The 2011 Census Coverage Assessment and Adjustment Process

July 2012

This is one of a series of reports published to support the release of results from the 2011 Census. This series of methods and quality reports provides information on the different methods used to collect, process, clean, adjust and protect the census results. The series also reports on the quality assurance of the results and provides quality indicators.

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Terms used in this report are explained in the 2011 Census glossary.

Office for National Statistics

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Summary

Every effort is made to ensure everyone is counted in a census. However, no census is perfect and inevitably some individuals are missed, for example they may be in hospital or temporarily overseas. This undercount does not usually occur uniformly across all geographical areas, or across sub-groups of the population (such as age and sex groups).

The 2011 Census for England and Wales included a coverage assessment process to measure the population that was missed, mainly using a large survey called the Census Coverage Survey. The 2011 Census estimation methods are based on this measurement. This paper outlines the key stages in the estimation process, providing links to the relevant published papers for each topic.

The estimation process was based on a number of assumptions and at each stage these assumptions were checked and adjustments made where necessary, based on evidence, to ensure the estimates are of the highest quality. This paper describes these adjustments and outlines how they fit together within the estimation framework. The adjustments were all modifications to the basic estimation process. Each was intended to address forms of bias in the estimates that resulted from the underpinning assumptions not being realised in practice.

1. The 2011 Census coverage assessment and adjustment process

The census provides a once-in-a-decade opportunity to get an accurate, comprehensive and consistent picture of the most valuable resource of the UK – its population – and a rich array of facts about it (Government White Paper, 2008). The key strategic aims included:

- giving the highest priority to getting the national and local population counts right
- maximising overall response and minimising differences in response rates in specific areas and among particular population subgroups, and
- providing high quality, value-for-money, fit for purpose statistics that meet user needs and that are as consistent, comparable and accessible across the UK as is possible

The measurement of small populations, one of the key reasons for carrying out the census, is increasingly challenging but it is important that this is done well so that the estimates are fit for the purposes they will be put to, for example resource allocation where minority groups can be those who attract higher levels of funding. Therefore, without any adjustment, the allocations based upon the census could result in monies being wrongly allocated. It is therefore traditional that census undercount is measured and the outcome disseminated to users.

In order to achieve the strategic aims described above, ONS outlined its coverage assessment and adjustment strategy in Abbott (2007), followed up by the detailed methodology in Abbott (2009), culminating in an independent review of the methodology (Plewis *et al*, 2011).

This paper outlines the final implemented methodology for the 2011 Census. It does not include the full detail, which can be found in the references throughout the text. The paper also provides an overview of the specific adjustments made to the 2011 Census estimates, noting how they fit into the overall framework.

The table Components of the census population estimates shows the contribution the different estimation components make to the final published census estimates for each local authority.

The census coverage assessment and adjustment methodology used is summarised below. The key stages are shown in Figure 1.

a) A Census Coverage Survey (CCS) was undertaken, independently of the 2011 Census. The survey was designed to estimate the under-enumeration (undercount) in the census. A sample of postcodes was drawn from each local authority in England and Wales, stratified by a hard to count (HTC) index. The HTC index was a proxy for non-response in the census. ONS (2009) outlined the methodology for constructing the HTC index. The CCS in England and Wales included 17,400 postcodes (around 340,000 households). ONS (2012a) summarises the key features of the CCS and gives the response rates achieved.

b) The CCS records were matched with those from the census using a combination of automated and clerical matching. The strategy was outlined in ONS (2011a). Further information about the matching will be published later in 2012.

c) A large sample (around 5 per cent) of census individuals were checked to see if they (the individuals) were duplicated within the English regions and within Wales, and the CCS data were used to help estimate the levels of overcount in the census by broad age-sex groups and the English regions and Wales. ONS (2012b) summarises the methodology used to measure and adjust for overcount including the results and adjustments made to local authority estimates.

