Evaluation of Small Area Estimates of Substance Use in the National Survey on Drug Use and Health

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Abstract
Small area estimation methods are used to produce State and substate estimates of substance use and mental disorders using data from a major U.S. behavioral health survey. State and local policymakers use these estimates to understand the nature and extent of the problem and to justify funding for substance abuse prevention and treatment programs in their jurisdictions. Design-based estimates could be used as an alternative. They are less expensive than small area estimates (SAEs) and take less time to produce. Thus, it is important to determine how the SAEs compare to their design-based counterparts in terms of accuracy and precision. In 2001, a validation study was conducted to judge the quality of the State SAEs. That study found that SAEs were generally more precise than design-based estimates while exhibiting only small levels of bias (Wright, 2001). We extend this analysis using more recent data to validate the substate SAEs in a similar fashion.

Key Words: Small area estimation, design based estimates, model based estimates, NSDUH SAEs

1. Background

The National Survey on Drug Use and Health (NSDUH)[1] is the primary source of statistical information on use of illicit drugs, alcohol, and tobacco by the U.S. civilian non-institutional population aged 12 or older. It is sponsored by the Substance Abuse and Mental Health Services Administration (SAMHSA), U.S. Department of Health and Human Services, and is planned and managed by SAMHSA's Center for Behavioral Health Statistics (CBHSQ). Data collection and analysis are conducted under contract with RTI International. NSDUH is an ongoing survey that administers a variety of questions on substance use and associated behaviors in a face-to-face setting via computer-assisted interviewing at the respondents' place of residence. NSDUH is a multi-stage area probability survey with a target sample of 67,500 persons nationwide. Prior to 1999, the NSDUH design employed a national probability sample which did not have a sufficient sample to produce State estimates. Beginning in 1999, the sample was expanded so that representative estimates could be provided in each State and the District of Columbia. The current NSDUH design includes eight large sample States (California, Florida, Illinois, Michigan, New York, Ohio, Pennsylvania, and Texas) which collectively account for approximately 50 percent of the U.S. population. The annual target sample sizes are 3,600 for each of these large States and 900 for the remaining 42 States and the District of Columbia. The design oversamples youths aged 12 to 17 and

[1] Prior to 2002, the survey was known as the National Household Survey on Drug Abuse (NHSDA).

young adults aged 18 to 25 so that each State's annual sample is approximately equally distributed among three major age groups: 12 to 17, 18 to 25, and 26 or older.

In previous validation studies (Wright 2002a, 2002b, 2003a, and 2003b), NSDUH State small area estimates (SAEs) were validated for annual sample sizes of about 900 (300 per age group) and two year pooled sample sizes of 1,800 (600 per age group) for the 12 or older age group. The results of the validation studies were presented to a group of small area estimation (SAE) expert panel members. The panel members recommended that single year NSDUH data will be sufficient to produce reliable age group-specific State estimates; however, single year data may not be sufficient to detect year-to-year changes in State prevalence rates for low prevalence outcome measures. They recommended producing State estimates using pooled 2 years of NSDUH data and estimating change as the difference between two consecutive 2-year moving averages.

It was inferred from the above-mentioned validation studies that if an area has a sample size of 300 respondents, then reliable point estimates could be produced. Based on this knowledge, for the first 1999 to 2001 substate report (OAS, 2005), the substate regions were formed by grouping contiguous counties (in some cases, Census tracts) so that each of the substate regions had at least 300 respondents in the pooled 3 years of NSDUH data. The main objective was to produce substate region estimates for the 12 or older population. With the availability of data from subsequent NSDUHs, the scope of the substate report was expanded to include the production of age group-specific substate region estimates as well as comparisons over time (e.g., comparison between the 2006 to 2008 prevalence rates and 2008 to 2010 prevalence rates). Moreover, the demand for substate region estimates has grown steadily because local area officials need such information for various purposes, such as treatment planning, intervention, and prevention. As a result, some substate region sample sizes are now becoming as small as 150 (50 per age group). To maintain the quality of substate region estimates, the age group-specific substate region estimates are subjected to a suppression rule that uses relative standard errors (RSEs) and effective sample size restrictions to suppress the unreliable estimates. However, the accuracy (i.e., the mean square error (MSE) that combines the squared bias and variance) of the substate region estimates depends heavily on model assumptions, and this validation study aims to provide some guidance about the validity of these assumptions. In the rest of this paper, the proposed methodology for validating SAEs for various small sample sizes (25 to 300) is discussed (Section 2), the results are discussed (Section 3), and conclusions and recommendations for future research are presented (Section 4).

