	0.440%	0.397%	0.457%
	Separated		1.277%	1.389%	1.207%	1.047%	1.159%	1.198%
	Never married	164,256	23.145%	0.293%	0.286%	0.258%	0.237%	0.260%
Eligible for NSCG	Yes	855,402	100.000%	0.000%	0.000%	0.000%	0.000%	0.000%
	No	-	-	-	-	-	-	-
Highest degree	Bachelor/Professional	601,590	71.430%	0.085%	0.088%	0.067%	0.088%	0.076%
	Master's	219,998	24.759%	0.245%	0.238%	0.174%	0.233%	0.216%
	Doctorate	33,814	3.811%	0.646%	0.715%	0.523%	0.698%	0.672%
	Less than bachelor's	-	-	-	-	-	-	-
Disabled	Yes	46,870	5.316%	0.492%	0.491%	0.494%	0.504%	0.517%
	No	808,532	94.684%	0.028%	0.028%	0.028%	0.028%	0.029%
Hispanic	Yes	50,624	7.027%	0.540%	0.568%	0.369%	0.455%	0.531%
	No	804,778	92.973%	0.041%	0.043%	0.028%	0.034%	0.040%
Race	White	713,936	80.714%	0.066%	0.059%	0.067%	0.076%	0.067%
	Black	51,845	7.725%	0.488%	0.409%	0.533%	0.594%	0.401%
	Asian	69,888	8.893%	0.389%	0.391%	0.352%	0.396%	0.428%
	AIAN[1]		0.813%	1.320%	1.331%	1.380%	1.549%	1.408%
	NHPI[2]		0.152%	3.664%	3.616%	4.693%	4.245%	3.814%
	Other	11,337	1.703%	1.218%	1.369%	1.314%	1.331%	1.141%
U.S. citizen at birth	Yes	740,543	84.592%	0.054%	0.056%	0.051%	0.066%	0.057%
	No	114,859	15.408%	0.299%	0.308%	0.281%	0.362%	0.315%
S&E[3] Degree	Yes	391,763	45.887%	0.139%	0.116%	0.156%	0.157%	0.155%
	No	463,639	54.113%	0.118%	0.098%	0.132%	0.133%	0.131%
Gender	Male	407,949	48.256%	0.105%	0.106%	0.094%	0.109%	0.095%
	Female	447,453	51.744%	0.098%	0.099%	0.088%	0.102%	0.088%
Age group	0-39	278,278	36.530%	0.164%	0.162%	0.163%	0.148%	0.146%
	40+	577,124	63.470%	0.094%	0.093%	0.094%	0.085%	0.084%
	Average coefficient of variation:			0.454%	0.450%	0.469%	0.476%	0.452%

1-AIAN- American Indian/Alaskan Native

2-NHPI-Native Hawaiian/Pacific Islander

3-S&E-Science and Engineering

Table 3. Relative Standard Errors of ACS Estimates Using Five Replication Methods with SDR Standard Errors as Benchmark - ACS Population

Variable	Value	n	Estimate	Relative Standard Errors				
				SDR	BRR-1	BRR-2	JKR-1	JKR-2
Covered by health	Yes	3,857,344	84.89%	-	6.41%	-2.59%	-1.65%	3.72%
	No	530,003	15.11%	-	6.41%	-2.59%	-1.65%	3.72%
In poverty	Yes	538,878	14.48%	-	-19.25%	-37.02%	-13.23%	-35.09%
	No	3,836,771	85.52%	-	-19.25%	-37.02%	-13.23%	-35.09%
Unemployed	Yes	203,237	6.57%	-	-5.94%	-8.60%	-12.84%	-16.45%
	No	3,282,884	93.43%	-	-5.94%	-8.60%	-12.84%	-16.45%
Urban/Rural	Urban	2,988,502	76.65%	-	8.05%	-4.31%	0.71%	2.72%
	Rural	1,398,845	23.35%	-	8.05%	-4.31%	0.71%	2.72%
Marital status	Married	1,966,981	39.79%	-	13.81%	-0.20%	-14.01%	1.96%
	Widowed	234,300	4.68%	-	4.59%	4.31%	1.81%	6.68%
	Divorced	364,267	8.54%	-	-32.67%	-22.33%	-15.74%	-21.39%
	Separated	63,327	1.76%	-	5.07%	-7.38%	-22.12%	-1.92%
	Never married	1,758,472	45.23%	-	29.60%	15.53%	6.63%	19.65%
Eligible for NSCG	Yes	855,402	18.52%	-	-5.26%	-4.73%	15.31%	9.34%
	No	3,531,945	81.48%	-	-5.26%	-4.73%	15.31%	9.34%
Highest degree	Bachelor/Professional	638,539	14.54%	-	-2.07%	6.20%	12.68%	17.27%
	Master's	234,133	5.06%	-	-0.89%	17.43%	-2.26%	1.80%
	Doctorate	37,286	0.81%	-	-15.47%	14.12%	-12.00%	-0.27%
	Less than bachelor's	3,319,916	79.59%	-	-7.38%	-4.71%	11.79%	12.36%
Disabled	Yes	566,409	14.97%	-	4.92%	-3.59%	6.91%	14.19%
	No	3,012,546	85.03%	-	4.92%	-3.59%	6.91%	14.19%
Hispanic	Yes	576,565	16.98%	-	-1.35%	0.44%	12.68%	17.59%
	No	3,810,782	83.03%	-	-1.35%	0.44%	12.68%	17.59%
Race	White	3,487,397	75.01%	-	5.55%	-6.38%	8.80%	-9.42%
	Black	436,943	12.94%	-	-2.69%	-7.78%	-21.98%	-6.90%
	Asian	204,798	4.96%	-	-3.47%	-1.46%	-7.87%	-14.37%
	AIAN[1]	75,381	1.56%	-	-9.37%	-4.92%	6.27%	-19.31%
	NHPI[2]	11,135	0.29%	-	1.98%	23.42%	-32.53%	-8.96%
	Other	171,693	5.25%	-	-1.08%	0.38%	22.26%	5.93%
U.S. citizen at birth	Yes	3,936,170	87.43%	-	-7.24%	-19.30%	-15.00%	1.60%
	No	451,177	12.58%	-	-7.24%	-19.30%	-15.00%	1.60%
S&E[3] Degree	Yes	415,280	8.94%	-	10.53%	-14.44%	0.79%	-6.19%
	No	3,972,067	91.06%	-	10.53%	-14.44%	0.79%	-6.19%
Gender	Male	2,117,585	49.04%	-	1.32%	-26.66%	-19.23%	-23.58%
	Female	2,269,762	50.96%	-	1.32%	-26.66%	-19.23%	-23.58%
Age group	0-39	2,059,756	52.49%	-	15.06%	0.62%	-8.99%	-17.38%
	40+	2,327,591	47.51%	-	15.06%	0.62%	-8.99%	-17.38%
	Average relative standard error:				0.00%	-5.79%	-3.44%	-3.13%

