

Demographic Statistical Methods Division
Sample Design and Estimation

Break-in-Series Evaluation for the 2015-2017 American Housing Survey

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Executive Summary

The year 2015 marked an important point in the history of the American Housing Survey (AHS). The prior AHS national longitudinal sample was in place from 1985 through 2013. In 2015, the Department of Housing and Urban Development (HUD) and the U.S. Census Bureau redesigned the AHS, including selecting a new longitudinal sample for the survey.

A redesign of this magnitude requires evaluation. Most importantly, the HUD, U.S. Census Bureau, and AHS data users need to know if the estimates from 2015 onward are a continuation of the 1985 to 2013 series, or if 2015 marks a break in the series due to the changes implemented in the redesign. This evaluation uses information collected from a bridge sample of 6,000 housing units interviewed in 2013, 2015, and 2017, and examines the impact the new sample and weighting had on the AHS estimates.

The key findings of this evaluation are:

Many estimates examined exhibit no evidence of a general break-in-series due to the new sample or the revised weighting. The estimates of this group are comparable with the 1985 to 2013 series and are consistent with estimates from other cross-sectional housing surveys. The general estimates examined include total housing units, occupied housing units, and vacant housing units.

Estimates of renter-occupied housing units and owner-occupied housing units demonstrate a change, which is most likely due to the revised weighting. The 2015 AHS estimates of this group differ from the 2015 AHS bridge sample under the old weighting methodology. Previously in the weighting, the weights were adjusted for housing unit totals derived from the Current Population Survey by tenure and householder characteristics including age, sex, race, marital status and Hispanic origin. In 2015, this weighting adjustment was removed.

Estimates of median household income demonstrate a change, which is likely due to revised nonresponse adjustment. The new weighting methodology includes income quartile data for the noninterview adjustment cells. This is an improvement upon the old methodology.

Estimates of single-attached housing units and multi-unit housing units show a change that is most likely due to a change in the questionnaire. There was an increase with single-attached housing units and a corresponding decrease with multi-unit housing units. This change is attributable to the known difficulties with the concepts/definitions of the two types of housing units within the questionnaire; this may have caused some housing units that would have been classified as multi-unit housing units to be classified as single-attached housing units. The estimates of the AHS bridge sample (using the old methodology) also showed a similar increase with single-attached housing units and a

similar decrease with multi-unit housing units, meaning that these changes cannot be attributed to the weighting methodology.

Estimates of vacant housing units by type show a change, which is most likely due to the revised weighting. Estimates of overall vacant housing units are comparable; however, estimates of different types of vacant housing units demonstrate a change that is likely due to a change in the weighting. The Year-Round Vacant Housing Unit domain saw a steep increase while, conversely, the Seasonally-Vacant Housing Unit domain had an offsetting decrease. Previously in the weighting, the weights were adjusted for the proportions of different types of vacant housing units from the Current Population Survey / Housing Vacancy Survey supplement of the Current Population Survey. In 2015, this weighting adjustment was removed.

1. Introduction

1.1 The American Housing Survey

The American Housing Survey (AHS), sponsored by the Department of Housing and Urban Development (HUD), underwent a major redesign in 2015 that included an entirely new sample design from which a new sample of housing units was selected, along with substantial revisions to the survey instrument and weighting methodology. The previous samples between 1985 and 2013 were comprised of the same core sample of housing units, used an evolving but similar survey instrument, and used relatively similar weighting methods in each biennial round of the survey. For brevity, we will refer to the weighting method used from 1985 to 2013 as the “old methodology”. Similarly, we will refer to the weighting methods of 2015 and 2017 as the “new methodology”.

Because the new sample and the new methodology differ from the old in several important aspects, a bridge sample was initiated to measure the changes to the survey in the event that the 2013 and 2015 estimates were incomparable. The bridge sample is a subsample of 6,000 housing units from the 2013 national sample which were interviewed in 2015 and 2017 using the new (2015, 2017) questionnaire. Estimates consistent with both the 2013 and 2015 weighting methods were derived from this sample by applying the essential features of the 2013 and 2015 weights. The estimates from the bridge sample were then used to examine the impact of the 2015 sample design changes due to weighting methodology on the estimates.

Whenever possible, this evaluation compares similar estimates from other surveys for context. Ideally, the AHS estimates of various housing characteristics would be similar to estimates from the American Community Survey (ACS), and the Current Population Survey / Housing Vacancy Survey (CPS/HVS). However, estimates of the same statistic from different surveys often differ due to different priorities, methodologies, definitions and question wording. What we may be able to surmise from the AHS with other surveys, is whether any unexpected increases or decreases in AHS estimates stem from the changes made in 2015 or if they track similar increases or decreases in the other surveys.

1.2 Break-in-Series

We define a break-in-series as a change in estimates from one survey cycle to the next that is substantial enough to make the results from the two cycles incomparable. A break-in-series may occur due to changes in the concept of a survey estimate, such as redefining a housing characteristic, or changes in the survey methodology.

The bridge sample serves as an evaluation tool. If something unforeseen happened with the 2015 sample, such as a problem with the sample or the weighting, the estimates from the bridge sample could measure what the 2015 estimates would have looked like if we had not redesigned the AHS sample. The next section describes some important limitations about using the bridge sample as an evaluation tool.

2. Limitations

Survey instrument. For an unconfounded comparison of a break-in-series, the 2013 survey instrument should have been used to interview the bridge sample in 2015. We were not able to use the 2013 instrument with the bridge sample due to budget limitations and instead used the 2015 instrument. The changes to the instrument, sample design, and weighting all occurred between 2013 and 2015 and therefore are confounded. For this reason we may not be able to definitively assert that a change was due to the sample because it could also be due to any one of the three changes.

Some Primary Sampling Units were excluded from the sample. Also due to cost, some Primary Sampling Units were removed from the bridge sample. Eighteen counties were excluded from the sample selection, leaving 817 counties with sample.

No adjustment for multiple comparisons. Several statistical comparisons were made in the evaluation, and Bonferroni or other methods for multiple comparisons were not used. In an exploratory evaluation such as this, the use of multiple comparisons is not crucial. Statistically significant differences are only indicators of potential issues that should be explored further. Because significant differences are more likely to occur, the use of unadjusted statistical tests in this evaluation is a conservative approach that increases the strength of the findings.

3. Bridge Sample Design

The bridge sample is a subsample of 6,000 completed interviews from the 2013 AHS national sample. It is nationally representative and can produce national-level estimates.

To reduce costs of interviewing for the bridge sample, the following alterations were made to the sample:

- 1) Eighteen counties were removed that were not in or adjacent to a 2015 Primary Sampling Unit and that were marked as particularly difficult to reach by regional office staff. It would have been prohibitively expensive to interview in these counties.

- 2) Only housing units successfully interviewed in the 2013 AHS were eligible for the bridge sample. This improved the chances of completing a future interview.

Within the remaining counties, the Census Bureau selected 6,000 sample housing units from the 2013 AHS sample proportional to an estimated population within each original 1980 stratum. The base weights of the bridge sample were then adjusted by the estimated current proportion of stratum population totals N_h by sample size n_h within each stratum h .

4. Weighting

This section describes the important aspects of the weighting methodology for the five different sets of weights and the resulting five sets of estimates used in this evaluation.

For AHS weighting, Killion (2014) and Ash et al. (2015) provide the full specifications for the old and new weighting methodologies, respectively. With both methodologies, each unit receives a basic weight, which reflects its probability of selection. This weight then undergoes a number of adjustments including:

- First-stage ratio adjustment to control totals
- Noninterview adjustment (Table 1)
- Raking adjustment to control totals (Table 2)

Table 1: Comparison of Noninterview Adjustment Cells

2007 - 2013	2015 - 2017
(a) Occupied & No prior data	(a) Type of housing unit
- Inside/Outside Central City	- House, apartment, flat
- Owner/renter	- Mobile home
- Type of Housing unit	- Other
(b) Owner & Prior data	(b) Metropolitan Status
- Metropolitan Status	- Metropolitan; Principal City
- Type of housing unit	- Metropolitan; not Principal City
- Number of rooms	- Micropolitan
(c) Renter & Prior data	(c) Urban/rural status
- Special Living/Not Special Living	- Urbanized Area
- Type of housing unit	- Urbanized Cluster
- Metropolitan Status	- Rural
- Inside/Outside Central City	(d) Tract-level quartiles of median income
- Number of units in structure	
(d) Vacant housing units	
- Year-round/seasonal	
- Special Living/Not Special Living	
- Metropolitan Status	
- Inside/Outside Central City	

Table 1 summarizes the main differences between the noninterview adjustment cells of the old and new weighting methodologies. In the new methodology, the nonresponse adjustment was updated based on research by Prunty (2016) that examined the variables used to form noninterview adjustment cells.

