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August 16, 2022

DSSD 2020 POST-ENUMERATION SURVEY MEMORANDUM SERIES #2020-J-02

MEMORANDUM FOR Patrick Cantwell
Chief, Decennial Statistical Studies Division

From: Timothy Kennel
Assistant Division Chief, Statistical Methods,
Decennial Statistical Studies Division

Prepared by: Elizabeth Marra and Timothy L. Kennel
Decennial Statistical Studies Division

Subject: Source and Accuracy of the 2020 Post-Enumeration Survey Housing Unit Estimates

This memorandum documents the Source and Accuracy of the housing unit estimates for the 2020 Post-Enumeration Survey. Please direct any inquiries to Elizabeth Marra at (301) 763-7760 or Timothy L. Kennel at (301) 763-6795.
1. INTRODUCTION

The 2020 Post-Enumeration Survey (PES)\(^1\) was an independent evaluation of coverage error for both the United States and Puerto Rico in the 2020 Census. This document describes the source of the PES data collected and the accuracy of the housing unit coverage estimates produced by the survey. For details on the source and accuracy of PES coverage estimates for people, refer to Marra and Kennel (2022).

1.1 PES Overview

The PES estimated the housing unit net coverage error and the housing unit components of coverage for the 2020 Census. Net coverage error refers to the difference between the census count and the population of housing units. The PES estimated the housing unit population size with a method called “dual-system estimation.” With this technique, the survey independently listed housing units across the nation in an operation called the Independent Listing. The Independent Listing occurred before April 1, 2020, which was the reference day for the census, also known as Census Day. The survey conducted extensive housing unit operations, all after Census Day. Each operation included matching activities and field followup activities, where the goal was to record the housing unit population that existed on Census Day in our sample blocks and match this information to the census housing unit results. After the matching was completed, we were able to use both the census and the survey to determine what housing units were counted:

- In the census only.
- In the PES only.
- In both the census and the PES.

This information allowed us to calculate the dual-system estimate (DSE). This was a synthetic estimator that used logistic regression models to estimate how many housing units existed in the United States on Census Day.

The PES also estimated three main components of coverage for housing units:

- Correct enumerations. These referred to housing units counted in the census that were actual housing units on April 1, 2020 (Census Day).
- Erroneous enumerations. These included duplicate records of housing units that were already counted in the 2020 Census as well as addresses that were counted but should not have been (e.g., an address for a business or a housing unit that was built after Census Day).
- Omissions. These refer to housing units that were missed by the 2020 Census.

We used the PES field and followup operations to determine which housing unit enumerations were correct and erroneous in the census. To estimate omissions, we took the number of correct enumerations provided by component estimation and subtracted that from the DSE.

1.2 Discussion on the Differences Between Housing Unit and Person Operations

Estimation of the U.S. housing unit population was different from, and simpler than, estimation for people. There were three concepts that we considered for people that were not applicable for housing units. They were:

- Mover status—Whether a person moved between Census Day and the day of the PES person interview. People moved in and out of housing units both before and after Census Day. We took this mover information into account during imputation and estimation of the person population. Housing units, however, are stationary, and did not have a mover status.
- Sufficient information—The person record had enough information to uniquely identify it for net coverage estimation. Most characteristics of housing units were easily observable. This included characteristics such as address, geographic location, and housing unit type. By nature, all PES listed housing units had sufficient information for unique identification and, unlike people, did not require full imputation of all characteristics.

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\(^1\) The Census Bureau’s Disclosure Review Board has reviewed this product for unauthorized disclosure of confidential information and has approved the disclosure avoidance practices applied to this release. CBDRB-FY22-342.
Whole-person census imputation—These were enumerations in the census where there was not enough information to identify the person, so the census imputed all their characteristics. For housing units, the concept of whole-housing unit census imputations did not exist because there was no analogous operation in the census.

PES housing unit operations differed from those of people as well. PES housing unit operations were divided into two phases: an Initial Housing Unit Phase and a Final Housing Unit Phase. For people, there was only one survey phase, which occurred between the initial and final housing unit phases. We provide more detail regarding the housing unit operations in the next section of this document.