1-AIAN- American Indian/Alaskan Native

2-NHPI-Native Hawaiian/Pacific Islander

3-S&E-Science and Engineering

Table 4. Relative Standard Errors of ACS Estimates Using Five Replication Methods with SDR Standard Errors as Benchmark - NSCG population

Variable	Value	n	Estimate	Relative Standard Errors				
				SDR	BRR-1	BRR-2	JKR-1	JKR-2
Covered by health	Yes	806,877	92.85%	-	4.98%	7.08%	10.39%	4.27%
	No	48,525	7.16%	-	4.98%	7.08%	10.39%	4.27%
In poverty	Yes	33,279	4.55%	-	9.89%	-0.40%	11.51%	1.45%
	No	822,123	95.45%	-	9.89%	-0.40%	11.51%	1.45%
Unemployed	Yes	31,095	3.96%	-	-35.16%	-24.23%	-35.36%	-23.61%
	No	824,307	96.04%	-	-35.16%	-24.23%	-35.36%	-23.61%
Urban/Rural	Urban	648,278	81.35%	-	9.96%	11.93%	-5.16%	-14.08%
	Rural	207,124	18.66%	-	9.96%	11.93%	-5.16%	-14.08%
Marital status	Married	589,424	64.37%	-	-5.53%	-1.10%	7.30%	1.89%
	Widowed	15,845	1.75%	-	3.52%	-8.39%	2.57%	13.70%
	Divorced	76,748	9.46%	-	12.13%	-0.42%	9.34%	-4.19%
	Separated	9,129	1.28%	-	13.10%	24.60%	16.59%	13.78%
	Never married	164,256	23.15%	-	2.23%	11.99%	19.02%	11.20%
Eligible for NSCG	Yes	855,402	100.00%	-	-	-	-	-
	No	.	.	-	-	-	-	-
Highest degree	Bachelor/Professional	601,590	71.43%	-	-3.75%	20.85%	-3.25%	10.82%
	Master's	219,998	24.76%	-	3.10%	29.18%	4.85%	11.84%
	Doctorate	33,814	3.81%	-	-10.77%	18.96%	-8.06%	-4.00%
	Less than bachelor's	.	.	-	-	-	-	-
Disabled	Yes	46,870	5.32%	-	0.17%	-0.58%	-2.54%	-5.12%
	No	808,532	94.68%	-	0.17%	-0.58%	-2.54%	-5.12%
Hispanic	Yes	50,624	7.03%	-	-5.24%	31.62%	15.76%	1.74%
	No	804,778	92.97%	-	-5.24%	31.62%	15.76%	1.74%
Race	White	713,936	80.71%	-	11.34%	-1.41%	-14.74%	-1.27%
	Black	51,845	7.73%	-	16.06%	-9.24%	-21.70%	17.85%
	Asian	69,888	8.89%	-	-0.54%	9.54%	-1.81%	-10.05%
	AIAN[1]	7,301	0.81%	-	-0.79%	-4.50%	-17.30%	-6.65%
	NHPI[2]	1,095	0.15%	-	1.29%	-28.09%	-15.86%	-4.10%
	Other	11,337	1.70%	-	-12.41%	-7.93%	-9.28%	6.28%
U.S. citizen at birth	Yes	740,543	84.59%	-	-3.00%	6.07%	-21.20%	-5.22%
	No	114,859	15.41%	-	-3.00%	6.07%	-21.20%	-5.22%
S&E[3] Degree	Yes	391,763	45.89%	-	16.74%	-12.37%	-13.27%	-11.49%
	No	463,639	54.11%	-	16.74%	-12.37%	-13.27%	-11.49%
Gender	Male	407,949	48.26%	-	-0.44%	10.56%	-3.95%	10.10%
	Female	447,453	51.74%	-	-0.44%	10.56%	-3.95%	10.10%
Age group	0-39	278,278	36.53%	-	1.11%	0.89%	9.99%	11.05%
	40+	577,124	63.47%	-	1.11%	0.89%	9.99%	11.05%
	Average relative standard error:				0.79%	3.39%	-2.94%	-0.14%

1-AIAN- American Indian/Alaskan Native

2-NHPI-Native Hawaiian/Pacific Islander

3-S&E-Science and Engineering