Chapter 7
Housing-Unit Method in Comparison: The Virginia Case

Qian Cai and Rebecca Tippett

Introduction

The housing unit (HU) method is widely used for making sub-state population estimates. It is an intuitive, appealing method for the production of small-area population estimates, but in past comparisons, the HU method did not perform as well as alternative methodologies in estimating the population of Virginia’s 134 counties and county-equivalent independent cities (Cai and Spar 2008). The HU method typically produced overestimates, and persons-per-household (PPH) estimates were critical for overall estimates accuracy. Smith and Mandell (1984) argue that improvements in the data and techniques used to estimate the components of the HU method can improve estimates and yield results comparable to other estimation methods.

This study draws on recently available data from the 2006–2010 American Community Survey (ACS) to examine whether using the more recent ACS PPH and occupancy rate estimates to derive household population improves the overall estimates. After choosing the best input variables for the HU method, we subsequently evaluate the population estimates produced by three different methods: the HU method, the ratio-correlation (RC) method, and the administrative records (AdRec) method used by the U.S. Census Bureau. Using 2010 census data for 134 counties in Virginia, we compare the precision, bias, and distribution of errors of these three sets of estimates. In addition, we explore the accuracy of averaging estimates produced by two different methods, an approach often suggested and applied in the estimates field (e.g., Hoque 2012). We conclude that while HU is a highly practical and valuable method for sub-county population estimates, it does not perform nearly as well as AdRec or RC for Virginia’s county population estimates.

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Estimation Methodologies

In the field of small area population estimates, three methodological approaches are commonly applied, the component method, the ratio-correlation method, and the housing unit method. Each has unique features and multiple variations.

Component Method

The first approach, the component method, estimates population utilizing the major components of population change: births, deaths, and migration. Variations of the component method are used by the Census Bureau and by many states that produce their own population estimates, such as Arizona, Oregon, Texas, and Wisconsin. For any time period, population is estimated using the equation

\[ P_t = P_0 + B - D + NM \]

where \( P_t \) equals the population for the estimate period; \( P_0 \) equals the population in the base period; \( B \) equals births occurring between \( P_0 \) and \( P_t \); \( D \) equals deaths occurring between \( P_0 \) and \( P_t \); and \( NM \) equals net migration occurring between \( P_0 \) and \( P_t \).

Variations of this method are largely determined by ways of estimating migration, among which is the administrative records method. AdRec estimates migration by examining the place of residence recorded on matched sets of federal income tax returns at two consecutive years. If the address on the return of the filer and any dependents changes from year one to year two, in-migrants to the receiving county and out-migrants from the sending county are recorded.

AdRec is the method used by the Census Bureau for its state and county population estimates; it is one of the best estimating methods and produces highly accurate estimates. The Bureau’s collaborative efforts with the Federal State Cooperative for Population Estimates and the National Center for Health Statistics in collecting vital statistics data, as well as their careful, extensive research into estimating migration have resulted in high quality estimates that closely capture population change due to births, deaths, and migration. Many states do not produce their own county-level population estimates and rely on the AdRec estimates from the Census Bureau.

Ratio-Correlation Method

The second approach, the ratio-correlation method, uses linear regression to estimate population based on a set of symptomatic indicator variables that capture population dynamics, such as births, school enrollments, driver’s licenses, housing, voter registrations, and Medicare enrollments. RC is used by many states in their
county population estimates, such as Texas, North Carolina, and Washington, and
has been implemented in Virginia for decades. The population estimates are de-
veloped using a multiple regression equation

\[ Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 \ldots + \beta_n X_n + e \]

where \( Y \) equals the dependent variable to be estimated (population); \( \beta_0 \) equals the
intercept to be estimated; \( \beta_1 - \beta_n \) are the coefficients to be estimated; \( X_1 - X_n \) are the
independent variables; and \( e \) is the error term.

In the ratio-correlation method, the resulting estimate is not a population total.
Rather, it is the percentage of the state's total household population that will be
allocated to the locality. The dependent and independent variables are represented as
double ratios.

First, single ratios (SR) are constructed for both base and estimating years. The
base year is the most recent decennial census and the estimating year is the year for
which estimates are being produced:

\[ SR_{\text{indicator}} = \frac{\text{Locality Total}_{\text{ind}}}{\text{State Total}_{\text{ind}}} \]

Next, a double ratio (DR) is constructed to compare the locality's share of the indicator
in the estimating year to its share of the state total in the base year.

\[ DR_{\text{indicator}} = \frac{\text{Estimating Year SR}_{\text{ind}}}{\text{Base Year SR}_{\text{ind}}} \]

These double ratios measure change in the locality's share of the state total for each
indicator. A double ratio less than one indicates that the locality's share of the state
total for that variable has fallen relative to its share in the base year; a double ratio
greater than one indicates the locality's share of that variable has grown relative to
the base year.