1.3. Housing Unit Operations
As previously mentioned, we divided the housing unit field data collection and matching activities into two phases, which allowed the PES to get a head start on the person operations and reduce recall error. We discuss recall error later in this document. The Initial Housing Unit Phase produced independent address lists within each sample block that were used to subsample housing units in large blocks and create the Person Interview workloads. We also attempted to match the independently listed PES data to a preliminary census address list. This match facilitated the subsampling of census housing units in large blocks. It also allowed for the inclusion of some nonmatching census housing units in the Person Interview, which reduced later person field followup and potential recall error.

However, since the Initial Housing Unit Phase was not matched to the final census, additional matching and followup were needed after the final census housing units were processed. This was done so that we could account for census housing units that were added to or deleted from the census after the preliminary census list was created. We did this additional work during the Final Housing Unit Phase. We also incorporated results from the Person Interview operation into the housing unit data during the final housing unit phase. The Person Interview operation gathered information on the Census Day status of the housing unit, which was essential for determining the Census Day housing unit status of P sample addresses which were not valid housing units at the time of the Independent Listing (e.g., they were under construction, or unfit for habitation). The Person Phase also collected information like occupancy, tenure (owned or rented), and race of the householder.

Table 1.
2020 PES Field Milestone Schedule

<table>
<thead>
<tr>
<th>Phase</th>
<th>Operation</th>
<th>Start</th>
<th>Finish</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Housing Unit Phase</td>
<td>Independent Listing</td>
<td>1/16/2020</td>
<td>3/20/2020</td>
</tr>
<tr>
<td>Field Operations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial Housing Unit</td>
<td>Field Followup</td>
<td>7/30/2020</td>
<td>9/21/2020</td>
</tr>
<tr>
<td>Field Operations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Person Phase Field Operations</td>
<td>Person Interview</td>
<td>9/23/2020</td>
<td>12/18/2020</td>
</tr>
<tr>
<td></td>
<td>Person Interview Reopen</td>
<td>2/11/2021</td>
<td>3/20/2021</td>
</tr>
<tr>
<td></td>
<td>Person Field Followup</td>
<td>6/14/2021</td>
<td>9/17/2021</td>
</tr>
<tr>
<td>Final Housing Unit Phase</td>
<td>Final Housing Unit Field</td>
<td>12/06/2021</td>
<td>3/17/2022</td>
</tr>
<tr>
<td>Field Operations</td>
<td>Followup</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Dates include quality control work.
All three housing unit and person phases contained field data collection, computer processing, and clerical matching operations. Field data collection included both initial interviews as well as followup work. During computer processing, we used a computer matching system to look for housing unit matches in the census. During clerical matching, we clerically reviewed and validated the output from computer processing. Table 1 presents the PES Field Milestone schedule for data collection operations. It does not include dates for the computer processing and clerical matching, which were data processing operations. For more information on the housing unit field and matching operations, refer to Kennel (2019).

Note that most of the 2020 PES survey cycle occurred during the COVID-19 pandemic. The PES encountered schedule delays, restricted access to certain areas due to lockdowns, and social distancing orders that may have made respondents less likely to interact with PES workers. To accommodate the health and safety measures implemented in response to the pandemic, we were more tolerant of interview by observation during the Initial Housing Unit Field Followup operations. While this benefited us when it came to collecting observable housing unit characteristics, we struggled to capture housing unit characteristics that required an in-person response for these housing units. For example, we relied on respondents to report things like hidden housing units such as basement apartments. We also relied on respondents to report characteristics, such as the race of the householder and tenure. The exception to this was the Independent Listing operation, which occurred before the start of the COVID-19 lockdowns during the months of January–March 2020. We were able to fully implement this operation on time and as planned.
2. SOURCE OF THE PES ESTIMATES

In this section, we describe the target population of the PES and provide a description of the Population (P) and Enumeration (E) samples.

2.1 Target Population

The 2020 PES aimed to estimate the number of housing units that existed in the United States and Puerto Rico on April 1, 2020. Housing units included occupied and vacant units, single and multiunit homes, apartments, and mobile homes or trailers. The housing unit target population excluded group quarters facilities such as prisons, jails, homeless shelters, and college housing. It also excluded housing units located in Remote Alaska areas. In-scope housing units could be occupied or vacant, but they needed to be fit for habitation. Some examples of units not fit for habitation were commercial establishments and demolished or burned-out housing units.

2.2 The Population Sample for Housing Units

The P sample was made up of housing units in sample areas across the nation that were listed independently of census operations during the PES Independent Listing. It provided information about housing units that were missed by the census.