2. Method

The main idea is to create various pseudo small States within each of the eight large States by pooling 2 years of NSDUH data so that the pseudo small State sample sizes range from 75 to 300 for the 12 or older age group (or 25 to 100 per age group); fit current SAE models and produce SAEs for each of the pseudo small States; and compare them with the corresponding large State design-based estimates (DBEs) that can be considered as "true values." The DBEs for each of the eight large States are based on about 7,200 respondents for the 12 or older age group (about 2,400 respondents in each of the three age groups) and are considered as "true values" here for comparison purposes. In the tables and plots presented in this paper, these "true values" are referred to as the benchmarked estimates (BEs). The methodology for creating pseudo small States is described below.

For this validation study, pooled 2009 and 2010 NSDUH data were used. There are 48 State sampling regions (SSRs) or strata in each of the eight large States. Each of the 48 SSRs is expected to have 8 segments (segments are defined as groups of contiguous Census blocks) in a single year of NSDUH data. Out of 8 segments, half are used again in the next year for data collection while the other half are replaced with new segments. For example, if s1,...,s8 were the 8 segments in one particular SSR (say, SSR1) in the 2009 NSDUH data, then in 2010, say, segments s1,...,s4 are kept and s5,...,s8 were replaced by s9,...,s12. Hence, in 2010, SSR1 will have segments s1,...,s4 and s9,...,s12. So, in the pooled 2009 and 2010 NSDUH data, SSR1 will have segments s1,...,s12. Each of the single year NSDUH segments is expected to have on average 9.375 respondents. Because the s1,...,s4 segments occur twice in the pooled 2009 and 2010 NSDUH data, they will have in all about 75 ($4 \times 9.375 \times 2$) respondents, and the remaining 8 segments (s5,...,s12) will have about 75 (8×9.375) respondents. Hence, SSR1 will have about 150 respondents in the pooled 2009 and 2010 NSDUH data, with one third of the segments (4 segments) containing on average 18.75 respondents per segment and two thirds of the segments (8 segments) containing 9.375 respondents per segment. Across 48 SSRs, there will be about $150 \times 48 = 7{,}200$ respondents in each of the 8 large States in the pooled 2009 and 2010 NSDUH data. For illustration purposes, the process of creating 8 pseudo small States (CA1 to CA8) using the California (CA) data from the pooled 2009 and 2010 NSDUH data is described below. The same process then is repeated for the other large States: Florida (FL), Illinois (IL), Michigan (MI), New York (NY), Ohio (OH), Pennsylvania (PA), and Texas (TX).

In the pooled 2009 and 2010 NSDUH data for CA, 8 SSR regions are first grouped together to form 6 such groups of 8 SSRs. As mentioned earlier, 2 years of pooled data have about 12 segments per SSR. In one grouped SSR, $12 \times 8 = 96$ segments are expected. Table 1 describes the pseudo small States' creation process. The 96 segments can be denoted in each of the grouped SSRs by a1,…,a96, b1,…,b96, and so on (i.e., grouped SSR #1 has a1,…,a96 segments and grouped SSR #2 has b1,…,b96 segments). Then, the grouped SSRs are treated as strata, and stratified simple random sampling without replacement is used to select 8 segments from each of the grouped SSRs. For example, from the grouped SSR #1, the 8 randomly selected segments are denoted by ra1,…,ra8; the 8 randomly selected segments from the grouped SSR #2 are denoted by rb1,…,rb8; and so on. In the next step, ra1 is assigned to a pseudo small State (denoted by CA1), ra2 is assigned to another pseudo small State (denoted by CA2), and so on. Similarly, rb1 is assigned to CA1, rb2 is assigned to CA2, and so on. At the end of this process, each of the pseudo small States will have one randomly selected segment from each of the 6 grouped SSRs (i.e., CA1 will have ra1, rb1, rc1, rd1, re1, rf1; similarly, CA2 will have ra2, rb2, rc2, rd2, re2, and rf2).