The key source of variation in the RC method is the selection of systematic indicator
variables available to the estimates producer and included in the model. The
Virginia estimates are produced using five indicator variables for each locality: total
housing stock; school enrollment in grades 1–8; 3-year aggregate of births; 3-year
aggregate of deaths; total licensed drivers. We use the Census Bureau's AdRec-
derived state population estimate minus statewide estimated group quarter (GQ)
population as the statewide control total. The final step in obtaining an estimate of
the total population for a county is the addition of the GQ population estimate to the
estimated household population.

Our office annually collects data on the group quarters population in federal and
state prisons, local jails, juvenile justice facilities, state mental health facilities,
and college dormitories. For the 2010 population estimates, these GQ counts were
combined with the 2000 census counts of nursing home and military group quarters
residents to create a GQ estimate for each locality.
**Housing Unit Method**

The third approach, the housing unit method, estimates population through changes in total housing stock, persons per household (PPH), occupancy rate, and people living in group quarters (such as college dormitories, nursing homes, prisons, and military barracks). The HU method is used to estimate county-level population by some states, such as Florida, New Hampshire, and Texas, and is used by the Census Bureau and many state agencies to estimate sub-county population. For any time period, the population is estimated using the equation

\[ P_t = (HU_t \times OCC_t \times PPH_t) + GQ_t \]

where \( P_t \) equals the population; \( HU_t \) equals the number of housing units; \( OCC_t \) equals the household occupancy rate; \( PPH_t \) equals the persons-per-household; and \( GQ_t \) equals the group quarters population.

Variations of this method largely come from ways of estimating housing units (such as building permits or utility hookups), occupancy rates, and PPH. In 2008, Cai and Spar found that the best housing unit method estimates for Virginia were produced by a model with updated housing stock, estimated PPH based on percent change between the latest two censuses, and a constant occupancy rate.

Housing units are estimated by the equation

\[ HU_t = HU_0 + BP_0 + MH_{t-0} \]

where \( HU_t \) equals housing units on the estimate date; \( HU_0 \) equals housing units in the base period; \( BP_0 \) equals cumulative building permits issued between the base period and the estimate date (6-month lag); and \( MH_{t-0} \) equals the estimated difference in mobile/manufactured homes between the base period and estimate date.\(^1\)

Estimated PPH for 2010 was derived by first calculating the percentage change in PPH between 1990 and 2000 for each locality. This percentage was then used to update the 2000 PPH to 2010, with the assumption that the percentage change in PPH between 1990 and 2000 held constant for the next decade.

\[ PPH_{2010} = \left(1 + \frac{PPH_{2000} - PPH_{1990}}{PPH_{1990}}\right) \times PPH_{2000} \]

Occupancy rate for 2010 in each county was held constant to the occupancy rate in the most recent census.

\[ OCC_{2010} = OCC_{2000} \]

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\(^1\) Housing unit estimates are typically produced for July 1 and were linearly interpolated between July 1, 2009, and July 1, 2010, to obtain an estimate for April 1, 2010.
This study evaluates two model specifications to identify the best input variables for the HU method:

1. HU1, or “2007 best,” used the most accurate model specification from the 2007 study.
2. HU2 drew on the newly available 5-year ACS data and used 2006–2010 ACS PPH and occupancy estimates.

We use the Census Bureau’s state population estimate (minus statewide estimated group quarters population) as the statewide control total. This estimate was summed with the GQ population to create a total population estimate.

Evaluation Measures

We constructed population estimates for April 1, 2010, for each of Virginia’s 134 localities using the ratio-correlation and housing-unit methodologies. We evaluate the accuracy and precision of these estimates by comparing them to the census counts for the same date. In the following formulas, EST refers to the calculated population estimate, CEN is the decennial census population count, and \( n \) is the total number of localities for which estimates have been prepared.