To create the P sample we used a systematic, three-phased sample design where the primary sampling unit was the block. In the first phase we used a preliminary list of census blocks and stratified these blocks by state, Washington, DC, Puerto Rico, and, for some states, American Indian Reservation (AIR). We also stratified by block size and medium and large blocks were stratified by tenure. In the PES Independent Listing operation, we traveled to these census blocks and listed every residential address within them, independently of the census. We then subsampled the small blocks by using the preliminary housing unit counts from the Independent Listing to re stratify the small blocks and subsequently select a subsample. Subsampling small blocks was a cost-effective strategy to reduce field work in areas where a large effort would have been put forth for only a small number of housing units.

Between the second and third phases of sampling, we conducted the Initial Housing Unit Clerical Matching and Field Followup operations. Here we clerically matched the independently listed housing units to a preliminary census inventory of housing units. We then conducted a field followup of these housing units to collect more information needed to determine the match status of some addresses. For the PES, a P-sample housing unit was considered a match if we were able to find the unit in the correct search area in the census. We also used the results of this field work to update PES housing unit counts in blocks. In the third sampling phase, we used the updated block sizes to subsample housing units in large blocks. Once all three phases of sampling were complete, this list of sample housing units was sent to the Person Interview operation.

The final PES P-sample sizes were roughly 161,000 housing units across the 50 states and the District of Columbia, and roughly 7,100 for Puerto Rico (refer to the appendix for the list of sample sizes by state). During the Person Interview operation, we visited each of these housing units and attempted to conduct an interview where we recorded information.


3 Technically, the PES sampled Basic Collection Units or BCUs, which roughly correspond to a block.

4 A small block contained 0-2 housing units, medium contained 3-57 housing units, and a large block contained 58 or more housing units.
about the people living there. This included occupancy, tenure, and race and Hispanic origin of the householder. For occupied housing units, we were not always able to conduct the interview, and in some cases, we did conduct the interview but were unable to collect enough information to perform person matching between the PES and the census. Housing units where this occurred were considered noninterviews for the purposes of estimation for people. In Figure 1, we show the distribution of the state-level interview rates for occupied housing units for the Person Interview operation. The numerator of these rates includes only those housing units where enough data was collected to be considered sufficient for matching.

2.3 The Enumeration Sample for Housing Units

The E sample consisted of census housing unit enumerations in the same sample areas as the P sample, and it provided information about both correct and erroneous enumerations in the census. For a housing unit to have been correctly enumerated in the census it must have been enumerated in the correct location and it was required that the housing unit be fit for habitation on Census Day, though it could have been vacant or occupied. Examples of housing units that would not have been fit for habitation were demolished or burned-out units and commercial buildings. We also excluded group quarters facilities from the E sample, and any housing units in Remote Alaska areas. While the census aimed to accurately list all housing units in the nation, it was possible for the census to erroneously enumerate some units. Examples of erroneous enumerations would have been duplicate enumerations and addresses for non-residential and nonexistent units. For more discussion on the features of a correct enumeration in the census, refer to Zamora (2022).

As mentioned earlier, there were two phases for housing unit operations. During the initial phase we used a preliminary census address list of housing units to perform initial matching and followup work. During the final phase we processed changes between this preliminary list and the final census file that ultimately defined the E sample. Having the E sample in the same sample blocks as the P sample helped to reduce the variance of our estimates and also reduced the followup workload in the Initial and Final Housing Unit Phases. The final E-sample sizes were roughly 180,000 housing units across the 50 states and the District of Columbia, and roughly 7,500 for Puerto Rico (Phan 2022).

Figure 1.
Distribution of State-Level, Occupied Housing Unit Interview Rates for the Person Interview Operation

3. PES COVERAGE ESTIMATION

In this section, we discuss dual-system estimation and components of coverage as they apply to housing units.

3.1 Dual-System Estimation and Net Coverage Error

The PES estimated the number of housing units in the United States and Puerto Rico with a method called dual-system estimation. As the name implies, there were two systems, the first being the housing unit correct enumerations from the 2020 Census, excluding group quarters and housing units in Remote Alaska areas. We sampled from all census enumerations to create the E sample and used this sample to estimate the number of correct enumerations. The second system was the housing units listed in the P sample.

