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A review of procedures for estimating the net undercount of censuses in Canada, the United States, Britain and Australia

by Don Kerr

Demography Division
1710 Main Building, Ottawa, K1A 0T6

Telephone: 1 800 263-1136

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How to obtain more information :
National inquiries line: 1 800 263-1136
E-Mail inquiries: infostats@statcan.ca

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Abstract

All countries that organize censuses have concerns about data quality and coverage error. Different methods have been developed in evaluating the quality of census data and census undercount. Some method make use of information independent of the census itself, while some others are designed to check the internal consistency of the data. These are expensive and complicated operations.

Given that the population in each country is organized differently and that the administrative structures differ from one country to another, there is no universal method that can be applied.

In order to compare the methods and identify their strengths and gaps, Demography Division of Statistics Canada has reviewed the procedures used in four industrialized countries: the United States, the United Kingdom, Australia and, of course, Canada. It appears from this review that demographic analysis can help considerably in the identification of inconsistencies through comparisons of consecutive censuses, while micro-level record linkage and survey based procedures are essential in order to estimate the number of people omitted or counted twice in census collection. The most important conclusion from this review is that demographers and statisticians have to work together in order to evaluate the figures whose accuracy will always remain questionable.

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Table of Contents


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Introduction

The enumeration of a population through a census is intended to be complete but, because this ideal is never achieved, government statistical agencies attempt to measure census undercount. Several procedures developed by demographers and statisticians have played an important role in evaluating the coverage of census data. The purpose of the present report is to review certain procedures used for this purpose in Canada, the United States, Britain and Australia.

In the context of the estimation of population, the goal of demographic analysis is to provide population estimates which are independent of the census being evaluated using information from other sources on the numbers of births, deaths and migrants. Demographic estimates can then be compared to census population counts as evidence of how many persons were missed on census day. The crux of the matter is whether the estimates are precise enough to measure census undercount, since the quality of the administrative data and vital statistics typically relied on is uncertain. Demographic analysis can be contrasted with micro-level approaches developed by statisticians, in which case-by-case matching procedures and record-linkage techniques are used. Such procedures systematically compare a sample of the population that should have been enumerated on census day to that actually counted. In the 1991 Census of Canada, this micro-level approach, primarily the Reverse Record Check Study (Statistics Canada, 1994), has provided Statistics Canada with its official adjustment for coverage error. For the 1996 census, the Reverse Record Check will also be the primary vehicle for estimating undercount at the national level and for establishing the undercoverage of the provinces and territories.

Procedures for estimating the completeness of census coverage serve two purposes. First, they are used to estimate the number of persons missed by the census and to describe them by certain census characteristics (age, sex, marital status, home language, work status, urban or rural residence, etc.). Second, they are used to adjust the base population used in official population estimates.[1] With respect to the first purpose, micro-level matching and record-linkage techniques are the only ones that provide the sort of detailed information necessary. With respect to second, demographic analysis can complement the results of micro-level techniques, minimizing the bias in population estimates by age and sex. This report focuses on the usefulness of alternative procedures for accomplishing the second purpose by improving the precision of population estimates by age and sex. This is not of minor significance, as such adjusted figures serve as the base for Statistics Canada's population estimates and projections. Furthermore, the relative undercount for provinces and territories is of upmost importance in the calculation of fiscal transfers, since a province's share of federal equalization payments would be affected by whether the undercoverage of its population exceeds or falls short of the national average.

It is important to emphasise the sequence of procedures typically followed in developing a baseline population estimate by age and sex fully adjusted for census undercount.

1) All countries attempt to achieve as complete an enumeration as possible. Inevitably, errors

1 This requires detailed information on persons missed by age, sex and place of residence.

are introduced at the data collection stage by the gathering of erroneous or incomplete information due to such factors as the misreporting of age or the failure to respond to specific items.

2) The data collected through enumeration are then edited for obvious reporting errors, followed by imputation procedures for non-response on all census items.

3) Estimates of census coverage are then obtained through alternative techniques, both demographic and matching/record-linkage, with systematic comparisons of the census base to some independently derived standard or sample.

4) Estimates of census undercount are then added to the census base as a final adjustment.

This process is complex, with a potential for bias at every stage. The primary emphasis of this report is on stages 3 and 4. Any account of the factors responsible for undercoverage by age and sex also requires an evaluation of the bias introduced in stages 1 and 2. While data-collection methods will be briefly discussed before reviewing specific micro-level and demographic techniques for estimating undercoverage, a systematic account of edit and imputation procedures is beyond the scope of this report.