Table 2: Comparison of Weighting Methods

Feature of the Weighting		Old Methodology	New Methodology
Geography for raking		- Census Region	- Census Division/selected states/selected Core Based Statistical Areas
Control Totals for the Raking	New construction totals	- Jan 1980-Dec 1984 - Jan 1985-Dec 1989 - Jan 1990-Dec 1994 - Jan 1995-Dec 1999 - Jan 2000-Dec 2004 - Jan 2005-Dec 2009 - Jan 2010-June 2013	Prior four years only 2015: - 2011-2012 - 2013-2014 2017: - 2013-2014 - 2015-2016
	Person totals	Housing unit estimates from CPS by Census Division, tenure, and householder characteristics including age, sex, race, marital status, Hispanic origin	- Population demographic estimates - Total persons - Black persons, - Persons aged 65+ - Hispanic persons
	Vacancy status	Used proportions from CPS/HVS	Did not use CPS/HVS or any other source.
	HUD totals	Not used	- Public Housing - Private Project Based - Voucher

Table 2 summarizes the main differences between the old and new weighting methodologies with respect to the control totals used in the raking. The changes in the control totals used in the raking adjustment are discussed in Ash (2015).

Five different bridge weights were calculated for the bridge sample: three weights using an approximation of the old methodology on 2013, 2015, and 2017 data, as well as two weights using an approximation of the new methodology on 2015 and 2017 data. All five weights of the bridge sample preserve the essential features of the weights, although a sample size of 6,000 sample units could not support the same number of cells within the noninterview adjustment or the raking adjustment. These simplified bridge weights yield estimates from the bridge sample that are comparable to the full-sample estimates, albeit with larger variances.

5. Statistical Comparisons

Testing for a break-in-series requires statistical comparisons of different estimates. Table 3 describes the statistical comparisons used in this evaluation and the conclusions that are supported by each comparison.

Table 3: Types of Statistical Comparisons in the Evaluation

	A statistical difference between the estimates...		...indicates...
1	American Housing Survey The full/new AHS sample with the revised weighting methodology	American Housing Survey Bridge Old Methodology Bridge sample with the old weighting methodology	There is a change in the weighting, the sample, or the instrument
2	American Housing Survey Bridge Old Methodology Bridge sample with the old weighting methodology	American Housing Survey Bridge New Methodology Bridge sample with new weighting methodology	There is a change in the weighting
3	American Housing Survey Full AHS sample with the revised weighting methodology	American Housing Survey Bridge New Methodology Bridge sample with the new weighting methodology	The new weighting method was implemented incorrectly.

All three comparisons of Table 3 are included in the results section for the 2015 and 2017 survey cycles. We next discuss each of the three tests further.

Comparison 1. American Housing Survey and American Housing Survey Bridge Old Methodology. This comparison is central to our analysis. We want to know whether the changes of the sample and the change to the weighting methodology produce estimates that differ with the old sample and old weighting methodology. This is done by comparing the “new” estimates and the “old” estimates, where the “new” estimates use the new 2015 sample and revised weighting and the “old” estimates use a subsample of the old sample and apply an approximation of the old weighting methodology. We say that the weighting of the bridge sample is an approximation of the “old” weighting methodology because the much smaller subsample cannot support the same number of weighting cells as the full sample so many of the cells were combined.

A limitation of this comparison is that three sets of changes occurred in the 2015 AHS including:

- (1) the new sample,
- (2) revisions to the weighting methodology,
- (3) improvements to the instrument.

Since all three of these changes happened at the same time, the effects are confounded and we are not able to explicitly attribute the difference to a specific change. However, for many of the differences that we found to be statistically different, we have found specific known changes that are most likely to be the cause of the difference.

Comparison 2. American Housing Survey Bridge Old Methodology and American Housing Survey Bridge New Methodology. When we compare estimates derived from the same bridge sample but using different weighting methods, it can be concluded that the difference is to a change in the weighting methodology.

Comparison 3. American Housing Survey and American Housing Survey Bridge New Methodology. The last comparison is not central to our evaluation and more of a check. The comparison uses different samples and the same weighting method: the revised method for 2015. Although we have used an approximation of the revised method with the bridge sample, the two estimates should not be different. With our evaluation, only one of these comparisons were different.

Other Estimates Presented. In addition to making these internal AHS comparisons, we also included estimates to other Census surveys, particularly the ACS and the CPS/HVS. The estimates from other surveys were used to examine whether AHS was generally tracking the same trends as the other surveys; however, strict statistical comparisons of the trends were not made.

All formal statistical comparisons were made at a 95 percent confidence level. In all tables, the numbers after estimates in parentheses represent the estimated standard error of the estimate.

6. Estimates from the American Community Survey and Current Population Survey / Housing Vacancy Survey

Estimates from the ACS and the CPS/HVS are included in this evaluation as a reference for AHS estimates. All estimates and associated measures of error are available online through the U.S. Census Bureau website.

For ACS, the following tables from American FactFinder were referenced: DP04, S1903, and B25004. See also U.S. Census Bureau (2014) for more information about the sample design and estimation methods for ACS.

For CPS/HVS, Annual Statistics, Table 11 was referenced for years 2009 – 2017. For the year 2007, Table 9 was referenced. See also U.S. Census Bureau (2016) for more information about the sample design and estimation methods for CPS/HVS.

7. Results

The key findings of this evaluation are:

Many estimates examined exhibit no evidence of a general break-in-series due to the sample or the weighting. The estimates of this group are comparable with the 1985 to 2013 series and are consistent with estimates from other cross-sectional housing surveys. The general estimates include median income, total housing units, occupied housing units, and vacant housing units.

Estimates of renter-occupied housing units and owner-occupied housing units demonstrate a change, which is most likely due to the revised weighting. The 2015 AHS estimates of this group differ from the 2015 AHS bridge sample with the old weighting methodology. At the same time, the 2015 AHS bridge sample with the new methodology is not different than either the 2015 AHS estimate or the 2015 bridge with old methodology estimate. We attribute this change to a known change in the weighting. Previously in the weighting, the weights were adjusted for housing unit totals derived from the CPS by tenure and householder characteristics including age, sex, race, marital status and Hispanic origin. In the new methodology, this weighting adjustment was removed.

Estimates of single-attached housing units and multi-unit housing units show a change that is most likely due to a change in the questionnaire. There was an increase with single-attached housing units and a corresponding decrease with multi-unit housing units. This change is most likely attributable to the known difficulties with the concepts/definitions of the two types of housing units within the questionnaire; this may have caused some housing units that would have been classified as multi-unit housing units to be classified as single-attached housing units.

The estimates of the AHS Bridge Sample (using the old methodology) also showed a similar increase with single-attached housing units and a similar decrease with multi-unit housing units, meaning that these changes cannot be attributed to weighting methodology.

Estimates of vacant housing units by type show a change, which is most likely due to a change in the revised weighting. Estimates of overall vacant housing units are comparable; however, estimates of different types of vacant housing units demonstrate a change that is likely due to a change in the weighting. The Year-Round Vacant Housing Unit domain saw a steep increase while, conversely, the Seasonally-Vacant Housing Unit domain had an offsetting decrease. Previously in the weighting, the weights were adjusted for the proportions of different types of vacant housing units from the Housing Vacancy Survey. In the new methodology, this weighting adjustment was removed.

Table 4 summarizes the four findings of this evaluation, the domains or groups of housing units that apply to those findings, and the sections of this document that provide the details.

Table 4: Summary of Results

Estimates	Finding	Section
Total Housing Units		
Total Occupied Housing Units	No Break-in-series	7.1
Total Vacant Housing Units		
Median Household Income		7.2
Renter-Occupied Housing Units	Change in Weighting	
Owner-Occupied Housing Units		7.3
Tenure Switching		
Single-Attached Housing Units	Change in Definition	
Multi-Unit Housing Units		7.4
Seasonally-Vacant Housing Units	Change in Weighting	
Year-Round Vacant Housing Units		7.5

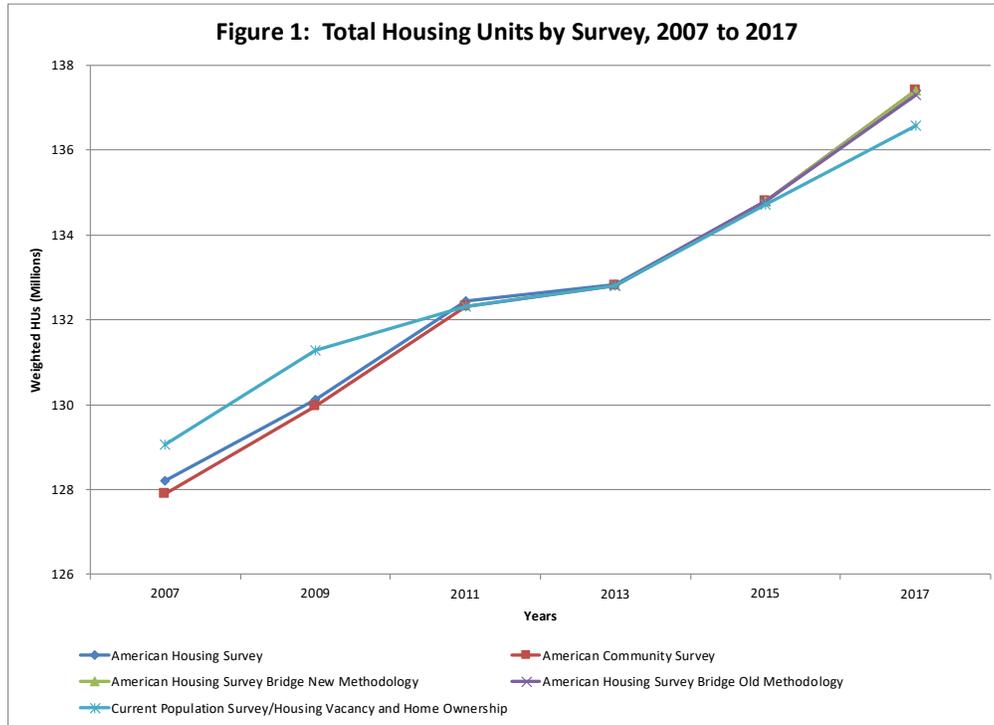
7.1 No Break-in-Series

With only a few exceptions, the newly selected sample and new weighting methodology did not appear to cause a break-in-series of AHS national sample estimates. A discussion of the key

estimates along with the small, yet significant exceptions, are discussed in the following sections.