In the 1990, 2000, 2010 and 2020 post-enumeration surveys, we performed this estimation using a synthetic dual-system estimator (Wolter, 1986). For 2010 and 2020, this estimator was motivated by the classic formation of the DSE, also known as the Petersen (1896) or Sekar-Deming (Sekar and Deming 1949) estimator. We used logistic regression models developed on the E and P samples to predict the probability of a census housing unit being a correct enumeration in the census and the probability of a P-sample housing unit matching to a census correct enumeration, respectively. We then predicted these modeled probabilities for each census housing unit enumeration and calculated the Coverage Correction Factor (CCF):

\[ CCF_j = \frac{\pi_{ce,j}}{\pi_{m,j}} \]

Where

- \( j \) is the census housing unit enumeration.
- \( \pi_{ce,j} \) is the predicted probability that the census housing unit enumeration is correct.
- \( \pi_{m,j} \) is the predicted probability that a P-sample housing unit matched to a census enumeration.

As previously mentioned, whole-housing unit imputations did not exist for the 2020 Census. Therefore, unlike during person estimation, we did not need to include a data-defined probability. We also did not need to apply a sex ratio adjustment, as was done for person estimation. For people, the sex-ratio adjustment aligned adult male-to-female ratios with those from the 2020 Demographic Analysis.\(^5\) Housing units do not have demographic characteristics so it would not have made sense to perform such an adjustment. Also, Demographic Analysis did not produce estimates for housing units and there were no other high-quality independent data sources for housing units that we could use to perform such an adjustment.

Once the final CCFs were calculated, we estimated the DSE for a specific estimation domain in the following manner:

\[ DSE = \sum_{j \in K} CCF_j \]

Where

- \( j \) is the census housing unit enumeration.
- \( K \) is the desired estimation domain.

We then estimated net coverage error rate in the following manner:

\[ \text{Net coverage error rate} = \frac{(\text{Census total} - DSE)}{DSE} \times 100 \]

To calculate the DSE from the net coverage error rate, use the following formula:

\[ DSE = \frac{\text{Census total} \times 100}{\text{Net coverage error rate} + 100} \]

\(^5\) More information on the 2020 Demographic Analysis can be found in Jensen et al. (2020).
The census total was calculated by summing the housing units in the estimation domain from a file of edited census data. These data edits ensured that each housing unit on the file had valid values and consistency across characteristics. In general, net coverage error rates were calculated from rounded numerators and denominators.

### 3.2 Component Estimation for Coverage of Housing Units

For the 2020 PES, we estimated three components of coverage for housing units:

- Correct enumerations.
- Erroneous enumerations.
- Omissions.

Every housing unit enumeration in the census was either correctly or erroneously enumerated. Housing units that were part of the target population but were not enumerated in the census were census omissions. To estimate rates of correct and erroneous enumerations in the census, we used the E sample and a design-based estimator. To estimate the total number of omissions, we subtracted the estimated number of correct enumerations in the census from the estimated population total (the DSE); refer to Marra and Kennel (2022).

We note that for people there was a fourth component: whole-person census imputations. Housing units did not require this kind of imputation because the census was able to collect enough identifying information for all housing units.

---

6 A design-based estimator uses sampling weights to make inferences.
4. ACCURACY OF PES ESTIMATES

As a sample survey, the PES was subject to a variety of errors, which we split into two categories: sampling and nonsampling error. These errors affected the accuracy and variability of the estimates produced by the survey. Their effects should be considered in any analysis performed using the survey data. While for some of these errors we produced estimates, others were much harder to quantify. However, we describe them in this document for clarity and transparency. For a more complete and detailed discussion of the possible errors, we refer to previous articles (Wolter, 1986; Hogan and Wolter, 1988; Mulry and Spencer, 1991; and Hogan, 2003).

4.1 Sampling Error

Sampling error occurs when the selected sample produces estimates that differ from what would have been obtained if all housing units in the target population were included in the sample. The PES used a complex, systematic sample design where the basic unit of sampling was the block. The design had three phases where, in each phase, the sampling units were stratified and sorted based on block-level characteristics such as the expected number of housing units and geography.

The PES estimated sampling error using a successive difference replication (SDR) method. Many other surveys implemented by the U.S. Census Bureau use this method, including the American Community Survey (ACS), the Current Population Survey (CPS), the Survey of Income and Program Participation (SIPP), and the National Crime and Victimization Survey (NCVS). All these surveys use a complex, systematic sample design. For more discussion on the SDR method, refer to Fay and Train (1995) or to U.S. Census Bureau (2014).