At the very least, demographic methods can assist in the evaluation of the success of micro-level record-linkage methodologies by providing independent estimates. But they can do much more, for example, replace failed estimates from micro-level post-enumeration studies as in Britain in 1991. Similar results from different methodologies add to the credibility of official estimates of population. This report concludes with recommendations for future Canadian research on demographic procedures related to the measurement of census coverage.

1. Canada

1.1 Canadian Collection Procedures (De Jure Census)

Given the goal of a complete count of all dwellings, households and individuals in Canada, census representatives must first compile or verify exhaustive lists of dwellings within each of the 46,000 Enumeration Areas (EAs). Within each EA (approximately 220 households, on average) census representatives identify residential dwellings and classify them as either private or collective and as either occupied or unoccupied. All usual occupants in each occupied dwelling are enumerated, primarily through self-reporting. To gather this information, Canada's census uses two enumeration methods: mail-back and canvasser.

Mail-back enumeration, in which census representatives leave a questionnaire at each dwelling with instructions to complete it on census day and mail it back, is used in collecting information for almost all dwellings. The canvasser method, which involves a personal interview, is reserved for a very small proportion of the population, that is those living in remote locations, Indian reserves and certain neighbourhoods of large cities. Both data collection methods require follow-up procedures to complete the enumeration, although initial non-responses rates — about 15% — are quite low by international standards. Data quality checks are introduced at all stages of data collection.

1.2 Micro-Level Approaches to the Evaluation of Canadian Census Coverage

The Coverage Error Measurement Program of the 1991 census includes four basic studies relying upon record-linkage and matching procedures:[2] (1) the Vacancy Check, (2) the Temporary Residents Check, (3) the Overcoverage Study, and most importantly, (4) the Reverse Record Check. Only the Reverse Record Check and the Overcoverage Study lead to official figures on net undercount. The Vacancy Check and Temporary Residents Check result in direct adjustments of the census data base. Consequently, the official estimates of net undercount reported in Statistics Canada publications measure coverage errors excluding those documented in two of the four studies.[3]

The Reverse Record Check (RRC) is a comprehensive record-linkage method and the means by which official gross undercoverage is estimated in Canada. It involves the construction of a sample intended to represent the same target population as the census, i.e., a complete sampling frame, obtained in such a manner as to be completely independent of the census evaluated, including such sources as the population enumerated in the previous census, birth

2 To be precise, there are four studies that rely upon "tracing selected persons, interviewing to obtain a census day address, and matching to individual census document procedures" (1991 Census Technical Report on Coverage Errors, Statistics Canada, 1993).

3 Briefly, the Vacancy Check involves a stratified multi-stage selection of EAs, where all selected dwellings are checked to determine whether census representatives correctly classified dwellings as occupied or unoccupied. This study leads to immediate adjustments of the census data base for households and individuals missed due to errors of census field representatives. The Temporary Residents study is a stratified sample of all persons who reported that they were temporarily absent from their usual place of residence on Census day on a questionnaire designed for this purpose and distributed at hotels, airports, etc. If it is found that they were not enumerated at their usual place of residence, the census base is adjusted to include them. The Temporary Residents Study was canceled in 1996.

registrations, administrative lists of immigrants and non-permanent residents, and persons missed in the previous RRC. In 1991, after selecting a sample of about 56,000 persons who should have been enumerated, a search of the census database was undertaken to identify persons not enumerated. They were then traced and interviewed, and the results used to determine the number and characteristics of unenumerated persons. Complementing the RRC, the Overcoverage Study is the primary means by which erroneous enumerations[4] are detected and involves both the sampling of persons reported residing in private and collective dwellings in order to determine where persons listed on the census forms should have been enumerated, as well as obtaining information on alternative addresses for checking, and automated matching procedures on the census database in order to identify duplicate households and persons. The results of the Overcoverage Study provide estimates of gross overcoverage. The combination of the RRC and the Overcoverage Study provide official estimates of net undercount.