7.1.1 Total Housing Units

Figure 1 shows estimates of total housing units for survey years 2007 to 2017.



Source: U.S. Census Bureau, 2007, 2009, 2011, 2013, 2015, and 2017 American Housing Survey; 2007, 2009, 2011, 2013, 2015, and 2017 American Community Survey; and 2007, 2009, 2011, 2013, 2015, and 2017 Current Population Survey / Housing Vacancy Survey

At a glance, the estimates are quite similar among the ACS, AHS, and AHS new methodology (NM) estimates. This is an expected result because the AHS (as of 2015) and ACS are both controlled to housing unit counts produced as part of the Census Bureau population estimates. Because the estimates of total HUs, for all surveys, are ratio adjusted, the estimates have no sample variance and due to this significance, testing is not applicable. ACS does adjust to HU totals, but it is not the last weighting adjustment so it reports a non-zero variance for total HUs.

Table 5 shows the estimates of the total housing units for 2013, 2015, and 2017.

Table 5: Estimates of Total Housing Units by Survey, 2013, 2015, and 2017

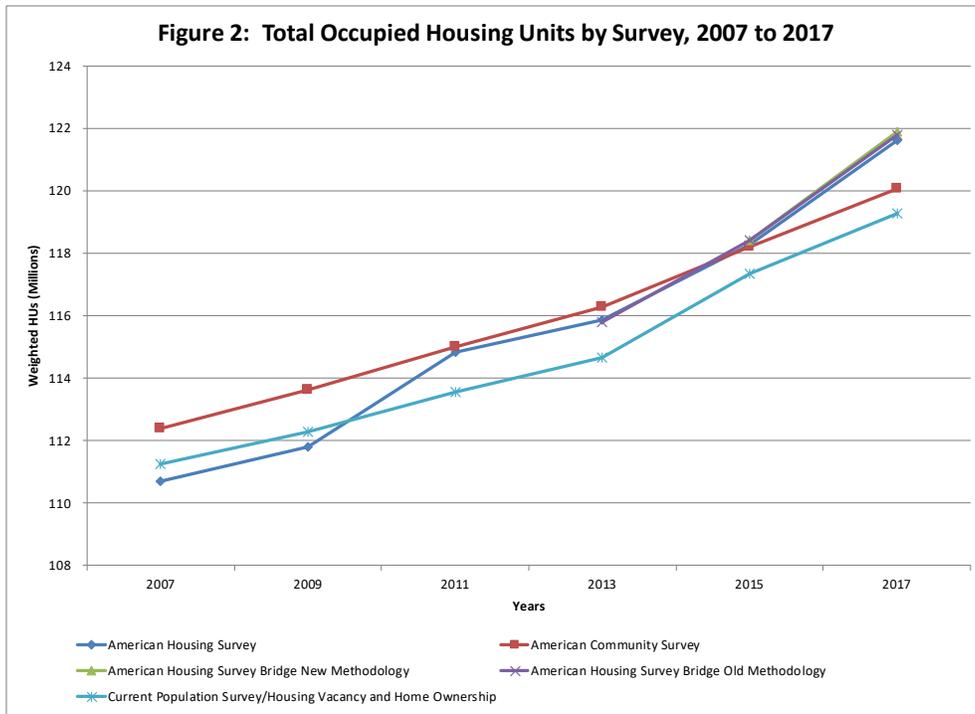
Survey	Estimate in thousands		
	2013	2015	2017
American Housing Survey	132,832 (8)	134,790	137,400
American Housing Survey Bridge Old Methodology	132,800	134,800	137,300 (35)
American Housing Survey Bridge New Methodology	(X)	134,800	137,400
American Community Survey	132,808 (1,750)	134,794 (1,467)	137,407 (2,506)
Housing Vacancy Survey	132,799	134,700	136,570

Source: U.S. Census Bureau, 2013, 2015, and 2017 American Housing Survey; 2013, 2015, and 2017 American Community Survey; and 2013, 2015, and 2017 Current Population Survey / Housing Vacancy Survey
(X) denotes an estimate that is not applicable and the standard error of an estimate follows the estimate in parenthesis.

Table 5 does not provide evidence supporting a break-in-series for total housing units.

7.1.2 Total Occupied Housing Units

Figure 2 shows estimates of total occupied housing units for survey years 2007 to 2017.



Source: U.S. Census Bureau, 2007, 2009, 2011, 2013, 2015, and 2017 American Housing Survey; 2007, 2009, 2011, 2013, 2015, and 2017 American Community Survey; and 2007, 2009, 2011, 2013, 2015, and 2017 Current Population Survey / Housing Vacancy Survey

Table 6 shows the estimates of the total number of occupied housing units for 2013, 2015, and 2017.

Table 6: Estimates of Total Occupied Housing Units by Survey, 2013, 2015 and 2017

Estimate	Estimates in thousands (Standard Error)		
	2013	2015	2017
American Housing Survey	115,852 (438)	118,290 (247)	121,600 (239)
American Housing Survey Bridge Old Methodology	115,800	118,400 (1,223)	121,800 (716)
American Housing Survey Bridge New Methodology	(X)	118,400 (699)	121,900 (695)
American Community Survey	116,291 (86)	118,208 (70)	120,063 (98)
Housing Vacancy Survey	114,673 (120)	117,345 (97)	119,272 (111)

Source: U.S. Census Bureau, 2013, 2015, and 2017 American Housing Survey; 2013, 2015, and 2017 American Community Survey; and 2013, 2015, and 2017 Current Population Survey / Housing Vacancy Survey

(X) denotes an estimate that is not applicable and the standard error of an estimate follows the estimate in parenthesis

Table 7 shows the results of significance testing of occupied housing unit estimates for 2015 and 2017 across AHS, the old methodology, and the new methodology.

Table 7: 95 Percent Confidence Intervals, Difference in Total Occupied Housing Units

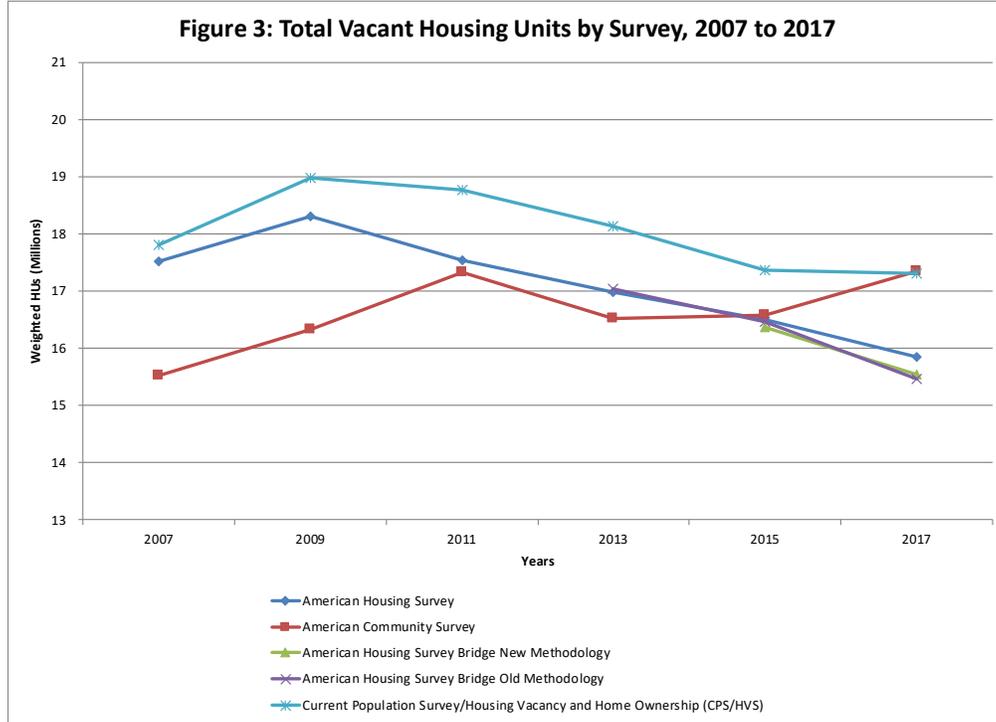
Estimate	Confidence Intervals of Difference	
	2015	2017
American Housing Survey and American Housing Survey Bridge Old Methodology	(-2,524, 2,368)	(-1,773, 1,224)
American Housing Survey Bridge New Methodology and American Housing Survey Bridge Old Methodology	(-1,761, 1,876)	(-590, 655)
American Housing Survey and American Housing Survey Bridge New Methodology	(-1,589, 1,318)	(-1,766, 1,152)

Source: U.S. Census Bureau, 2015 and 2017 American Housing Survey

Table 7 provides no evidence supporting a break-in-series for total occupied housing units.