The PES used the same SDR replicate factors produced by the ACS to create 80 replicate samples. We created the replicate weights by multiplying the final PES sample weights for both the P and E samples by the 80 ACS replicate factors within each sample block. Each replicate sample underwent the weight trimming, unresolved status imputation, and modeling processing separately. Thus, the sampling error includes variability due to reweighting, imputation, and modeling for dual-system estimation. Additionally, for the estimates of components of coverage, based only on the E-sample housing units, we applied a ratio adjustment to known census totals for each replicate. This resulted in each housing unit having one final full sample weight and 80 replicate weights. The variance estimate was then calculated as a function of the difference between the estimate for each replicate and the estimate for the full sample. More information on SDR and how it was applied to the 2020 PES can be found in Hill et al. (2019).

By implementing the SDR method in 2020, the PES improved variance estimation compared to prior post-enumeration surveys. SDR accounts for the sample design by capturing some of the implicit stratification and order of systematic sampling. Additionally, repeating the PES weighting adjustments, imputation, and dual-system estimation for each of the 80 replicates captured variability introduced by these post-processing steps.

The PES performed statistical testing for estimates of net coverage error rates and certain components of coverage. Statements of comparison were statistically significant at the 90 percent confidence level (α=0.10) using a two-sided test. For any PES release, estimated net coverage error rates that were statistically significantly different from zero were identified by an asterisk (*). We also produced 90 percent confidence intervals and margins of error for many estimates. These intervals, based on estimated standard errors, show the variability of our estimates over many different samples. If we were to produce this confidence interval estimate over and over, with a different sample each time, 90 percent of the intervals created would have contained the value that would have resulted if we had used the entire sampling frame. We calculated 90 percent margins of error in the following manner:

\[
\text{Margin of error} = 1.645 \times \text{Standard error}
\]
Using the margin of error, we calculated the 90 percent confidence interval with the following formula:

\[
\text{Confidence Interval} = (\text{Estimate} - \text{Margin of error}, \text{Estimate} + \text{Margin of error})
\]

4.2. Nonsampling Error

For a given estimator, the difference between the estimate that would result if the sample were to include the entire population and the true population value being estimated is known as nonsampling error. There are many sources of nonsampling error. In this document we will discuss coverage error, nonresponse error, measurement error, processing error, and analysis error. Unlike sampling error, nonsampling errors are not accounted for in the estimates of variance or the confidence intervals. Rather, they are potential sources of bias and variance.

4.2.1. Coverage Error in the P Sample

P-sample coverage error refers to the differences between the P-sample target population and the housing units included in the P sample. In the P sample, missed housing units could cause P-sample undercoverage, while undetected duplicates or erroneous inclusions could cause P-sample overcoverage. Efforts were taken to remove erroneous inclusions such as duplicates and housing units outside the target population from the P sample, but some unmeasured amount of overcoverage in the P sample was still present. To quantify undercoverage in the P sample, we estimated the P-sample omission rate. The national P-sample housing unit omission rate was 8.56 percent (0.74 percent standard error). This omission rate is the difference between the national DSE and the weighted P-sample total number of housing units, as a fraction of the national DSE. The omission rate quantifies how much of the population was not included in the P sample. We calculated this rate in the following manner:

\[
P - \text{sample omission rate} = \frac{\text{DSE} - \hat{p}}{\text{DSE}}
\]

Where

\[
\hat{p} = \sum_{i} w_i
\]

- i is a housing unit that was included in the P sample.
- \(w_i\) is the final P-sample weight.
- N is the total number of housing units included in the P sample.

Undercoverage in the P sample was not a primary concern because dual-system estimation is, by design, robust to coverage errors if the coverage errors are independent between the two systems. While increases in coverage errors in the P sample and the census put more reliance on the independence assumption, it would not bias the DSEs if independence between the P and E samples held. Higher PES coverage rates would make the DSE more robust to such violations.

There are many things that could violate this independence assumption. An example of an operational violation of independence would be if an interviewer worked the same block for both the census and the PES. Their prior knowledge of the block from their census work could affect the performance of their PES work. Causal violations of independence could exist if the fact that a housing unit was captured in the census affected its probability of being captured in the PES. More discussion on errors related to violations of independence are in the section on analysis error.