d) The undercount was estimated within groups of geographically contiguous (i.e. neighbouring) local authorities (called estimation areas) to ensure that CCS sample sizes were adequate. ONS (2010) describes how these estimation areas were constructed and provides a look-up for local authorities. The matched census and CCS data were used within a dual system estimator (DSE) to estimate the population in the areas sampled in the CCS. The DSEs were then used within a simple ratio estimator to derive population estimates for the whole of the estimation area. The DSE and ratio methodology were detailed by Abbott (2009). As the data were processed, various modifications were made to the DSE and ratio estimation process to ensure that the estimates were robust and to reduce variability where appropriate. This included in some cases collapsing HTC groups, collapsing age-sex groups and removing CCS sample postcodes with no data. ONS (2012c) outlines the criteria used and the outcomes for each estimation area.

e) The DSEs were assessed for any bias at household level using an alternative household estimate (AHE) from the census field process. ONS (2012d) outlines the AHE methodology, and the method for using it to adjust the estimates. The assumption of independence for individuals within households was explored using social survey data. ONS (2012e) reports on the findings.

f) The sample was assessed for balance, which would affect the ratio estimator, using the dummy questionnaire data from the census field process. ONS (2012f) outlines the statistical test used, and the method for adjusting the estimates where an extreme sample was detected.

g) The population within communal establishments (CEs), which were defined as managed accommodation, was assessed for under-coverage using both the CCS (for small communal establishments) and administrative data and local information (for large communal establishments). Adjustments were made to the communal establishment population where these checks highlighted significant undercount. ONS (2012g) outlines the methods and data used to make these adjustments.

h) The national population estimates were assessed for quality and plausibility by comparisons with sex ratios from alternative sources. ONS (2012h) outlines the evidence and methodology used to make adjustments to the estimates, including how the adjustment was disaggregated down to estimation area and local authority level.

i) A synthetic estimator (a robust statistical methodology for estimating small areas) was used to estimate the local authority population, using the patterns observed at estimation area level. The local authority estimation methodology was detailed by ONS (2011b).

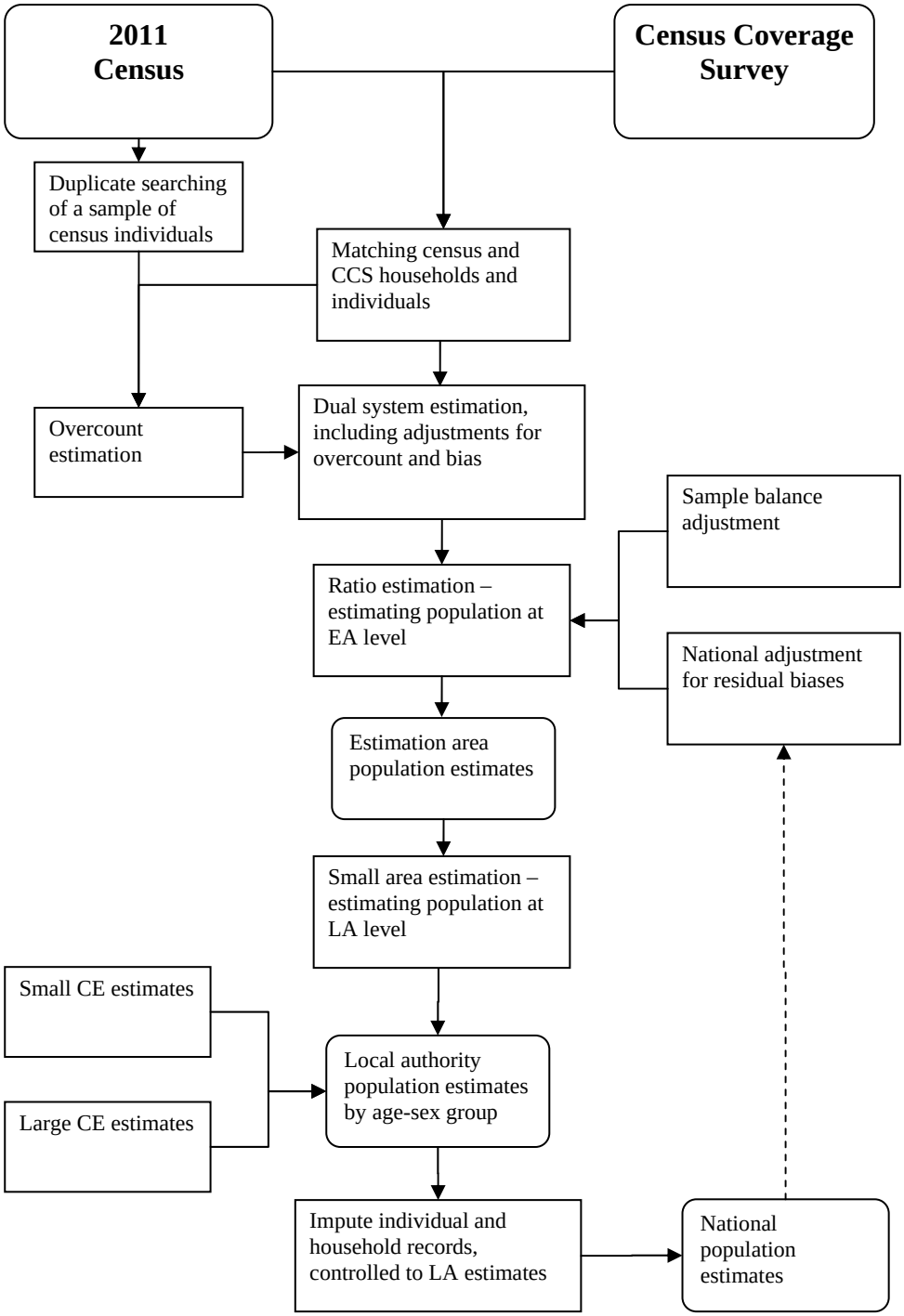
j) To provide a measure of variability in the estimates, 95 per cent confidence intervals were calculated for the estimation area and local authority estimates by age-sex group using a bootstrapping technique. ONS (2012i) outlines the methodology and results.