We use mean absolute percent error (MAPE) measured as

\[
MAPE_{est} = \frac{\sum |EST - CEN|}{CEN} \times 100
\]

as a measure of precision. MAPE gives the overall average error when the direction of the error (over or under estimate) is ignored. The bias of the estimates are indicated by the mean algebraic percent error (MALPE) measured as

\[
MALPE_{est} = \frac{\sum (EST - CEN)}{CEN} \times 100
\]

A positive MALPE indicates that the estimates tend to be higher than the census counts, indicating a tendency for the method to overestimate, while a negative MALPE indicates a tendency to underestimate. Last, we examine extreme errors greater than 5 and 10%, measured as total count of errors larger than \( \pm 5 \) and \( \pm 10\% \), respectively. These measures provide an indication of the occurrence of extreme errors.
Table 7.1 Accuracy of VA county population estimates by housing-unit model specification, 2010

<table>
<thead>
<tr>
<th>Methodology</th>
<th>MAPE</th>
<th>MALPE</th>
<th>Extremes</th>
</tr>
</thead>
<tbody>
<tr>
<td>HU1</td>
<td>3.73</td>
<td>0.39</td>
<td>31</td>
</tr>
<tr>
<td>HU2</td>
<td>4.21</td>
<td>1.22</td>
<td>34</td>
</tr>
</tbody>
</table>

What are the Best Input Variables for the House Unit Method?

We compared two HU model specifications to determine the best ways to measure occupancy rates and persons-per-households in the HU method. HU1 or “2007 best” used the most accurate model specification from the Cai and Spar (2008) evaluation, while HU2 drew on the recently available 2006–2010 ACS for PPH and occupancy rate. Each HU method was evaluated based on its accuracy in estimating total population, which includes household population based on the HU method plus the estimated group quarters population.

As Table 7.1 shows, estimates based on ACS PPH and occupancy rate (HU2) are less accurate than the “2007 best” (HU1) on all evaluation measurements. HU2 has a MAPE of 4.21 while HU1 is, on average, more accurate, with a MAPE of 3.73. Both HU1 and HU2 have positive MALPEs, indicating a tendency to overestimate population (Stasinski and Zitter 1968), with the positive bias more pronounced for HU2. Last, the incidence of extreme errors, particularly for errors greater than 10%, is much higher for HU2.

The poor performance of HU2 compared to HU1 may seem counter-intuitive, since the more current ACS should do a better job of capturing changes in both PPH and occupancy rates than the past Census data. The failure of the ACS data may be linked to the declining accuracy of the population and housing unit estimates used as control totals for the 2006–2010 ACS. Both PPH and occupancy rate are controlled by the population and housing totals; therefore, they are influenced by the accuracy of these two estimates.

How Well Do the Three Methods Perform?

Prior research found that the HU method was less accurate than the RC and AdRec methods in producing county estimates for Virginia (Cai and Spar 2008). To evaluate whether these findings still held true, estimates from three methods—HU, RC, and AdRec—were compared to the 2010 Census counts. For the purposes of this comparison:

- The HU estimates are those produced by HU1, with estimated PPH based on percent change and constant occupancy rate.
- The RC estimates are based on an estimating model that includes five independent variables: housing stock, births, public school enrollment for grades 1–8, driver’s licenses, and state income tax exemptions.
- The AdRec estimates are the Census Bureau’s “pure” estimates. They are the estimates derived directly from the method, without subsequent adjustments from the challenge process, obtained from the Census Bureau for the purposes of this research. This comparison allows evaluation of the best method for producing estimates.

Table 7.2 presents the accuracy measures of these three estimating methodologies for all Virginia’s localities overall, as well as by growth rate and 2010 population size. Both RC and AdRec performed better than HU, across all accuracy measures. While RC and AdRec both produce highly accurate estimates with minimal bias, the RC estimates slightly outperform those produced by AdRec. Compared to AdRec, the ratio-correlation estimates have a lower MAPE (2.66 versus 2.72), a lower MALPE (0.17 versus 0.25), and a tendency to produce a smaller proportion of extreme errors.

Virginia’s counties vary widely in their growth patterns and total population. Evaluation by growth rate and population size shows that AdRec performs most consistently across size and growth categories, with no discernible patterns in precision, bias, or extreme errors. RC is increasingly accurate for faster growing and larger counties; as growth rate and size increase, MAPE and the presence of extreme errors declines. HU is consistently the least accurate in most categories. These patterns for the RC and HU methods are similar to evaluations of estimation methodology in other states (Hoque 2012).