4.2.2. Nonresponse Error

PES nonresponse errors included both PES unit nonresponse and item nonresponse. Housing unit imputation processes dealt mostly with item nonresponse while person imputation processes dealt with both unit and item nonresponse. For people, unit nonresponse occurred when we knew a housing unit was occupied but were unable to obtain an interview from either a householder or a proxy respondent. For housing units, if we knew a housing unit existed but were unable to obtain an interview, we still collected most required information through observation. This
ability to observe housing unit details made it less likely that the PES would have unit nonresponse for housing units, although it was possible. For example, this may have occurred in instances where the unit was “hidden” or not easily located by observation. A basement apartment could have been considered a hidden unit if it was not easily observable from the outside.

Item nonresponse refers to missing data on P-sample listed or census enumerated housing units. For the PES, there were two kinds of item nonresponse, the first being missing housing unit characteristics. While many housing unit characteristics could be obtained by observation, for characteristics that could not be recorded by observation we used imputation when those characteristics were missing. This included imputation for characteristics like tenure and race and Hispanic origin of the householder. However, Census Day occupancy was one exception to this. If we did not obtain an in-person interview for the housing unit, we were unable to determine Census Day occupancy of the housing unit. When this occurred, we assumed the housing unit was occupied on Census Day and imputed tenure and all characteristics for the householder. This methodology for the resolution of occupancy for a housing unit was the same as what was done for the 2010 post-enumeration survey (i.e., the Census Coverage Measurement survey). If this assumption was systematically incorrect for housing units with missing occupancy status, it could have introduced nonresponse error into the survey. For more information on characteristic imputation, refer to Phan and Lawrence (2022).

The second type of item nonresponse were missing statuses. This occurred when we could not determine the match status of a P-sample housing unit or the enumeration status of an E-sample housing unit. When that happened, we imputed these statuses using logistic regression models. Refer to Table 2 for the nonresponse rates for housing unit match and enumeration status.

In the 2020 PES, the rates of unresolved match and enumeration housing unit statuses were higher than in 2010. However, the 2020 PES rates of missing housing unit statuses were still quite low compared to that of person missingness rates. For more information on missing data for housing units in the PES, refer to Sakouvoigui and Beaghen (2022). For more information on missing data for people in the PES, refer to Beaghen et al. (2022).

4.2.3. Measurement Error
Measurement error refers to the accuracy of the collected data. Some examples of measurement error would be if a housing unit was recorded as vacant when really it was occupied, or if it was recorded as a housing unit when really it was a group quarters facility.

The PES housing unit data were collected by in-person interview and observation. In-person surveys are subject to interview effects. The PES provided high quality training to all its field representatives. However, it was still possible that field representatives misinterpreted their training or did not follow survey procedures as specified. Such errors could lead to added variability or bias in the reported data. Further, during an in-person interview, the respondent may have misreported something, such as stating the wrong race for the householder.

<table>
<thead>
<tr>
<th></th>
<th>2020</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unresolved rate for match status</td>
<td>0.1</td>
<td>0.0</td>
</tr>
<tr>
<td>Unresolved rate for enumeration status</td>
<td>0.5</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Note: United States only.
One COVID-19 safety measure that the PES implemented for Initial Housing Unit Field Followup work was more flexibility to allow for observation followup instead of in-person followup. Initially, the rule for all housing unit field followup work was that multiple contact attempts must be made before completion by observation was allowed. However, for the PES Initial Housing Unit Field Followup work, if the required details of the housing unit could be recorded by observation, then an in-person interview was not required. While this allowed for social distancing, it risked introducing more error if the field representative’s observations did not accurately reflect the truth.

In addition, delays in the PES schedule may have increased some measurement errors. While the Independent Listing was conducted at the planned time, both Initial Housing Unit and Final Housing Unit operations were delayed, allowing more time for housing units to be demolished or built. The PES tried to accurately record these changes to the housing unit population with respect to Census Day, but the increased time between operations made this harder to do. These delays may have also increased recall error in collected data. This occurs when, the further away from the reference day the interview takes place, the more likely it is for the respondent to have a hard time accurately recalling exact details as of the reference day. For example, a landlord may report in the census that their rental unit is vacant. Then between Census Day and the PES interview, a tenant moves into the unit. When the PES interview occurs, the tenant may not remember the exact date that they moved into the unit, and they report that they were renting it on Census Day.

Table 3 presents a confusion matrix in which we show the cross-tabulation of occupancy and tenure between the PES and the census.