k) Households and individuals estimated to have been missed from the census were imputed on to the census database, after reducing the measured undercount by the estimated level of overcount. This process copied a subset of characteristics from real households and individuals to create the imputed households and imputed individuals estimated to have been missed. The households and persons were imputed into geographical locations across the whole estimation area and local authority. The coverage adjustment (or imputation) methodology was detailed by ONS (2011c).

The process above was not necessarily linear, as there was some iteration. For instance, the national population estimates could only be assessed using an initial set of estimates for every estimation area.

After the coverage assessment process, all the population estimates were quality assured using demographic analysis, survey data, qualitative information, administrative data and local information to ensure the estimates were plausible. ONS (2012j) outlines the quality assurance process, data sources and findings.

Figure 1 – The 2011 coverage assessment and adjustment process overview



2. Improvements to the estimates

The estimation process was based on a number of assumptions. At each stage these assumptions were checked and adjustments were made where necessary, based on evidence, to ensure the estimates are of the highest quality. This section outlines how those adjustments fit together within the estimation framework. These were all essentially modifications to the basic estimation process. Each was intended to address forms of bias in the estimates which resulted from the underpinning assumptions not being realised in practice, in summary those being that:

- the census and CCS were independent and capture probabilities were homogenous
- there was no overcount in the census
- the sample was balanced with respect to coverage
- there was no undercount in communal establishments
- the national and local estimates were plausible

The methods for assessing and adjusting for these sources of bias were planned and published as part of the census methodology, and references are given to these as appropriate. A mathematical explanation of how these adjustments fit together is included in Annex A.

A brief summary of these methods, or adjustments, is provided below together with the size of the adjustment.

2.1 Dual system estimation bias adjustment

DSE methodology makes a number of assumptions about the two counting processes (the census and Census Coverage Survey), including assumptions of independence (i.e. that an individual's likelihood to respond to the CCS was not influenced by how they responded to the census) and homogeneity of capture probabilities (i.e. that the population to which the DSE was applied have similar response patterns in either the census or CCS). The 2001 Census highlighted that DSE tends to be negatively biased (i.e. the estimates are always lower than they should be) due to any failure of these assumptions (see Brown *et al*, 2006).

The assumptions in the DSE applied to both the process for counting households, and also the process for counting individuals within households. The assessment of whether these assumptions held were evaluated separately.

2.1.1 Between-household bias assessment

Between-household bias could occur when, for instance, a household would refuse to respond to the census and CCS, or a household that had responded to the census would then be more likely to respond to the CCS. The methodology for measuring any bias as a result of these assumptions not holding for households (whatever the source of the bias) was to use an estimate of occupied households (called the Alternative Household Estimate (AHE)), by the hard to count index (HTC) within each estimation area to compare to the results of household level DSEs. If the AHE was greater than the DSE, the difference provided a measure of bias at household level.