The RRC is considered the most reliable source of information on gross undercoverage in Canada at both the national level and for the provinces. Using the RRC, gross undercoverage has been estimated from 1971 to 1991, and has been used in 1993 to re-base all of Statistics Canada's population estimates for this period (Statistics Canada, 1994).[5] The 1991 age distribution of the net undercount shows a relatively low level of net undercoverage for children, a dramatically higher level for both sexes at ages 20-24 and 25-29, and very low levels among Canadians in their late 40s and 50s. As will be introduced, this pattern is similar to that detected in two other countries investigated, namely Australia and Britain, but differs substantially from the pattern observed in the U.S. It deserves to be noticed that the pattern shown by the R.R.C. of a higher undercount among males than females, particularly for young adults, is unchanged since 1971.

Despite sound procedures, the RRC has some limitations. Not surprisingly, the primary source of error is the sampling error of the RRC methodology itself, which increases with the level of disaggregation. Furthermore, while Statistics Canada's publications consistently present standard errors, non-sampling error has normally not been quantified. For example, a significant percentage (4.9%) of the unweighted RRC sample was actually "not traced" in the record-matching procedure (i.e., the selected person had moved from his last known address and neither he nor a member of his household could be traced using available information). As a result, these could not be classified as either "successfully enumerated" or "missed". These "not traced" records were then imputed as "enumerated", "missed", "deceased" or "emigrated/abroad/out-of-scope", with roughly the same distribution as those who moved from their last known address but were successfully traced. An

4 Double counting, false reporting, fabricated households, persons who died before census day, etc.

5 Since the Overcoverage Study was first used for the 1991 census, no actual measurement of overcoverage is available before then. Consequently, this new series of population estimates (1971-1991) adjusted for net undercount used an estimate of overcoverage before 1991 based on the assumption that the distribution was unchanged. For further details on the estimation of this series, see Michalowski, 1993.

unknown level of bias is associated with the imputation, given that those successfully traced may not resemble the untraced in terms of type of migration.[6]

Statistics Canada's coverage studies are considered to produce high-quality estimates of net undercount at the national and provincial levels. Of course, the sampling errors associated with these coverage studies increase with the level of disaggregation, so it is not surprising that the RRC does not produce precise estimates for detailed age-sex categories. Yet, when analysing adjustments for net undercount for such disaggregations, one must also take into account census collection procedures and the quality of response for such census variables as date of birth and sex. For example, in 1991, date of birth and/or sex were imputed for over 727,000 persons. More specifically this figure includes persons in around 200,000 households whereby strictly no information was collected (both household size and characteristics were imputed) along with non-response to age and sex to well over 150,000 individuals whereby only partial or completely implausible information was collected. In addition to this imputation for over 727,000 persons, the result (profiles) of the Temporary Resident Study (involving 92,584 persons) and the Vacancy check Study (involving 134,668 persons) are added to the census data base using the random-addition technique, which could be considered imputation (for a total of over 950,000 persons). Not quantified here are respondent errors (proxy respondents), data-capture errors and systematic processing errors that cannot be detected by the systems or certification analysis. It is therefore difficult to establish whether difficulties at the disaggregated level are due to the non-sampling bias and sampling variance of the coverage studies or the non-sampling bias in the census counts.

While errors in successive censuses can potentially be quite different, if not contradictory, for the same cohort, selected adjustments have resulted in inconsistencies in census figures as we followed specific cohorts through time. While the population figures are generally acceptable for Canada and the provinces, they become less so for specific age groups. Census counts for specific cohorts over time after adjustment by the coverage studies are not necessarily consistent with what demographers know of their mortality and migration. If the data on mortality and migration that enter into population estimates are reasonably reliable and valid, some adjusted census figures for specific cohorts are highly unlikely. To take one example, the difference observed between the adjusted census estimate of the male population aged 20-24 in 1986 and the adjusted census estimate for the same cohort in 1991 appears virtually inexplicable given what is known from vital statistics and immigration data. Overall, for this cohort, the observed difference in adjusted census figures was less than 20% of the difference estimated using demographic methods.

Demographic methods suggest that further improvements are desirable, particularly to achieve intercensal consistency in Canadian census counts. This is an important objective of demographic models for the adjustment of census data.