In this case, the sample sizes for the pseudo small States can range on average from 56 (9.375×6) to about 112 (18.75×6) depending on how many repeat and nonrepeat segments are contained in a pseudo small State. Note that repeat segments are common between two consecutive years of NSDUH data and are expected to have about 18.75 respondents in 2 years of pooled NSDUH data; nonrepeat segments, on the other hand, contain about 9.375 respondents in 2 years of pooled NSDUH data. The selection process is repeated for other large States. Table 2 gives descriptive statistics for age group-specific sample sizes across all 64 (8 pseudo small States in each of the 8 large States) pseudo small States when one segment per grouped SSR was selected. In this case, note that each of the 64 pseudo small States has on average 75 respondents (about 25 in each age group).

Table 1: Simple Random Sampling without Replacement in California: One Segment per Grouped SSR (Sample 1)

	Grouped SSR	Segments	Selected Segments	Pseudo Small States							
				CA1	**CA2**	**CA3**	**CA4**	**CA5**	**CA6**	**CA7**	**CA8**
CA	1	a1,…,a96	ra1,…,ra8	ra1	ra2	ra3	ra4	ra5	ra6	ra7	ra8
	2	b1,…,b96	rb1,…,rb8	rb1	rb2	rb3	rb4	rb5	rb6	rb7	rb8
	3	c1,…,c96	rc1,…,rc8	rc1	rc2	rc3	rc4	rc5	rc6	rc7	rc8
	4	d1,…,d96	rd1,…,rd8	rd1	rd2	rd3	rd4	rd5	rd6	rd7	rd8
	5	e1,…,e96	re1,…,re8	re1	re2	re3	re4	re5	re6	re7	re8
	6	f1,…,f96	rf1,…,rf8	rf1	rf2	rf3	rf4	rf5	rf6	rf7	rf8

CA = California; SSR = State sampling region.

Table 2: Descriptive Statistics for all Pseudo Small State Sample Sizes: One Segment per Grouped SSR (Sample 1)

Age Group	Sample Sizes*		
	Minimum	**Maximum**	**Mean**
12 to 17	7	52	24
18 to 25	7	96	24
26 or Older	13	50	26
12 or Older	39	144	75

* Minimum, maximum, and mean are calculated over all 64 pseudo small State sample sizes.

In the next step, respondent-level data are merged with the selected segments from the pooled 2009 and 2010 NSDUH data. By doing so, the respondent-level data are obtained for the 64 pseudo small States. To create the SAE modeling sample, respondent-level data corresponding to the 64 pseudo small States are appended to the respondent-level data for the 43 small States from the pooled 2009 and 2010 NSDUH data. The SAE modeling sample had 107 States (43 actual small sample States[2] + 64 pseudo small sample States). This SAE modeling sample is denoted by Sample 1.

Recall that to create Sample 1, pseudo small States were first created by selecting one segment from each grouped SSR using stratified simple random sampling without replacement where grouped SSRs were treated as strata. The above process was repeated, and two segments, three segments, and four segments were selected to create Sample 2, Sample 3, and Sample 4, respectively. Note that each of the pseudo small States in Sample 1, 2, 3, and 4 had 6, 12, 18, and 24 segments, respectively. For illustration purposes, Table 3 describes the creation of the pseudo small States when two segments are selected. Tables 4, 5, and 6 provide analogue information given in Table 2 for the pseudo small State sample sizes for Samples 2, 3, and 4, respectively.

[2] For the purpose of this paper, the District of Columbia is treated as a small sample State.

Table 3: Simple Random Sampling without Replacement in California: Two Segments per Grouped SSR (Sample 2)