To make an adjustment for the measured bias, the AHE was used to calibrate the household level DSEs for each estimation area. This provided a measure of bias at household level, which was then used within a model to estimate bias at individual level, making the assumption that there is no bias within counted households. ONS (2012d) provides more details on the AHE and the between-household bias adjustment methodology.

2.1.2 Within-household bias assessment

Within-household bias could occur when, for instance, a person would always be excluded from a counted household in the census and CCS. The methodology for measuring any bias as a result of these assumptions not holding for individuals within counted households (whatever the source of the bias) was to use social survey data. The survey data was matched to 2011 Census data to provide a measure of within-household coverage. If the survey found more individuals missed from counted households than the CCS, the difference provided a measure of bias for individuals within counted households. ONS (2012e) describes how ONS tested for bias within counted households using social survey data. No evidence of within-household bias from this method was detected, and so no adjustments to the census coverage estimates were made using the social survey data. However, that does not necessarily imply there was no within-household bias. The assessment of a need for a national adjustment (see section 2.6) would include any unmeasured within-household bias.

2.1.3 Adjusting the estimates for DSE bias

The two components, between-household and within-household bias, were brought together in a single adjustment method that resulted in a set of adjustments that increased the ‘missed by both’ estimate part of the DSE.

In 2011, the bias adjustment increased the census estimates by 583,000 individuals (1.1 per cent). The 2001 Census methodology described by Brown et al (2006) resulted in 230,000 individuals being added. The main reasons for this difference are that the 2001 adjustment was conservative, being the first attempt at such an adjustment and there was less confidence in the data used to construct an AHE. It is possible that, with changes in society over 10 years, the levels of bias when using DSE have increased.

2.2 Overcount estimation and adjustment

Overcount of individuals could occur in the census due to:

- duplicate returns at the same location (for example, a person on an internet return and a paper return from the same household)
- duplicate returns from different locations (for example, children of separated parents who both include them)
- individuals being counted in the wrong location (for example, a student who is counted incorrectly with their parents and does not return a questionnaire at their term-time address). Whilst this is not an overcount from a national perspective (as they are only counted once) they are at local level when the overcount occurs in a different local area than the undercount
- erroneous returns (for example, falsified returns for pets)

Duplication of individuals at the same location (for example, where an internet and paper questionnaire were returned from the same household including the same individuals) were identified and resolved by a specifically designed process. This process was not designed to deal with the other types of overcount and so the residual was to be measured and corrected in the estimation process.

The chosen approach for dealing with the residual overcount was to estimate the level and to feed this into a net adjustment for coverage, so that the estimated overcount reduced the adjustment to the census database (ONS, 2011b). This meant that residual duplicates were not removed from the census data, and fewer individuals were imputed.

The method involved two parts. The first was to estimate the level of duplication by drawing a sample of census records (stratified by the types of population expected to be duplicated, such as students) and searching for them within Wales or each English region. The second was to estimate overcount (i.e. both duplication and individuals counted in the wrong location), using the CCS as the ‘true location of enumeration’. The second part was then calibrated using the information from the first to improve accuracy. The result was a set of overcount propensities (or weights) for broad age-sex groups within an English region or Wales. The weights estimated for each stratum were applied to each individual census record within the DSE (for example, an individual aged 91 in a HTC 1 sampled postcode in a Welsh local authority would be given the weight estimated for those aged 85+ in HTC 1 in Wales). The application of the weights reduced the DSE, and thus the census estimates.