7.1.3 Total Vacant Housing Units

Figure 3 shows estimates of total vacant housing units in millions by survey years 2007 to 2017.



Source: U.S. Census Bureau, 2007, 2009, 2011, 2013, 2015, and 2017 American Housing Survey; 2007, 2009, 2011, 2013, 2015, and 2017 American Community Survey; and 2007, 2009, 2011, 2013, 2015, and 2017 Current Population Survey / Housing Vacancy Survey

Table 8 shows the estimates of the total number of vacant housing units for 2013, 2015, and 2017.

Table 8: Estimates of Total Vacant Housing Units by Survey, 2013, 2015, and 2017

Estimate [thousands]	Data Collection Years		
	2013	2015	2017
American Housing Survey	16,980 (439)	16,501 (247)	15,843 (239)
American Housing Survey Bridge Old Methodology	17,030	16,460 (1,221)	15,470 (723)
American Housing Survey Bridge New Methodology	(X)	16,360 (699)	15,540 (695)
American Community Survey	16,517 (87)	16,585 (70)	17,344 (99)
Housing Vacancy Survey	18,127 (179)	17,355 (176)	17,298 (165)

Source: U.S. Census Bureau, 2013, 2015, and 2017 American Housing Survey; 2013, 2015, and 2017 American Community Survey and; 2013, 2015, and 2017 Current Population Survey / Housing Vacancy Survey

(X) denotes an estimate that is not applicable and the standard error of an estimate follows the estimate in parenthesis.

Table 9 shows the results of significance testing comparisons of total vacant housing unit estimates.

Table 9: 95 Percent Confidence Intervals, Difference in Total Vacant Housing Units

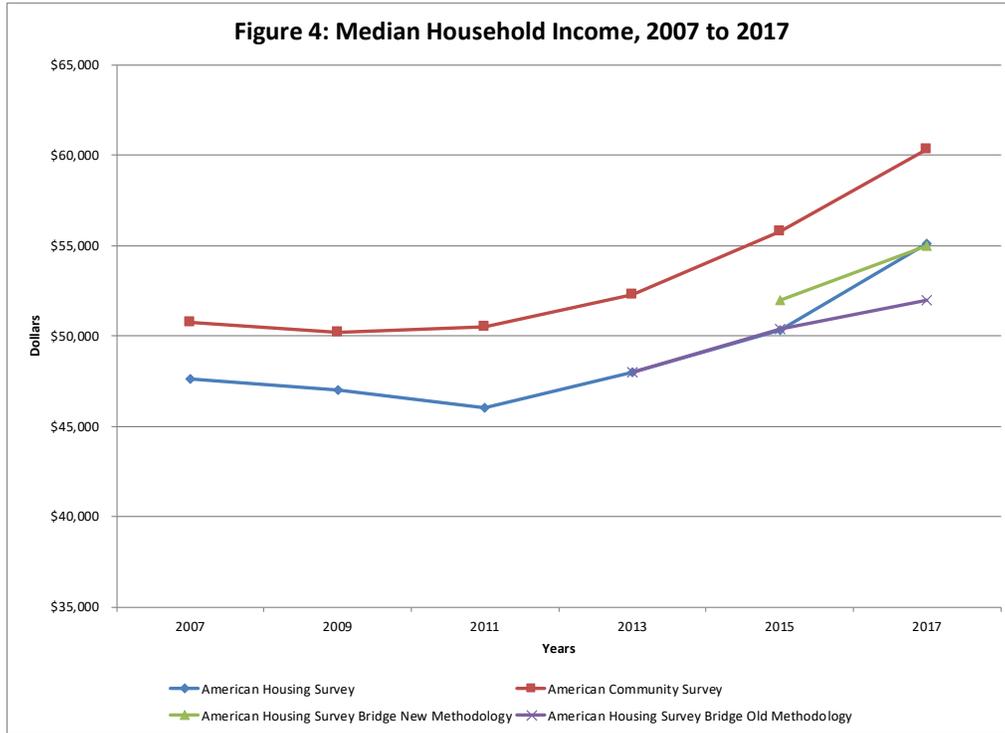
Sample	Confidence Intervals of Difference	
	2015	2017
American Housing Survey and American Housing Survey Bridge Old Methodology	(-2,406, 2,478)	(-1,139, 1,880)
American Housing Survey Bridge New Methodology and American Housing Survey Bridge Old Methodology	(-1,919, 1,719)	(-558, 685)
American Housing Survey and American Housing Survey Bridge New Methodology	(-1,318, 1,590)	(-1,152, 1,766)

Source: U.S. Census Bureau, 2015 and 2017 American Housing Survey

Table 9 provides no evidence supporting a break-in-series for total vacant housing units.

7.2 Change in the Weighting – Median Household Income

Figure 4 shows the estimate of median household income from 2007 to 2017.



Source: U.S. Census Bureau, 2007, 2009, 2011, 2013, 2015, and 2017 American Housing Survey and 2007, 2009, 2011, 2013, 2015, and 2017 American Community Survey

Table 10 shows the estimates of median household income for 2013, 2015, and 2017.

Table 10: Estimates of Median Household Income by Survey, 2013, 2015, and 2017

Estimate	Data Collection Years		
	2013	2015	2017
American Housing Survey	\$48,000 (137)	\$50,300 (617)	\$55,100 (697)
American Housing Survey Bridge Old Methodology	\$48,000	\$50,350 (1,122)	\$52,000 (1,138)
American Housing Survey Bridge New Methodology	(X)	\$52,000 (1,597)	\$55,000 (1,297)
American Community Survey	\$52,250 (40)	\$55,775 (52)	\$60,336 (52)

Source: U.S. Census Bureau, 2013, 2015, and 2017 American Housing Survey and 2013, 2015, and 2017 American Community Survey

(X) denotes an estimate that is not applicable and the standard error of an estimate follows the estimate in parenthesis.

Table 11: 95 Percent Confidence Intervals, Difference in Median Household Income

Sample	Tested by Percent Difference	
	2015	2017
American Housing Survey and American Housing Survey Bridge Old Methodology	(-1,264, 1,160)	(1,731, 4,469)
American Housing Survey Bridge New Methodology and American Housing Survey Bridge Old Methodology	(-164, 3,460)	(771, 5,233)*
American Housing Survey and American Housing Survey Bridge New Methodology	(-2,912, -488)***	(-1,271, 1,467)

Source: U.S. Census Bureau, 2015 and 2017 American Housing Survey

*** denotes significance

In Table 11, the 2017 comparison of the old methodology and production estimate shows a significant difference, supporting a break-in-series. This is likely due to a change in the weighting, particularly the inclusion of income quartiles for the creation of noninterview adjustment cells in the new weighting methodology.

7.3 Change in the Weighting – Renter- and Owner-Occupied Housing Units

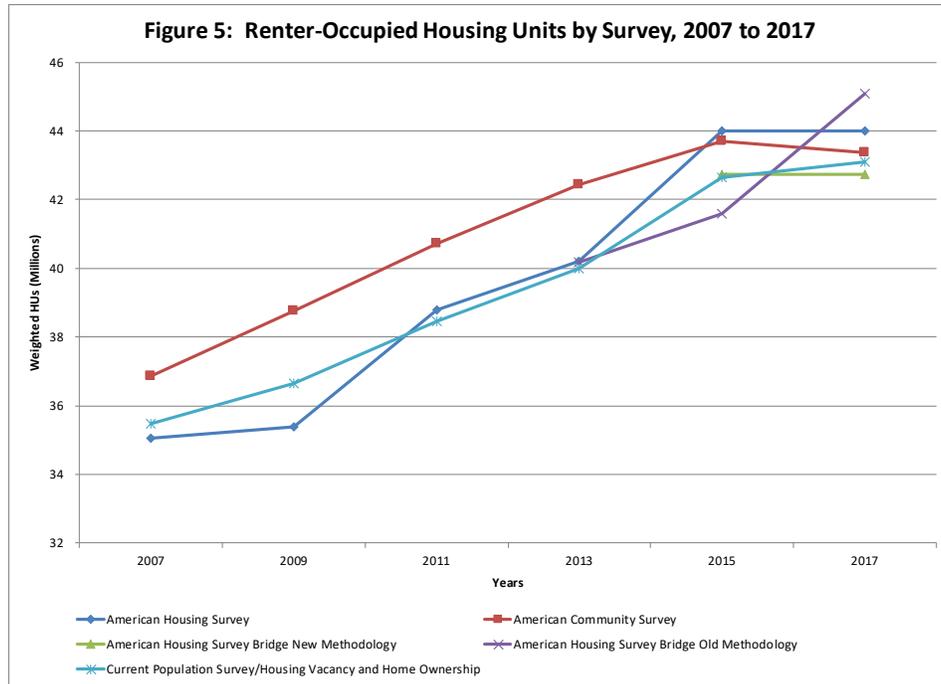
Estimates of owner-occupied housing units decreased and renter-occupied housing units increased. Additionally, the increase and decrease of the renter and owner-occupied estimates were off-setting because estimates of total occupied housing units show no evidence of a break (see Section 7.1.2).