	Grouped SSR	Segments	Selected Segments	Pseudo Small States							
				CA1	**CA2**	**CA3**	**CA4**	**CA5**	**CA6**	**CA7**	**CA8**
	1	a1,…,a96	ra1,…,ra16	ra1, ra2	ra3, ra4	ra5, ra6	ra7, ra8	ra9, ra10	ra11, ra12	ra13, ra14	ra15, ra16
	2	b1,…,b96	rb1,…,rb16	rb1, rb2	rb3, rb4	rb5, rb6	rb7, rb8	rb9, rb10	rb11, rb12	rb13, rb14	rb15, rb16
CA	3	c1,…,c96	rc1,…,rc16	rc1, rc2	rc3, rc4	rc5, rc6	rc7, rc8	rc9, rc10	rc11, rc12	rc13, rc14	rc15, rc16
	4	d1,…,d96	rd1,…,rd16	rd1, rd2	rd3, rd4	rd5, rd6	rd7, rd8	rd9, rd10	rd11, rd12	rd13, rd14	rd15, rd16
	5	e1,…,e96	re1,…,re16	re1, re2	re3, re4	re5, re6	re7, re8	re9, re10	re11, re12	re13, re14	re15, re16
	6	f1,…,f96	rf1,…,rf16	rf1, rf2	rf3, rf4	rf5, rf6	rf7, rf8	rf9, rf10	rf11, rf12	rf13, rf14	rf15, rf16

CA = California; SSR = State sampling region.

For producing small area estimates, the age group-specific (12 to 17, 18 to 25, 26 or older) respondent-level weights in each of the 64 pseudo small States were poststratified to the corresponding one eighth of the large State analysis weight totals. For example, respondent-level weights for youths aged 12 to 17 in CA1 were poststratified to one eighth of the weight totals for youths aged 12 to 17 in California. Using Samples 1, 2, 3, and 4, age group-specific small area estimates then were produced for 107 States, and estimates were retained for only the 64 pseudo small States.

Small area estimates were produced for past month binge alcohol use (BNGALC), past month cigarette use (CIGMON), past year cocaine use (COCYR), and past month marijuana use (MRJMON) using the current SAE models except that only age group-specific State-level random effects were included in the models. In the current SAE models, State as well as within State level (grouped 3 SSRs or substate region) random effects are fitted. In this validation study, only State level random effects were included in the models because age group-specific sample sizes at the grouped SSR-level within pseudo small States were very small. From Tables 2, 4, 5, and 6, it can be seen that age group-specific small area estimates for pseudo small States are based on varying sample sizes ranging from about 25, 50, 75, 100, 150, 225, and 300. The four outcome measures given above were chosen from the 25 NSDUH SAE outcome measures to represent low, medium, and high prevalence rates.

Table 4: Descriptive Statistics for all Pseudo Small State Sample Sizes: Two Segments per Grouped SSR (Sample 2)

Age Group	Sample Sizes*		
	Minimum	**Maximum**	**Mean**
12 to 17	29	103	51
18 to 25	29	87	50
26 or Older	23	95	53
12 or Older	101	269	154

* Minimum, maximum, and mean are calculated over all 64 pseudo small State sample sizes.

Table 5: Descriptive Statistics for Pseudo all Small State Sample Sizes: Three Segments per Grouped SSR (Sample 3)

Age Group	Sample Sizes*		
	Minimum	**Maximum**	**Mean**
12 to 17	44	120	76
18 to 25	40	186	76
26 or Older	44	113	79
12 or Older	136	330	230

* Minimum, maximum, and mean are calculated over all 64 pseudo small State sample sizes.

Table 6: Descriptive Statistics for all Pseudo Small State Sample Sizes: Four Segments per Grouped SSR (Sample 4)

Age Group	Sample Sizes*		
	Minimum	**Maximum**	**Mean**
12 to 17	58	185	100
18 to 25	63	216	107
26 or Older	72	161	104
12 or Older	226	466	312

* Minimum, maximum, and mean are calculated over all 64 pseudo small State sample sizes.