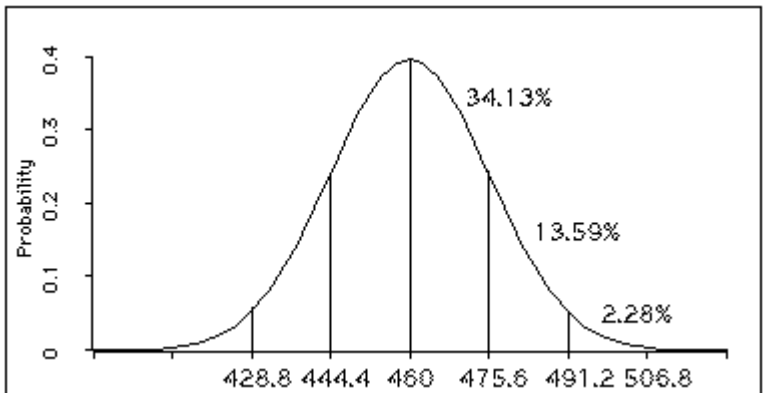
In 2011, the residual overcount adjustment reduced the adjustment for under-coverage by 352,000 individuals (0.6 per cent). This is in addition to the 237,000 duplicates removed at the same location during the initial processing stages. This was expected to be much larger than in the 2001 Census due to societal change, use of post-out and the availability of internet completion. For context, an assessment of overcount in the 2001 Census using the longitudinal study was made after the results were published. This estimated 200,000 (0.4 per cent), but adjustments to the 2001 Census results were not made.

2.3 Sample balance adjustment

For every sampling process, there is a risk that a sample may be an outlier amongst all possible samples (i.e. the CCS sample is drawn at random from all possible samples and, purely by chance, a sample of postcodes where the census had counted everyone was drawn). Such a sample would result in a set of estimates that is also an outlier amongst all possible estimates (i.e. the sample above would estimate zero undercount). For the CCS, there were 106 estimation areas each with approximately three HTC strata, and so there were around 300 samples used for estimation. Under normal assumptions the expectation was that about 5 per cent (i.e. 15) of these may have been 'extreme' purely by chance.

Figure 1 shows the typical distribution of estimates from all possible samples. This is called a sampling distribution. The top and bottom tails of this distribution are where outlying samples result in estimates that are also outlying – for instance the estimate of 506.8 shown could be considered an outlier amongst all possible samples (it is 10 per cent larger than the mean estimate of 460).

Figure 1 – A typical sampling distribution for an estimate



The numbers of census dummy questionnaires were used to evaluate whether any of the CCS samples were outlying (or not balanced). These data were believed to be the best possible proxy for coverage as they represented households from which a return was not received. The idea was to compare the proxy census dummy response rates in sample areas with the corresponding response rates across the whole estimation area (by HTC). If the two were significantly different the sample was unbalanced or an outlier. If this was the case, an adjustment was calculated, based on the ratio of the population level dummy questionnaire implied coverage to the equivalent for the sample. This was applied to the ratio estimator uniformly across all age-sex groups within HTC. ONS (2012f) outlines the methodology, analysis and resulting adjustments to the estimates.

Overall, the net effect on the population was a reduction of 20,000 (-0.2 per cent). There were 14 estimation areas (out of 106) where an outlying sample was detected. Eight of these were in the positive end of the distribution which would have given estimates that were too high, and six were in the negative end of the distribution. The largest upward adjustment in population within a HTC group was 2.2 per cent, and the largest downwards adjustment in population within a HTC group was 3.6 per cent. No adjustments for sample balance were made in the 2001 Census, although some of the local authority study adjustments which affected 15 local authorities are similar in nature but made after the 2001 Census results were published (ONS, 2004).

2.4 Coverage in small communal establishments
Whilst the CCS enumerated small communal establishments (those with fewer than 100 bed spaces), the CCS was not designed to be able to make localised estimates of coverage for the population that are resident in communal establishments, mainly due to small sample size. Estimates of coverage within communal establishments were made using a DSE for English regions and Wales level by broad age-sex group. Even at this level, the sample size was not sufficient to allow estimation by type of communal establishment. The result was a set of coverage weights which were used to adjust the census count for small communal establishment populations by age and sex across the local authorities within the relevant English region or Wales. ONS (2012g) outlines the methodology, analysis and estimates for this component.

In the 2011 Census, 43,000 individuals were added to small communal establishments. No adjustment was made to this population in the 2001 Census.

2.5 Coverage in large communal establishments The CCS did not cover large communal establishments (those with 100 or more bed spaces such as prisons and large student halls of residences). Therefore, administrative data and local evidence were used to determine whether the census missed significant numbers of persons in any such establishment. The adjustments required were aggregated and added into the estimates by age-sex group for each specific communal establishment. ONS (2012g) details these investigations and adjustments.

In the 2011 Census, 55,000 individuals were added to the large communal establishments. This compares to the 27,000 added in the 2001 Census.