The questions in the survey instrument about tenure status have not changed, but the weighting methodology did change with respect to tenure. In the old methodology, the weights were controlled to housing unit totals derived from the CPS that included tenure status, Census Division, and characteristics of the householder including age, sex marital status, and Hispanic origin. The new weighting method did not use the CPS estimates that included tenure status. The bridge sample also provides evidence that supports the conclusion that the weighting caused a break with the occupied owner and renter estimates, as the two weighting methodologies on the bridge sample show significant differences.

The analogous owner estimates were not significant, but the renter-occupied estimates do support the conclusion that the change in the weighting methodology had an impact on the estimates of owners and renters.

7.3.1 Renter-Occupied Housing Units

Figure 5 shows estimates of renter-occupied housing units by survey years 2007 to 2017.



Source: U.S. Census Bureau, 2007, 2009, 2011, 2013, 2015, and 2017 American Housing Survey and 2007, 2009, 2011, 2013, 2015, and 2017 American Community Survey

Table 12 shows the estimates of the total number of renter-occupied housing units for 2013, 2015, and 2017.

Table 12: Estimates of Renter-Occupied Housing Units by Survey, 2013, 2015, and 2017

Estimate [thousands]	Data Collection Years		
	2013	2015	2017
American Housing Survey	40,201 (166)	43,991 (291)	43,990 (255)
American Housing Survey Bridge Old Methodology	40,190	41,590 (1,062)	45,070 (362)
American Housing Survey Bridge New Methodology	(X)	42,730 (945)	42,750 (1,032)
American Community Survey	42,447 (73)	43,702 (69)	43,379 (69)
Housing Vacancy Survey	40,004 (304)	42,639 (309)	43,102 (159)

Source: U.S. Census Bureau, 2013, 2015, and 2017 American Housing Survey; 2013, 2015, and 2017 American Community Survey; and 2013, 2015, and 2017 Current Population Survey / Housing Vacancy Survey
(X) denotes an estimate that is not applicable and the standard error of an estimate follows the estimate in parenthesis.

Table 13 shows the results of significance testing of renter-occupied housing unit estimates.

Table 13: 95 Percent Confidence Intervals, Difference in Renter-Occupied Housing Units

Sample	Confidence Intervals of Difference	
	2015	2017
American Housing Survey and American Housing Survey Bridge Old Methodology	(405, 4,723)***	(-1,934, -215)***
American Housing Survey Bridge New Methodology and American Housing Survey Bridge Old Methodology	(-492, 2,770)	(-4,259, -386)***
209 American Housing Survey and American Housing Survey Bridge New Methodology	(-2,248, 1,846)	(-757, 3,252)

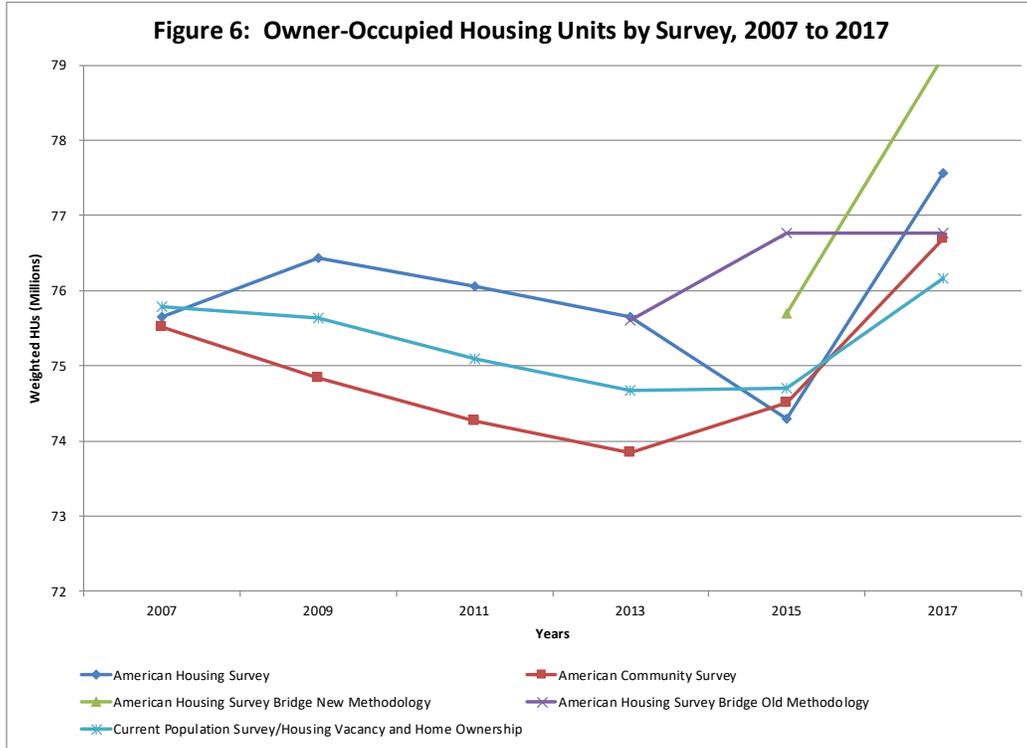
Source: U.S. Census Bureau, 2015 and 2017 American Housing Survey
The standard error of an estimate follows the estimate in parenthesis.

*** denotes significance

The results of Table 13 provide evidence of a break-in-series for estimate of renter-occupied housing units, which may be due to the changes in the weighting method.

7.3.2 Owner-Occupied Housing Units

Figure 6 shows estimates of owner-occupied housing units in millions by survey years 2007 to 2017.



Source: U.S. Census Bureau, 2007, 2009, 2011, 2013, 2015, and 2017 American Housing Survey and 2007, 2009, 2011, 2013, 2015, and 2017 American Community Survey

Table 14 shows the estimates of the total number of owner-occupied housing units for 2013, 2015, and 2017.

Table 14: Estimates of Owner-Occupied Housing Units by Survey, 2013, 2015, and 2017

Estimate [thousands]	Data Collection Years		
	2013	2015	2017
American Housing Survey	75,650 (308)	74,299 (301)	77,570 (312)
American Housing Survey Bridge Old Methodology	75,600	76,770 (1,025)	76,770 (557)
American Housing Survey Bridge New Methodology	(X)	75,690 (1,042)	79,120 (1,039)
American Community Survey	73,844 (129)	74,507 (139)	76,684 (148)
Housing Vacancy Survey	74,668 (343)	74,706 (343)	76,170 (181)

Source: U.S. Census Bureau, 2013, 2015, and 2017 American Housing Survey; 2013, 2015, and 2017 American Community Survey; and 2007, 2009, 2011, 2013, 2015, and 2017 Current Population Survey / Housing Vacancy Survey
(X) denotes an estimate that is not applicable and the standard error of an estimate follows the estimate in parenthesis.

Table 15 shows the results of significance testing of owner-occupied housing unit estimates.

Table 15: 95 Percent Confidence Intervals, Difference in Owner-Occupied Housing Units

Sample	Confidence Intervals of Difference	
	2015	2017
American Housing Survey and American Housing Survey Bridge Old Methodology	(4,737, 548)***	(-517, 2,117)
American Housing Survey Bridge New Methodology and American Housing Survey Bridge Old Methodology	(-2,381, 4)	(456, 4,253)***
American Housing Survey and American Housing Survey Bridge New Methodology	(-3,687, 565)	(-3,680, 570)

Source: U.S. Census Bureau, 2015 and 2017 American Housing Survey
The standard error of an estimate follows the estimate in parenthesis.

*** denotes significance

(X) denotes an estimate that is not applicable and the standard error of an estimate follows the estimate in parenthesis.

The results of Table 15 show no evidence of a break-in-series for estimates of owner-occupied housing units.

7.3.3 Tenure Switching

Three survey cycles of interviewing the bridge sample – 2013, 2015, and 2017 – allow us to examine tenure switching. We define tenure switching as when a housing unit switches its tenure status from owner to renter or renter to owner between two survey cycles. This estimate is a longitudinal estimate and therefore different from the other estimates of this report because it requires the results from two rounds of the surveys.

We define the proportion of tenure switching as the proportion of housing units that changed their tenure status, from either owner to renter or from renter to owner. The denominator for this proportion is the number of housing units that we know their tenure status for both rounds of AHS: this excludes vacant housing units and noninterviews.

Table 16 provides the estimates for the proportion of housing units that switched tenure.

Table 16: Estimates of Tenure Switching

Estimate	Data Collection Years	
	2013/2015	2015/2017
American Housing Survey	(X)	5.9% (0.1%)
American Housing Survey Bridge Old Methodology	5.7% (0.4%)	8.4% (0.5%)
American Housing Survey Bridge New Methodology	6.0% (0.4%)	8.3% (0.5%)

Source: U.S. Census Bureau, 2013, 2015, and 2017 American Housing Survey and 2013, 2015, and 2017 American Community Survey

The standard error of an estimate follows the estimate in parenthesis.

Table 17 presents the confidence intervals for the difference in the proportion of tenure switching.