Figures 7.1 and 7.2 present MAPE by methodology and by growth rate and population size, respectively. Figure 7.1 shows that both HU and RC perform less well when estimating slow-growing or declining populations (growth rate of less than 1%).
Table 7.2 Accuracy measures by estimating methodology, growth rate, and population size, 2010

<table>
<thead>
<tr>
<th>Methodology</th>
<th>n</th>
<th>MAPE</th>
<th>MALPE</th>
<th>Extremes &gt;5%</th>
<th>Extremes &gt;10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Housing unit</td>
<td>134</td>
<td>3.73</td>
<td>0.39</td>
<td>31</td>
<td>8</td>
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<tr>
<td>Ratio-correlation</td>
<td>134</td>
<td>2.66</td>
<td>0.17</td>
<td>16</td>
<td>2</td>
</tr>
<tr>
<td>Administrative records</td>
<td>134</td>
<td>2.72</td>
<td>-0.25</td>
<td>22</td>
<td>3</td>
</tr>
<tr>
<td>Housing-unit Growth rate, 2000-2010</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Less than 1%</td>
<td>35</td>
<td>5.77</td>
<td>5.11</td>
<td>13</td>
<td>6</td>
</tr>
<tr>
<td>1 to 4.99%</td>
<td>28</td>
<td>3.65</td>
<td>-0.43</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>5 to 14.99%</td>
<td>36</td>
<td>2.47</td>
<td>-0.93</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>15% or higher</td>
<td>35</td>
<td>3.06</td>
<td>-2.31</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>Total population, 2010</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Less than 15,000</td>
<td>37</td>
<td>4.95</td>
<td>2.44</td>
<td>14</td>
<td>6</td>
</tr>
<tr>
<td>15,000-49,999</td>
<td>62</td>
<td>3.49</td>
<td>0.13</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>50,000-100,000</td>
<td>20</td>
<td>2.70</td>
<td>-1.64</td>
<td>4</td>
<td>0</td>
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<tr>
<td>100,000 or more</td>
<td>15</td>
<td>3.08</td>
<td>-0.85</td>
<td>3</td>
<td>0</td>
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<tr>
<td>Ratio-correlation Growth rate, 2000-2010</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Less than 1%</td>
<td>35</td>
<td>3.54</td>
<td>2.49</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>1 to 4.99%</td>
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<td>2.80</td>
<td>-0.05</td>
<td>5</td>
<td>1</td>
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<td>5 to 14.99%</td>
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<td>2.30</td>
<td>-0.65</td>
<td>3</td>
<td>0</td>
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<tr>
<td>15% or higher</td>
<td>35</td>
<td>2.03</td>
<td>-1.14</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Total population, 2010</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Less than 15,000</td>
<td>37</td>
<td>3.06</td>
<td>0.81</td>
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<td>15,000-49,999</td>
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<td>2.70</td>
<td>0.59</td>
<td>10</td>
<td>2</td>
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<td>50,000-100,000</td>
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<td>2.33</td>
<td>-1.47</td>
<td>0</td>
<td>0</td>
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<tr>
<td>100,000 or more</td>
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<td>1.92</td>
<td>-1.00</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Administrative records</td>
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<tr>
<td>Growth rate, 2000-2010</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Less than 1%</td>
<td>35</td>
<td>2.86</td>
<td>1.34</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>1 to 4.99%</td>
<td>28</td>
<td>2.50</td>
<td>-0.27</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>5 to 14.99%</td>
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<td>2.77</td>
<td>-0.68</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>15% or higher</td>
<td>35</td>
<td>2.70</td>
<td>-1.36</td>
<td>6</td>
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<tr>
<td>Total population, 2010</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Less than 15,000</td>
<td>37</td>
<td>3.24</td>
<td>-0.53</td>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>15,000-49,999</td>
<td>62</td>
<td>2.42</td>
<td>0.49</td>
<td>9</td>
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<td>50,000-100,000</td>
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<td>2.94</td>
<td>-1.71</td>
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<td>0</td>
</tr>
<tr>
<td>100,000 or more</td>
<td>15</td>
<td>2.36</td>
<td>-0.64</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

Figure 7.2 shows that, across all methods, smaller populations, defined here as less than 15,000, are prone to greater estimate errors than larger populations, a finding consistent with other estimates evaluation research (Smith and Cody 2013). Both figures clearly display the improved accuracy of RC as growth rates and total population size increase and the relative consistency of AdRec method across categories.

Estimates of the total population that fall within 2% of the Census counts are generally regarded as “high accuracy.” Figures 7.3a, b, c show localities with
estimates within ±2% of 2010 Census count by the HU (3a), RC (3b), and AdRec (3c) methods. While there is substantial overlap between the methods, especially between RC and AdRec, the number of localities with estimates within ±2% of 2010 Census counts is substantially lower for the HU estimates. Among Virginia's 134 localities, only 51 have estimates in this range under the HU method, compared to 62 and 64 with RC and AdRec, respectively.

Does Averaging Two Methods Improve Accuracy?