2.6 Making a national adjustment for residual biases
When the first set of estimates for all estimation areas in England and Wales had been produced (including many, but not all, of the adjustments in the previous sections), the national census estimates for England and Wales were assessed for plausibility against alternative sources. Evidence at national level, consisting primarily of sex ratios from alternative sources, was used to assess the census estimates to examine whether there were any residual biases. This evidence showed that whilst the numbers of females was plausible, the numbers of males aged 20-49 was outside the bounds of plausibility. Sex ratios were used to define an adjustment to the male age group estimates, and this was cascaded to estimation area by HTC level using the method outlined in ONS (2012h). The outcome was a multiplying factor that was applied to the male age-groups within each estimation area.

In the 2011 Census, 303,000 (0.5 per cent) males aged 20-49 were added to the census estimates. In the 2001 Census, a similar adjustment was made, which totalled 186,000 males.

2.7 Quality assurance of census population estimates

The 2011 Census estimates have been through a rigorous quality assurance (QA) process.

The aim of the QA process was to identify where further adjustments were required before the estimates could be finalised, such as if there was evidence that there may have been difficulties in data collection, in processing or in the estimation process. The final estimates have been through the quality assurance process to ensure they are as accurate as possible.

Two main QA panels reviewed a consistent set of evidence for all 348 local authority estimates. A high level QA panel ran alongside the main panels and reviewed the emerging regional and national estimates and issues referred to it by the main panels. The high level panel included four members who were external to ONS and who provided valuable challenge during the QA process from the perspective of the users of the data and from a methodological perspective.

Central to the process were the QA panels which reviewed evidence and ultimately each panel recommended to the National Statistician that the 2011 Census estimates at local authority level should be published.

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4. Annex A – Adjustments expressed as a formula

This section outlines how the adjustments to the basic estimation process work mathematically.

The following formula shows how the adjustments made at the estimation stage interacted and were combined to produce an overall population estimate for the household population (i.e. CEs were not included here) at estimation area level:

$$T_a = \sum_h A_{ah} S_h B_{ah} \frac{DSE^o_{ah}}{x_{ah}} X_{ah} \quad (1)$$

Where:

A_{ah} was the national adjustment factor by age-sex group and HTC

S_h was the sample balance adjustment factor by HTC (where applied)

B_{ah} was the DSE bias adjustment factor by age-sex group and HTC

DSE^o_{ah} was the DSE adjusted for overcount and assuming independence by age-sex group and HTC

x_{ah} was the census count in the sampled areas by age-sex group and HTC

X_{ah} was the census count across all areas by age-sex group and HTC

While most adjustments were multiplicative, the bias adjustment was a function of the DSEs, and the national adjustments were a function of the DSEs and bias adjustment values. Also note that the DSE/x was the ratio estimator, and all the adjustments effectively made a modification to this ratio – even the bias adjustment which could also be thought of as a multiplicative factor that was applied to the DSE (although the result was mathematically the same).

In terms of how this formula was 'built' up over time, the process was:

1) The first run of estimation used no adjustments, so it looked like:

$$T_a = \sum_h \frac{DSE_{ah}}{x_{ah}} X_{ah} \quad (2)$$

2) The second run of estimation used the AHE to define and apply the bias adjustment, which used the patterns seen in (2) to define the adjustment factor

$$T_a = \sum_h B_{ah} \frac{DSE_{ah}}{x_{ah}} X_{ah} \quad (3)$$

3) The third run of estimation assessed the sample balance and if an adjustment was required it looked like:

$$T_a = \sum_h S_h B_{ah} \frac{DSE_{ah}}{x_{ah}} X_{ah} \quad (4)$$

4) The fourth run of estimation turned on the overcount adjustment (as this was assessed regionally), which did alter the bias adjustment slightly as it was a function of the DSE patterns, so it looked like:

$$T_a = \sum_h S_h B'_{ah} \frac{DSE^O_{ah}}{x_{ah}} X_{ah} \quad (5)$$

5) The final run of estimation turned on the national adjustment (assessed nationally), so it looked like:

$$T_a = \sum_h \quad A_{ah} S_h B'_{ah} \frac{DSE^O_{ah}}{x_{ah}} X_{ah} \quad (6)$$