3. Results

Recall that there are 8 large sample States and that for each large sample State, 8 pseudo small sample States were created; hence, there are 64 pseudo small sample States. A total of 4 age group-specific (12 or older, 12 to 17, 18 to 25, and 26 or older) SAEs for BNGALC, CIGMON, COCYR, and MRJMON were produced for each of the 64 pseudo small States using Samples 1, 2, 3, and 4. Hence, 4,096 (64 pseudo small States $\times$ 4 age groups $\times$ 4 outcome measures $\times$ 4 samples) SAEs were produced and compared with the corresponding DBEs and BEs. Figures 1 to 4 shows the SAEs, DBEs, and BEs for MRJMON for Samples 1 to 4, respectively. For example, Figure 1 displays age group-specific SAEs, DBEs, and BEs for MRJMON obtained by using Sample 1. The BEs are displayed by the horizontal red lines in the figures, the SAEs are displayed by the blue lines, and the DBEs are displayed by the yellow lines. It is clear from Figures 1 to 4 that DBEs fluctuate substantially more around BEs than SAEs and that SAEs are closer to BEs than DBEs to BEs. This translates into SAEs having lower relative root mean square errors (RRMSEs) than DBEs. Moving from Sample 1 to Sample 4 (i.e., as the average pseudo small State sample size increases), the fluctuation of DBEs and SAEs around BEs decreases. Clearly, Figures 1 to 4 demonstrate the superiority of SAEs over DBEs in terms of lower RRMSEs. The results for other outcome measures show similar patterns and are not displayed here due to page limitations. Next, results were summarized by comparing RRMSEs and relative absolute biases (RABs) of SAEs and DBEs, which are defined below.

Let SAE_i and DBE_i represent the small area estimate and the DBE for the *i*th (1 to 8) pseudo small State and let BE represent the corresponding benchmarked estimate (large State DBE). Then

$$RAB - SAE = 100 \times \frac{abs(\overline{SAE} - BE)}{BE},$$

$$RAB - DBE = 100 \times \frac{abs(\overline{DBE} - BE)}{BE},$$

$$RRMSE - SAE = 100 \times \frac{\sqrt{\frac{1}{8}\sum_{i=1}^{8}(SAE_i - BE)^2}}{BE},$$

and

$$RRMSE - DBE = 100 \times \frac{\sqrt{\frac{1}{8}\sum_{i=1}^{8}(DBE_i - BE)^2}}{BE}$$

where $\overline{SAE} = (\sum_{i=1}^{8} SAE_i \div 8)$ and $\overline{DBE} = (\sum_{i=1}^{8} DBE_i \div 8)$. Additionally, small area estimate Bayes confidence interval (BCI) (prediction interval) widths were compared with the design based confidence interval (CI) widths by calculating "Ratio of width" which is defined as

$$Ratio\ of\ \ width = \frac{1}{8}\sum_{i=1}^{8}\frac{design\ based\ CI\ width\ for\ the\ ith\ pseudo\ small\ State}{SAE\ BCI\ width\ for\ the\ ith\ pseudo\ small\ State}.$$

In some cases, a design-based CI did not exist because some of the pseudo small State DBEs were 0. Those cases were excluded when calculating the ratio of widths. The RRMSE, RAB, and ratio of width were available for 512 (8 large sample States $\times$ 4 outcome measures $\times$ 4 age groups $\times$ 4 samples) cases. Out of the total 512 cases the RAB for a small area estimate was smaller in 322 cases than the RAB for a DBE. This may be due to the fact that only eight pseudo small States were created and due to the sampling variability DBEs are not averaging closer to the corresponding BEs. The relatively small number of segments (6 to 24) per pseudo small State may also lead to nonnegligible ratio estimation bias. Note that SAEs are designed to accept some bias in order to minimize MSE, whereas the DBEs should be almost unbiased under repeated sampling. Hence, if there are a large number of pseudo small States (or replicates), the RAB for the DBEs is expected to be smaller than the RAB for the small area estimates. Nevertheless, it is interesting to note that for more than 60 percent of the cases, the RAB for a small area estimate was smaller than the RAB for a DBE.

The results corresponding to the 512 cases were further aggregated by calculating simple averages of RRMSE, RAB, and ratio of width over 8 large sample States and 4 outcome measures. Table 7 summarizes these aggregated results. A “sample size” column has been added to table 7 to depict the average pseudo small State sample sizes for Samples 1 to 4. As the sample size increases, the RRMSE of the small area estimate, the RRMSE of the DBE, and the ratio of CI widths are expected to decrease. This pattern is evident in

Table 7. It is clear that the small area estimate BCI widths are always smaller than the design-based CI widths. Moreover, the RRMSE for a small area estimate is always smaller than the RRMSE for a DBE. It can be noted that the small area estimates are clearly performing much better than the DBEs in terms of RAB, RRMSE, and the ratio of widths.