Table 17: 95 Percent Confidence Intervals, Difference in Estimates of Tenure Switching

Sample	Tested by Percent Difference	
	2013/2015	2015/2017
American Housing Survey and American Housing Survey Bridge Old Methodology	(X)	(1.5%, 3.5%) ^{***}
American Housing Survey Bridge New Methodology and American Housing Survey Bridge Old Methodology	(-0.1%, 6.0%)	(-0.7%, 0.4%)
American Housing Survey and American Housing Survey Bridge New Methodology	(X)	(1.3%, 3.4%) ^{***}

Source: U.S. Census Bureau, 2013, 2015, and 2017 American Housing Survey

^{***} denotes significance

Table 17 shows that there is evidence of a break-in-series for estimates of year-round vacant housing units. We see a significant difference between the full sample weighting and both old methodology estimates of tenure-switching proportions. This may be attributed to the change in the weighting with respect to tenure. As discussed in Section 7.3, the old weighting methodology control the weights to the proportions by tenure from the CPS and the new weighting methodology does not control to any other source. The test comparing the new methodology of the full sample and the bridge sample was also significant. At this time, we cannot offer an explanation.

7.4 Change in Definition

The estimates discussed in this section have some difference that may be due to definitional changes in housing unit classifications.

From 2013 to 2015, the AHS estimate of single-attached housing units increased almost 30 percent, and the estimate of multi-unit housing units had a decrease of 0.46 percent. There is potential that this is due to the confusing nature of the two housing unit classifications and data collection instrument redesign.

The definitions of detached and attached housing units and a multi-unit structure are given below and can be found in U.S. Census Bureau and HUD (2011).

A housing unit is...

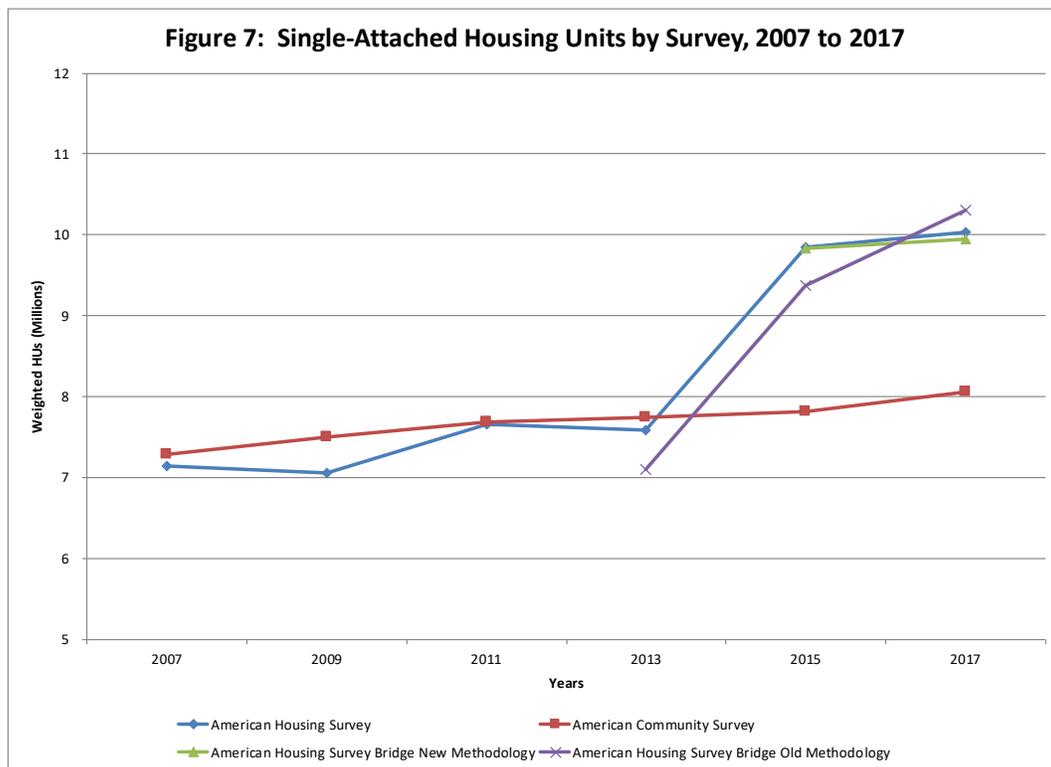
Detached, if it has open space on all four sides.

Attached, if it has unbroken walls extending from the ground to the roof that divide it from other adjoining structures as in many row houses or townhouses. If a unit shares a furnace or boiler with adjoining units, then the walls are pierced by pipes or ducts, and all of the units thus are included in one structure.

Multi-unit structure – A building that contains more than one housing unit (for example, an apartment building).

7.4.1 Single-Attached Housing Units

Figure 7 shows estimates of single-attached housing units for survey years 2007 to 2017.



Source: U.S. Census Bureau, 2007, 2009, 2011, 2013, 2015, and 2017 American Housing Survey and American Community Survey

Table 18 shows the estimates of the total number of single-attached housing units for 2013, 2015, and 2017.

Table 18: Estimates of Single-Attached Housing Units by Survey, 2013, 2015, and 2017

Estimate [thousands]	Data Collection Years		
	2013	2015	2017
American Housing Survey	7,581 (153)	9,840 (161)	10,040 (185)
American Housing Survey Bridge Old Methodology	7,100	9,373 (560)	10,307 (595)
American Housing Survey Bridge New Methodology	(X)	9,834 (560)	9,952 (597)
American Community Survey	7,741 (25)	7,814 (23)	8,056 (29)

Source: U.S. Census Bureau, 2013, 2015, and 2017 American Housing Survey and 2013, 2015, and 2017 American Community Survey

(X) denotes an estimate that is not applicable and the standard error of an estimate follows the estimate in parenthesis.

Table 19 shows the results of significance testing of single-attached housing unit estimates.

Table 19: 95 Percent Confidence Intervals, Difference in Single-Attached Housing Units

Sample	Confidence Intervals of Difference	
	2015	2017
American Housing Survey and American Housing Survey Bridge Old Methodology	(-671, 1,615)	(-1,463, 929)
American Housing Survey Bridge New Methodology and American Housing Survey Bridge Old Methodology	(-11, 932)	(-972, 262)
American Housing Survey and American Housing Survey Bridge New Methodology	(1,129, 1,153)	(-1,093, 1,269)

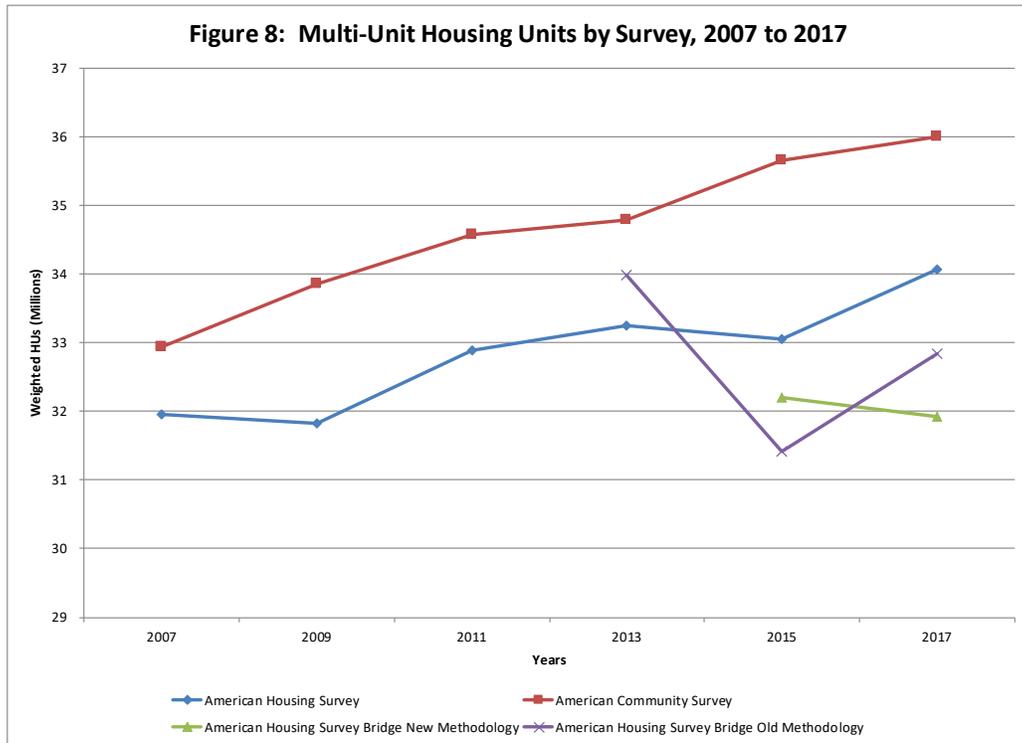
Source: U.S. Census Bureau, 2015 and 2017 American Housing Survey
The standard error of an estimate follows the estimate in parenthesis.

*** denotes significance

The results of Table 19 show no evidence of a break-in-series for estimates of single-attached housing units.

7.4.2 Multi-Unit Housing Units

Figure 8 shows estimates of multi-unit housing units in millions for survey years 2007 to 2017.



Source: U.S. Census Bureau, 2007, 2009, 2011, 2013, 2015, and 2017 American Housing Survey and 2007, 2009, 2011, 2013, 2015, and 2017 American Community Survey

Table 20 shows the estimates of the totals number of multi-unit housing units in 2013, 2015, and 2017.

Table 20: Estimates of Multi-Unit Housing Units by Survey, 2013, 2015, and 2017

Estimate [thousands]	Data Collection Years		
	2013	2015	2017
American Housing Survey	33,256 (218)	33,046 (286)	34,064 (264)
American Housing Survey Bridge Old Methodology	33,990	31,410 (670)	32,840 (627)
American Housing Survey Bridge New Methodology	(X)	32,200 (839)	31,930 (871)
American Community Survey	34,790 (61)	35,660 (56)	35,989 (60)

Source: U.S. Census Bureau, 2013, 2015, and 2017 American Housing Survey and 2013, 2015, and 2017 American Community Survey

(X) denotes an estimate that is not applicable and the standard error of an estimate follows the estimate in parenthesis.