Classification error existed in both the census and the PES. Table 3 shows that the PES and the census did not always agree on the classification of occupancy and tenure for a housing unit. For example, of the 16,300 vacant E-sample housing units, 3,100 were found to be owned in the P sample, 3,100 were found to be rented in the P sample, 6,200 were confirmed to be vacant in the P sample, and 3,900 were not found in the P sample.

As was previously mentioned in the nonresponse section of this report, if the status of Census Day occupancy was not reported in the PES interview, we assumed that the unit was occupied on Census Day, and we imputed tenure as well as all characteristics of the householder. While this assumption was made for both the 2010 and 2020 post-enumeration surveys, we acknowledge that it may have introduced measurement error in the survey if we incorrectly assumed a housing unit was occupied when it was vacant.

Table 3.
Confusion Matrix for Occupancy Tenure Between Matched and Nonmatched P-Sample and E-Sample Housing Units

<table>
<thead>
<tr>
<th>P-sample status</th>
<th>Owned</th>
<th>Rented</th>
<th>Vacant</th>
<th>Not in E sample</th>
<th>P-sample totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Owned . . . . .</td>
<td>72,000</td>
<td>6,700</td>
<td>3,100</td>
<td>1,800</td>
<td>83,600</td>
</tr>
<tr>
<td>Rented . . . .</td>
<td>6,500</td>
<td>42,500</td>
<td>3,100</td>
<td>1,700</td>
<td>53,800</td>
</tr>
<tr>
<td>Vacant . . . .</td>
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<td>2,900</td>
<td>6,200</td>
<td>2,000</td>
<td>13,400</td>
</tr>
<tr>
<td>Not in P sample . .</td>
<td>10,000</td>
<td>11,000</td>
<td>3,900</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E-sample totals</td>
<td>90,800</td>
<td>63,100</td>
<td>16,300</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes: This table does not include P-sample housing unit matches to census enumerations that were excluded from the E sample. We also excluded addresses that were part of the field data collection, but that were later determined to not be eligible for the P sample. For these reasons, the total number of P-sample housing units in this table (150,800) does not match the total number of units presented in the appendix (161,000). This table represents the P and E samples for the United States only.

4.2.4. Processing Error

Processing error refers to any errors that occur during the editing and coding of response data. For the PES, this could include errors in the way we implemented our computer and clerical matching operations. For example, matching error may have occurred if the PES incorrectly coded a nonmatching P-sample housing unit as a match, or vice versa. There were numerous activities in the PES that could have contributed to matching error, including the way we defined the search area for matching, computer matching operations, and clerical matching operations. One advantage of PES operations was that we implemented quality control safeguards meant to reduce matching error. Expert analysts routinely reviewed samples of all cases that had already been clerically matched. We also ensured that all newly trained technicians’ work was 100 percent reviewed for quality control until they were able to demonstrate that their match codes met an error threshold. While we tried to mitigate clerical matching error with training, guided practice, and ultimately a qualifying exam, there could have been errors in the training, or the clerical matching staff may not have followed procedures correctly.

The PES search area was highly relevant to controlling processing errors. The search area was the geographic area in which we searched for a census match to the P-sample housing unit. In general, as the size of the search area increases, the potential for false matches increases. For the PES we defined the search area as the sample block plus the set of surrounding blocks. If a P-sample housing unit matched to a census housing unit in the surrounding block, then the final status was considered a match. More information on the search area can be found in Hogan (2003).

Computer matching could be a source of error if the thresholds used to determine whether two different addresses were the same were not set properly. However, during clerical matching, technicians and analysts reviewed all matches and nonmatches from computer matching, removing false matches and adding new matches. However, there still could have been false matches because of clerical error.

4.2.5. Analysis Error

Analysis error, or error in the estimation processes, arose from various efforts after data collection that were meant to improve inference and correct other errors in the survey lifecycle. The PES estimation process used many statistical techniques, such as weighting adjustments and imputation, to correct for errors in the data. Although these techniques were intended to improve the data, they may also have introduced some errors.

Imputation was used to reduce errors resulting from missing data. For housing units this included imputing match and correct enumeration statuses, as well as characteristic imputation for householders. Violations of assumptions underlying the imputation procedures could add both systematic and random errors to coverage estimates. Estimates of sampling error should include many of the random errors resulting from imputing P-sample match status and E-sample enumeration status; however, bias resulting from the imputation procedures could not be quantified. Nevertheless, well-researched and robust imputation procedures were used to fill in missing data in the PES. The imputation models fit the data very well and likely reduced the impact of missing statuses. For more information on missing data for housing units, refer to Sakouvogui and Beaghen (2022).