Noting that the 512 cases correspond to 128 possible average sample sizes (the sample size remains the same for the 4 outcome measures). The 128 average sample sizes were grouped into 5 groups, and for each group the average of the RAB for the small area estimate, the RAB for the DBE, the RRMSE of the small area estimate, the RRMSE of the DBE, and the ratio of CI widths was obtained. These averages are presented in Table 8. From Table 8, it can be seen that as the sample size increases, the RAB for the small area estimate, the RAB for the DBE, the RRMSE of the small area estimate, the RRMSE of the DBE, and the ratio of CI widths decrease. It is also interesting to note that when the sample size increases from about 25 to 225 (9 times), the RAB and the RRMSE for the small area estimate decrease slowly as opposed to the DBE where a decrease in the RAB and the RRMSE is quick. Table 8 could provide some guidance about the accuracy of the substate estimates. Even for the largest sample sizes (about 225), the SAE methodology provides generally higher quality estimates than the design-based methods. In the case of small sample sizes, small area estimates are of substantially higher quality than the DBEs.

4. Conclusions and Recommendations

This validation study has attempted to measure the accuracy of SAEs with respect to various small sample sizes and, as a result, provides useful information about the quality of the NSDUH substate estimates. Using the suppression rule on the age group-specific substate estimates, where sample sizes could be as low as 35, further ensures that only good quality estimates are published. In the future, a similar validation study is recommended in order to judge the quality of the substate year-to-year change estimates with respect to various small sample sizes. In conclusion, the use of SAE techniques to produce State and substate estimates provides substantial improvement in accuracy relative to their design based counterparts.

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Table 7: Age Group × Sample Specific Averages: Simple Averages over 8 Large States and 4 Outcome Measures

Age Group	Sample	Sample Size	RAB SAE (%)	RAB DBE (%)	RRMSE SAE (%)	RRMSE DBE (%)	Ratio of Widths
12 or Older	1	75	8.80	12.54	14.30	58.73	4.05
	2	154	8.65	12.60	15.22	45.43	2.65
	3	230	6.91	9.25	14.16	32.44	2.16
	4	312	6.11	7.82	12.98	29.28	1.94
12 to 17	1	24	19.07	35.60	22.43	139.13	12.27
	2	51	15.71	20.74	18.12	78.79	6.66
	3	76	15.82	18.87	18.21	75.24	4.73
	4	100	17.13	14.91	19.90	58.05	4.14
18 to 25	1	24	11.85	17.37	18.01	59.78	3.35
	2	50	7.53	10.98	13.67	41.35	2.51
	3	76	7.69	8.91	15.07	35.24	1.99
	4	107	6.97	8.76	12.96	29.88	1.94
26 or Older	1	26	10.86	22.04	16.35	91.85	6.32
	2	53	12.21	19.33	19.16	69.42	3.54
	3	79	7.95	12.11	16.17	47.46	2.85
	4	104	8.46	11.02	15.36	45.92	2.47

Table 8: Overall Averages by Five Sample Size Groups

Average Sample Size	RAB SAE (%)	RAB DBE (%)	RRMSE SAE (%)	RRMSE DBE (%)	Ratio of Widths
26	13.45	24.28	18.51	93.46	6.97
54	11.79	16.38	16.90	62.58	4.21
77	10.82	13.75	16.28	56.47	3.47
100	10.52	11.73	16.21	44.74	2.87
224	7.13	9.67	14.01	35.48	2.23

Figure 1: Small Area Estimation (SAE) Estimates and Design-Based Estimates (DBE) versus Benchmarked Estimates (BE), for MRJMON and Sample 1