Table 21 shows the results of significance testing comparisons of multi-unit housing unit estimates.

Table 21: 95% Confidence Interval, Difference in Multi-Unit Housing Units

Sample	Confidence Interval of Difference	
	2015	2017
American Housing Survey and American Housing Survey Bridge Old Methodology	(262, 3,116)***	(-96, 2,543)
American Housing Survey Bridge New Methodology and American Housing Survey Bridge Old Methodology	(-1,311, 2,897)	(-2,681, 862)
American Housing Survey and American Housing Survey Bridge New Methodology	(-842, 2,633)	(342, 3,923)

Source: U.S. Census Bureau, 2015 and 2017 American Housing Survey

The standard error of an estimate follows the estimate in parenthesis.

*** denotes significance

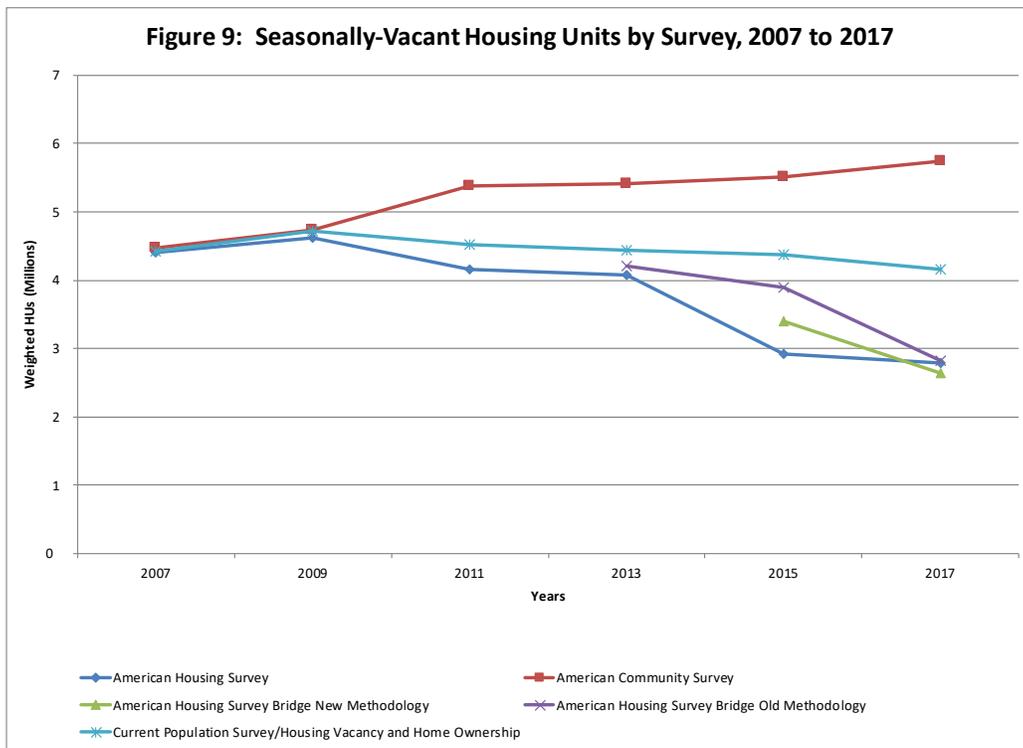
Table 21 shows that there is evidence of a break-in-series for estimates of multi-unit housing units.

7.5 Change in Weighting – Vacant Housing Units

Estimates of different types of vacant housing units changed. Although the types of vacant housing units changed, the overall estimate of vacant housing units did not change – see Section 6.1.3. The questions about vacant housing units have not changed but the weighting methodology did change. In the 2013 methodology, the weights were controlled so that the proportion of vacant housing units by type of vacant was consistent with the same proportions from the Housing Vacancy Survey. In 2015, this was changed and the weights are no longer adjusted to the proportions of vacant housing units from CPS/HVS.

7.5.1 Seasonally-Vacant Housing Units

Figure 9 shows estimates of seasonally-vacant housing units in millions by survey years 2007 to 2015.



Source: U.S. Census Bureau, 2007, 2009, 9, 2011, 2013, 2015, and 2017 American Housing Survey and American Community Survey

Table 22 shows the estimates of the total number of seasonally-vacant housing units for 2013, 2015 and 2017.

Table 22: Estimates of Seasonally-Vacant Housing Units by Survey, 2013, 2015, and 2017

Estimate [thousands]	Data Collection Years		
	2013	2015	2017
American Housing Survey	4,067 (204)	2,922 (165)	2,793 (155)
American Housing Survey Bridge Old Methodology	4,213	3,885 (394)	2,818 (259)
American Housing Survey Bridge New Methodology	(X)	3,400 (338)	2,645 (281)
American Community Survey	5,416 (28)	5,502 (32)	5,745 (30)
Housing Vacancy Survey	4,432 (126)	4,379 (126)	4,151 (114)

Source: U.S. Census Bureau, 2013, 2015, and 2017 American Housing Survey; 2013, 2015, and 2017 American Community Survey; and 2013, 2015, and 2017 Current Population Survey / Housing Vacancy Survey
(X) denotes an estimate that is not applicable and the standard error of an estimate follows the estimate in parenthesis.

Table 23 shows the results of significance testing comparisons of seasonally-vacant housing units estimates.

Table 23: 95% Confidence Interval, Seasonally-Vacant Housing Units

Sample	Confidence Interval of Difference	
	2015	2017
American Housing Survey and American Housing Survey Bridge Old Methodology	(-1,801, -126)***	(-624, 545)
American Housing Survey Bridge New Methodology and American Housing Survey Bridge Old Methodology	(-904, -65)***	(-486, 140)
American Housing Survey and American Housing Survey Bridge New Methodology	(-1,216, 259)	(-487, 784)

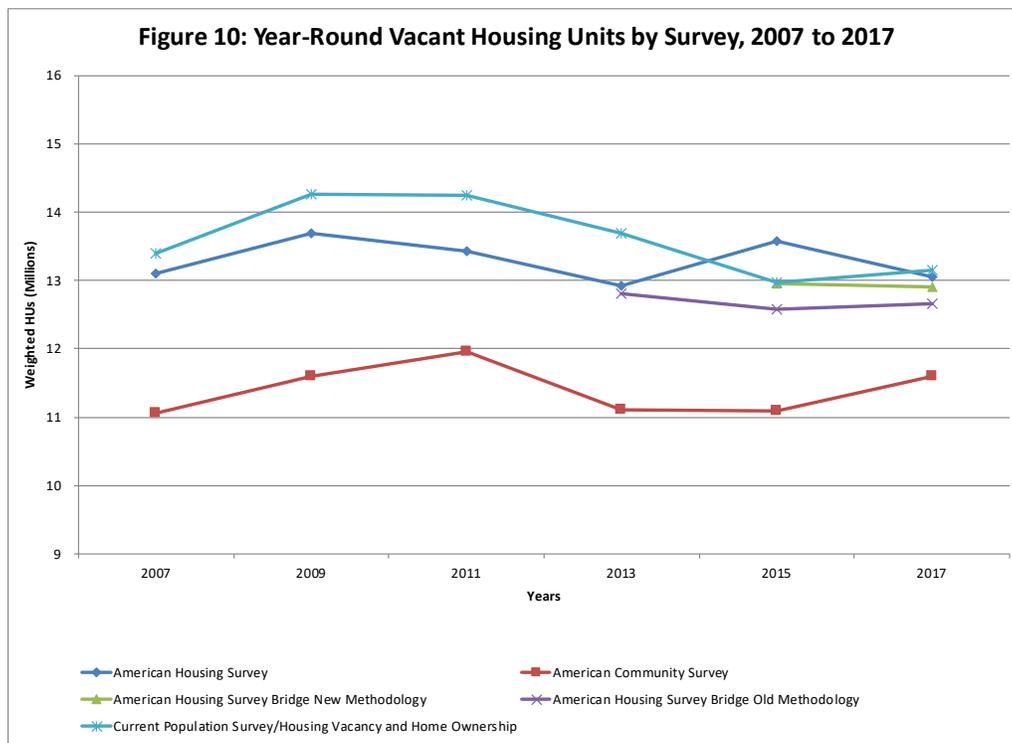
Source: U.S. Census Bureau, 2015 and 2017 American Housing Survey
The standard error of an estimate follows the estimate in parenthesis.
*** denotes significance

The results of Table 23 show evidence of a break-in-series for estimates of seasonally-vacant housing units between 2013 and 2015. Since the only difference between the two different designs is the raking methodology for weighting, this is the most likely explanation of this break-in-series.

For the adjustments that involved vacancy status with the 2013 weighting methodology, no known totals of vacant housing units or different types of vacant housing units were available. As shown in Table 2, the 2013 weighting used estimated proportions of different types of vacant housing units from the CPS/HVS. Ratio adjustments were applied to the 2013 weights so that the estimated proportions from AHS were equivalent to the proportions from CPS/HVS. In contrast, the 2015 weighting made no special adjustment for any type of vacant housing units.