Some estimators are inherently biased. For example, it is well known that the ratio estimator (and other nonlinear estimators) is biased, meaning it differs on average from the ratio it is estimating. This bias becomes very small as the sample size increases, so it usually is not a concern. While the DSE is not a ratio estimator, like the ratio estimator, it is also biased. Fortunately, the PES sample sizes are large, reducing this bias of the DSE.
Synthetic error is the difference between the estimate calculated from the synthetic models using the full population and the population total. For dual-system estimation, synthetic error could have occurred if we produced estimates for domains that were not included as covariates in our models. For the 2020 PES, we tried to mitigate this error by ensuring that all desired estimation domains were included as main effects in the DSE models. For example, state was added as a main effect so that we could produce state-level estimates of net coverage error.

A final source of analysis error could arise from violations of the assumptions on which dual-system estimation is based. Mulry and Spencer (1991) and Wolter (1986) discuss many of the assumptions and models supporting dual-system estimation. However, we will focus on the independence assumption. Although dual-system estimation did not require complete coverage and response from the census and PES, it relied on the statistical independence between the census and PES housing unit enumerations. One of the ways that this assumption could have failed was if there was correlation bias between the two systems. In dual-system estimation, correlation bias occurs if the probability of counting a housing unit in one system impacts the probability of counting the housing unit in the other system. For the census and the PES, correlation bias typically occurs if a unit that is more likely to be missed by the census is also more likely to be missed by the PES. Correlation bias could have arisen in two ways:

- Causal dependence between the census and PES: This occurs if the event of a housing unit being enumerated in the census affects whether PES was able to list that same unit in the P sample.
- Heterogeneity in probabilities of inclusion: This occurs where housing units with identical estimated probabilities of inclusion differ in their true probabilities of inclusion.

For more discussion on correlation bias and the different violations of independence, refer to Sekar and Deming (1949), Wolter (1986), and Mulry and Spencer (1991).

The PES tried to minimize causal dependence by designing the survey to be operationally independent from the census. This means that the census activities did not influence the PES activities. To achieve operational independence, we performed our listing of housing units from scratch (without prior address lists or map spots of addresses), employed separate staff for the PES who had not worked the same areas in the census, safeguarded PES information (including the knowledge of which areas were in sample) from census staff, and conducted the PES data collection after census field operations were finished in the area. This operational independence played an important role in allowing us to meet the statistical independence requirements for dual-system estimation.

The PES tried to reduce heterogeneity of probabilities of inclusion by modeling specific inclusion probabilities for each housing unit. We did this using logistic regression models that had both main effects and interaction terms that were highly predictive of housing unit statuses. However, missing covariates or interaction terms in the models could result in heterogeneity and add to the bias of the dual-system estimates. Also, if covariates were misspecified, this may have also introduced heterogeneity. Nonresponse error, measurement error, and processing error could all contribute to the misspecification of covariates and heterogeneity of capture probabilities.
5. REFERENCES


Appendix Table 1.  
Housing Unit P-Sample Sizes by State

<table>
<thead>
<tr>
<th>State</th>
<th>Total</th>
<th>Vacant</th>
<th>Not a housing unit</th>
<th>Occupied</th>
<th>Person interview operation</th>
</tr>
</thead>
<tbody>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Interviewed housing units</td>
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<td>2,200</td>
<td>250</td>
<td>80</td>
<td>1,800</td>
<td>1,600</td>
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<tr>
<td>Alaska</td>
<td>1,100</td>
<td>100</td>
<td>40</td>
<td>900</td>
<td>750</td>
</tr>
<tr>
<td>Arizona</td>
<td>4,700</td>
<td>650</td>
<td>350</td>
<td>3,700</td>
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</tr>
<tr>
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<td>100</td>
<td>1,000</td>
<td>900</td>
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<td>90</td>
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<td>950</td>
<td>800</td>
</tr>
<tr>
<td>District of Columbia</td>
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</tbody>
</table>

Note: Counts may not sum to totals shown due to rounding. Some of the Not Interviewed Housing Units were contacted but not enough data was collected for the interview to be sufficient for matching the people between the census and the PES. The people in these housing units were subject to a noninterview adjustment for the PES person P sample. For housing unit estimation, we could determine the match status of most of these units because we had the address and geographic information.