Theoretically, estimates produced by different methods should track each other closely, as they measure the same population. In reality, estimates produced by different methods can differ significantly, largely due to variations in data input quality and specific methodological limitations. When such occasions arise, averaging is often suggested as a way to mitigate potential large errors by one, or both, methods and is commonly employed in states that produce their own estimates (e.g., Hoque 2012). Two averages were examined to see if they performed better than the estimates by the single better method:

1. RC and HU.
2. AdRec and HU.

RC and AdRec estimates were not averaged because, practically, it would not be feasible for either the Bureau or the Cooper Center to incorporate the other's estimates in a timely manner.

Table 7.3 shows the accuracy measures for averaging both RC and AdRec with HU and the performance of the methods on their own. While averaging HU and RC produced good estimates overall, they are not as good as estimates produced by
the RC method alone. The average has slightly higher MAPE (2.80 versus 2.66), MALPE (0.17 versus 0.28), and a greater incidence of extreme errors than RC alone.

Averaging HU and AdRec produced slightly better results than AdRec alone, especially in terms of reducing bias and number of localities with errors larger than 5%. This may be because the AdRec method's tendency to underestimate total population (MALPE of −0.25) is counterbalanced by the HU method's tendency to overestimate total population (MALPE of 0.39).
Table 7.3  Accuracy measures for averages

<table>
<thead>
<tr>
<th></th>
<th>MAPE</th>
<th>MALPE</th>
<th>≥5%</th>
<th>≥10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average, RC and HU</td>
<td>2.80</td>
<td>0.28</td>
<td>19</td>
<td>3</td>
</tr>
<tr>
<td>RC alone</td>
<td>2.66</td>
<td>0.17</td>
<td>16</td>
<td>2</td>
</tr>
<tr>
<td>Average, AdRec and HU</td>
<td>2.71</td>
<td>0.07</td>
<td>15</td>
<td>3</td>
</tr>
<tr>
<td>AdRec alone</td>
<td>2.72</td>
<td>-0.25</td>
<td>22</td>
<td>3</td>
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</table>

Discussion

This case study provided a comprehensive evaluation of three methods for county population estimates, as well as the value of averaging more than one method’s results. The findings have multiple implications for the methodological choices for the estimates programs.

First, while HU is a highly practical and valuable method for sub-county population estimates, results from this study and prior work indicate that it does not perform nearly as well as AdRec or RC for Virginia’s county population estimates. One major reason may be that, other than housing stock, which is drawn from administrative data, two key components of the HU method, PPH and occupancy rate, often need to be estimated without reliable methods or techniques. This subsequently compounds the estimates errors and makes it difficult to identify the error sources. In comparison, the RC and AdRec methods draw almost entirely on administrative data that reflect population change. As such, they more directly capture the dynamics of population change and the potential error sources are more readily identifiable.

While the availability of the ACS data offers promise for potential improvements in PPH and occupancy rate, both our evaluation and other empirical evidence indicate that, in its current form, the ACS data fall short of providing reliable data for use in post-censal population estimates production. Swanson and Hough’s (2012) evaluation of the PPH estimates in the ACS finds that the nature of the ACS survey, and the presence of both sampling and non-sampling error, leads to volatility in the PPH estimates that is inconsistent with demographic theory. That is, demographic theory typically predicts PPH will trend consistently in one direction or another, following broader societal or population changes, and not fluctuate significantly from year-to-year as it does in the ACS.

Although a number of states produce HU estimates for county population, most incorporate them into their overall estimates process via averaging, a method employed in Texas (Hoque 2012). Among states that produce county-level population estimates, the HU method performs consistently well in Florida. Over the course of decades (Smith and Lewis 1980; Smith and Mandell 1984; Smith 1986), Florida has tailored the HU method to produce highly accurate estimates at the state, county, and subcounty level (Smith and Cody 2013). Their work offers suggestions on how to refine and improve the HU method, if the resources and data are available to estimate producers. For example, they advocate the use of utility hook ups and not just building permits to estimate housing units (see also Starsinic and Zitter 1968), and
disaggregating housing units by type and applying type-specific occupancy rates and PPH (Smith and Lewis 1980).

Based on the evaluation of the performance of the three methodologies in Virginia, RC alone is preferred for Virginia's county estimates. The evaluation of averaging suggests that the Census Bureau and other states may want to evaluate averaging AdRec and HU estimates to see if the results for Virginia hold true for the entire country. If the benefit of averaging is positive, but minimal, it is perhaps still better to use AdRec alone, as the costs of producing a parallel set of HU estimates far exceed the benefit of minimally improved accuracy.

References