7.5.2 Year-Round Vacant Housing Units

Figure 10 shows estimates of Year-Round Vacant housing units in millions for survey years 2007-2017.



Source: U.S. Census Bureau, 2007, 2009, 2011, 2013, 2015, and 2017 American Housing Survey and American Community Survey

Table 24 shows the estimates of the total number of year-round vacant housing units from 2013, 2015, and 2017.

Table 24: Estimates of Year-Round Vacant Housing Units by Survey, 2013, 2015, and 2017

Estimate [thousands]	Data Collection Years		
	2013	2015	2017
American Housing Survey	12,914 (370)	13,579 (200)	13,050 (190)
American Housing Survey Bridge Old Methodology	12,810	12,580 (1,083)	12,660 (677)
American Housing Survey Bridge New Methodology	(X)	12,960 (608)	12,900 (632)
American Community Survey	11,100 (52)	11,084 (52)	11,599 (55)
Housing Vacancy Survey	13,695 (187)	12,976 (182)	13,147 (131)

Source: U.S. Census Bureau, 2013, 2015, and 2017 American Housing Survey; 2013, 2015, and 2017 American Community Survey; and 2013, 2015, and 2017 Current Population Survey / Housing Vacancy Survey
(X) denotes an estimate that is not applicable and the standard error of an estimate follows the estimate in parenthesis.

Table 25 shows the results of significance testing of year-round vacant housing unit estimates.

Table 25: 95% Confidence Interval, Year-Round Vacant Housing Units

Sample	Confidence Interval of Difference	
	2015	2017
American Housing Survey and American Housing Survey Bridge Old Methodology	(-1,160, 3,158)	(-963, 1,753)
American Housing Survey Bridge New Methodology and American Housing Survey Bridge Old Methodology	(-1,176, 1,945)	(-286, 759)
American Housing Survey and American Housing Survey Bridge New Methodology	(-640, 1,870)	(-1,137, 1,453)

Source: U.S. Census Bureau, 2015 and 2017 American Housing Survey
The standard error of an estimate follows the estimate in parenthesis.

*** denotes significance

Unlike seasonally-vacant housing units, there is no evidence of a break-in-series for estimates of year-round vacant housing units, even with the new methodology weighting change.

8. References

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Appendix A: Variance Estimation for Differences

This appendix discusses how to estimate the variance of the difference of two estimated totals with replication. We discuss some theory, provide an example, and summarize with some conclusions. To begin, we define some notation.

U	universe of interest
s	the sample
k	index of units in U or s
r	index on replicates, $r = 1$ to R
w_k	sample weight for unit k
w_{rk}	replicate weight for unit k and replicate r
y_k	first variable in difference for unit k
x_k	second variable in difference for unit k
Δ_k	difference of first and second variable of interest for unit k , i.e., $\Delta_k = y_k - x_k$

Let's say we have two totals

$$Y = \sum_{k \in U} y_k \quad \text{and} \quad X = \sum_{k \in U} x_k$$

that can be estimated as

$$\hat{Y} = \sum_{k \in s} w_k y_k \quad \text{and} \quad \hat{X} = \sum_{k \in s} w_k x_k.$$

Define their difference as $\Delta = Y - X$ which can be estimated as $\hat{\Delta} = \hat{Y} - \hat{X}$.

Method 1. The following steps can be used to estimate the variance of $\hat{\Delta}$.

Step 1. Use the replicate weights w_{rk} to produce $r = 1$ to R replicate estimates of \hat{Y} and \hat{X} as

$$\hat{Y}_r = \sum_{k \in s} w_{rk} y_k \quad \text{and} \quad \hat{X}_r = \sum_{k \in s} w_{rk} x_k.$$

Step 2. Estimate the R replicate estimates as $\hat{\Delta}_r = \hat{Y}_r - \hat{X}_r$.

Step 3. Estimate the variance of

$$\hat{v}(\hat{\Delta}) = \frac{1}{R} \sum_{r=1}^{160} (\hat{\Delta}_r - \hat{\Delta})^2 \quad (\text{A.2})$$

Method 2. Estimate the parts of the variance of a difference separately.

$$\hat{v}(\hat{\Delta}) = \hat{v}(\hat{Y}) + \hat{v}(\hat{X}) - 2\widehat{cov}(\hat{Y}, \hat{X})$$

where

$$\begin{aligned} \hat{v}(\hat{Y}) &= \frac{4}{160} \sum_{r=1}^{160} (\hat{Y}_r - \hat{Y})^2 \\ \hat{v}(\hat{X}) &= \frac{4}{160} \sum_{r=1}^{160} (\hat{X}_r - \hat{X})^2 \\ \widehat{cov}(\hat{Y}, \hat{X}) &= \frac{4}{160} \sum_{r=1}^{160} (\hat{Y}_r - \hat{Y})(\hat{X}_r - \hat{X}) \end{aligned}$$

Example. Using the 2017 AHS, estimate the difference of the number of housing units (HUs) that have central air conditioning with the number of HUs that have room air conditioning (window units). We derived these estimates where

$$y_k = \begin{cases} 1, & \text{if sample HU } k \text{ has central air conditioning} \\ 0, & \text{otherwise} \end{cases}$$

$$x_k = \begin{cases} 1, & \text{if sample HU } k \text{ has room air conditioning} \\ 0, & \text{otherwise} \end{cases}$$

and we also define

$$\Delta_k = \begin{cases} 1 & \text{if sample HU } k \text{ has central air conditioning and has no room air conditioning} \\ -1 & \text{if sample HU } k \text{ has no central air conditioning and has room air conditioning} \\ 0 & \text{if sample HU } k \text{ has both central air conditioning and room air conditioning} \\ 0 & \text{otherwise} \end{cases}$$

The estimate for the number of 2017 HUs with central air conditioning is $\hat{Y} = 93,841,079$ and the estimate of the number of 2017 HUs with room air conditioning is $\hat{X} = 32,899,614$. The estimated difference is $\hat{\Delta} = 60,993,393$.

If we estimate $\hat{v}(\hat{\Delta})$ with Method 1, and get $\widehat{se}(\hat{\Delta}) = \sqrt{\hat{v}(\hat{\Delta})} = 698,512$.

If we estimate $\hat{v}(\hat{\Delta})$ with Method 2, we get the same result as with Method 1, but with the following pieces: $\widehat{se}(\hat{Y}) = \sqrt{\hat{v}(\hat{Y})} = 499,590$, $\widehat{se}(\hat{X}) = \sqrt{\hat{v}(\hat{X})} = 327,554$, and the covariance is $\widehat{cov}(\hat{Y}, \hat{X}) = -6,5518,923,290$; i.e.,

$$\begin{aligned}\widehat{se}(\hat{\Delta}) &= \sqrt{\hat{v}(\hat{Y}) + \hat{v}(\hat{X}) - 2\widehat{cov}(\hat{Y}, \hat{X})} \\ &= \sqrt{(698,512)^2 + (499,590)^2 - 2(-6,5518,923,290)} \\ &= 698,512\end{aligned}$$

BIG POINT: If we estimated the variance without using the covariance, we would get

$$\begin{aligned}\widehat{se}(\hat{\Delta}) &= \sqrt{\hat{v}(\hat{Y}) + \hat{v}(\hat{X})} \\ &= \sqrt{(698,512)^2 + (499,590)^2} \\ &= 597,396\end{aligned}$$

as the estimate of the variance is an **underestimate**. In our example, the covariance was negative, so it added to the variance of the difference.

Conclusion 1. We do not need to account for the covariance if the estimates are derived from independent samples, i.e.,

$$\hat{\Delta} = \sum_{k \in S_1} w_k y_k - \sum_{k \in S_2} w_k x_k$$

where s_1 and s_2 are independent samples. Independence implies zero covariance. Remember, that the expectation is with respect to the sample design and this means that the probabilities of selection (both the first-order and second-order) of the sample designs for s_1 and s_2 do not depend on each other.

Conclusion 2. We need to account for the covariance with dependent samples because we do not know if it is negative or positive. This applies when comparing estimates derived (a) from the same sample, (b) one sample is a subsample of the other, or (c) two samples where one of the selection methods coordinates the sample selection with the other sample: minimizes or maximizes the overlap of the two samples.

Table A.1 summarizes how we estimated the variance for the differences of the Break-in-series analysis.

Table A.1: Types of Statistical Comparisons in the Evaluation

	A statistical difference between the estimates...		...indicates...
1	American Housing Survey The full/new AHS sample with the revised weighting methodology	American Housing Survey Bridge Old Methodology Bridge sample with the old weighting methodology	Independent samples; no covariance
2	American Housing Survey Bridge Old Methodology Bridge sample with the old weighting methodology	American Housing Survey Bridge New Methodology Bridge sample with new weighting methodology	Same sample but different weights; include covariance
3	American Housing Survey Full AHS sample with the revised weighting methodology	American Housing Survey Bridge New Methodology Bridge sample with the new weighting methodology	Independent samples; no covariance

Final Note. Nothing in this appendix is new. Wolter (1985; Section 3.4) explains that replication can be applied directly to both linear and non-linear estimators. With replication, we don't need to apply Taylor series to linearize the estimator and estimate the separate variances and covariances. Our difference $\hat{\Delta}$ is a simple estimator as compared to Wolter's more general specification of $\hat{\theta}$.