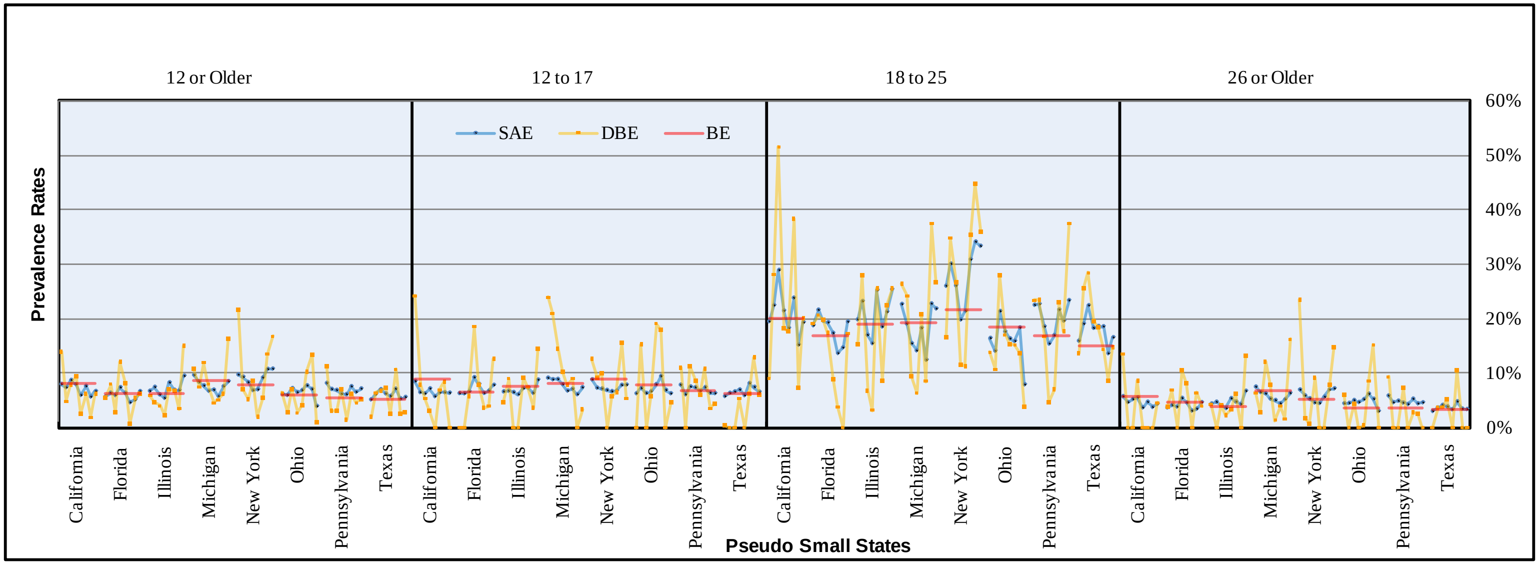

Figure 2: Small Area Estimation (SAE) Estimates and Design-Based Estimates (DBE) versus Benchmarked Estimates (BE), for MRJMON and Sample 2

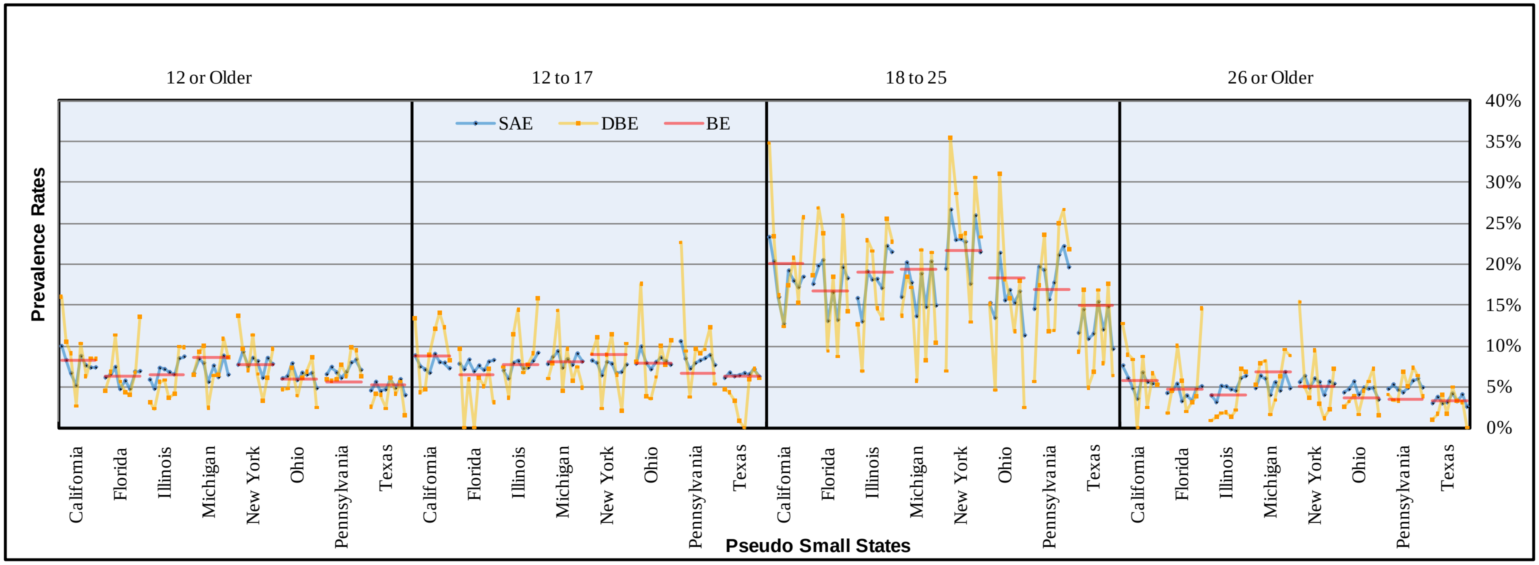

Figure 3: Small Area Estimation (SAE) Estimates and Design-Based Estimates (DBE) versus Benchmarked Estimates (BE), for MRJMON and Sample 3

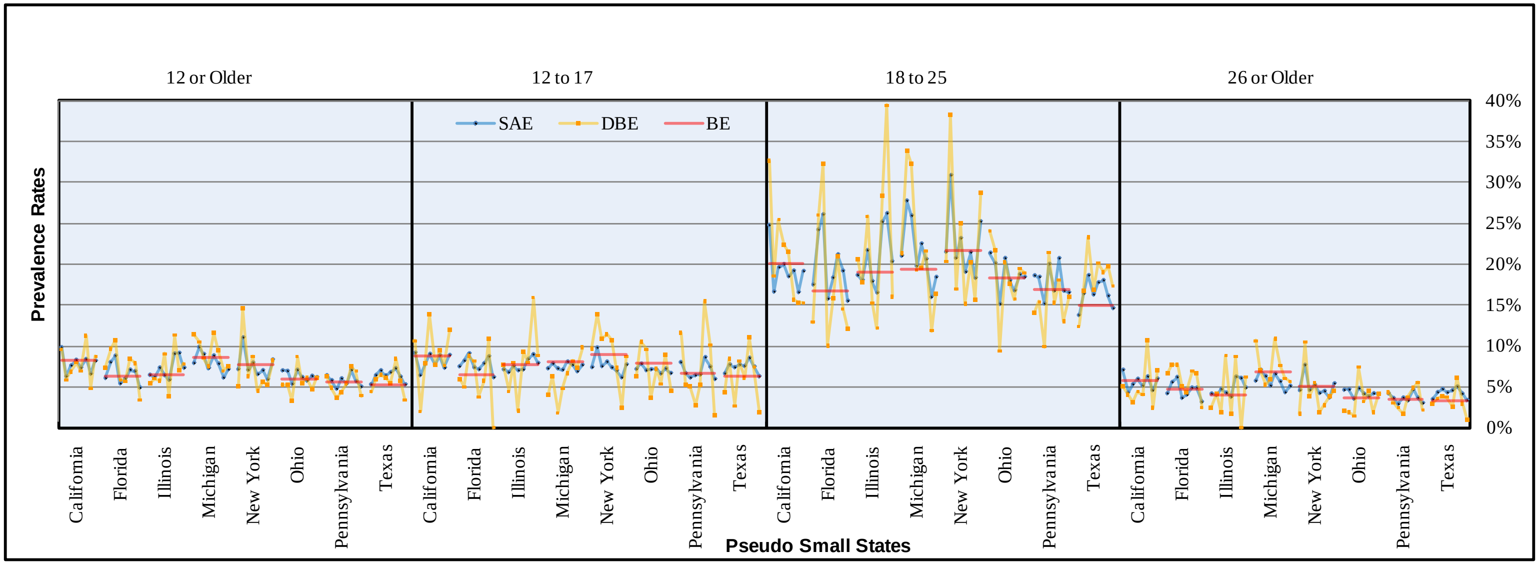

Figure 4: Small Area Estimation (SAE) Estimates and Design-Based Estimates (DBE) versus Benchmarked Estimates (BE), for MRJMON and Sample 4