1.3 Demographic Methods with Canadian Data

In the Canadian context, the usefulness of demographic methods appears to be two-fold. First,

6 For a review of certain difficulties associated with earlier versions of the RRC methodology, see Burgess (1988). Most of the problems outlined by Burgess in the 1986 census have been corrected, including problems of small sample size and significant gaps in the RRC sampling frame.

they allow the evaluation of the coverage studies and, second, they provide more refined estimates of the Canadian population by detailed age-sex categories. It is worth noting that the evaluation of RRC results using demographic analysis has already led to the revision of RRC estimates of net undercoverage for certain age-sex categories. For example, taking the 1991 RRC results for children aged 0-4, the estimated net undercount was significantly higher among female children (3.75%) than male (2.26%), with no obvious reason why this should occur beyond sampling error. Through demographic analysis, using precise information on the sex ratio at birth and mortality data from vital statistics, it was clear that the RRC results added to the census results gave an impossible figure. Consequently, the number of females was revised to correspond with the sex ratio at ages 0-4 derived using demographic analysis. Similarly, demographic analysis has suggested certain difficulties in adjusted census counts for older age groups. As a result, estimates of net undercoverage by five-year age group among Canadians over 55 were generated by Demography Division, allocating the total RRC undercount for these ages in proportion to cohort size. Since the RRC was designed solely to estimate the number of persons missed by the census, the sample size is not large enough to give accurate estimates for the older age groups. Crude techniques were relied upon at the oldest ages, with proportional allocation according to age distribution of the population aged 55 and over.

1.3.1 The Basic Demographic Method Applied to Canadian Data

As indicated, the application of demographic methods to the evaluation of census coverage is limited by the quality of data on fertility, mortality and migration. The basic demographic accounting equation begins with a cohort at birth, and adds and subtracts the components of demographic change (deaths, immigration and emigration) for each year up to the census year being evaluated. With Canadian data, a relatively long time series is available, since the components of demographic change are available from 1921. Using this time series, Bender (1992) has estimated the population of Canada for the last several census years by sex and five-year age groups. These estimates have been compared to unadjusted census data to produce independent estimates of census net undercoverage nationally by age and sex.

Briefly, the basic demographic accounting procedure relies upon the balancing equation:

$$C_t = B_y - D_{y,t} + I_{y,t} - E_{y,t},$$

where C_t denotes the cohort size in year t, B_y represents the cohort size at its origin (the number of births in year y) and $D_{y,t}$, $I_{y,t}$ and $E_{y,t}$ designate the cumulative number of events (deaths, immigrants and emigrants) affecting the size of the cohort between the years y and t. As data on the components of demographic change are available from 1921, the pure demographic method can generate estimates of the age group 0-4 in 1926, age groups 0-4 and 5-9 in 1931, age groups 0-4, 5-9 and 10-14 in 1936, and so on to the age groups 0-4 to 65-69 inclusive in 1991.

This technique suffers to the extent that there are errors in Statistics Canada's birth-registration data by sex, registration data on deaths by age and sex, and estimates of immigration, emigration, non-permanent residents and returning Canadians by age and sex. Further, these errors cumulate as the time series lengthens. Fortunately the two fundamental components, births and deaths, are

also those measured with the greatest precision.[7] The quality of estimates on international migration by age and sex decline as we move back in time, particularly with respect to emigration.

The effect of various data quality problems make estimates of net undercount obtained with the accounting technique unreliable for older ages. For example, very high levels of overcoverage were estimated for Canadians born before 1951. This is not surprising since Demography Division has less confidence in its time series before 1971. It is possible that reasonable estimates independent of census data are only available for the youngest ages. At older ages, the cumulative effect of error in the components is likely to result in unreliable estimates.

1.3.2 Canadian Postcensal Estimates

In the evaluation of the 1986 census, Romaniuc (1988) used the component method to obtain postcensal estimates, errors of closure and the corresponding estimates of undercoverage for the national and provincial populations. This method differs from the basic demographic accounting formula in that births and immigrants are added to, and deaths and emigrants are subtracted from, the base census population five years earlier, rather than starting with a cohort at birth. In the evaluation of the 1991 census, Bender (1992) has also relied upon this method to estimate levels of net undercoverage by age and sex in 1981, 1986 and 1991. Both demonstrated the strengths and weaknesses of the procedure in deriving estimates of net undercount. Compared to the accounting formula, there is clearly less possibility of error in the components of demographic growth with this technique, as they are limited to the previous intercensal period. On the other hand, the census base population plays a major role in the subsequent estimates since it is assumed to represent the net effect of all previous components of demographic change for each cohort.

A comparison of 1991 RRC adjusted census figures to postcensal estimates can provide estimates of net undercount by age and sex only if it is accepted that the 1986 base year was measured with complete accuracy and that intercensal events by age and sex were measured or estimated without error. In the Canadian context, both assumptions are unrealistic, especially the first, since there is no evidence that the error in 1986 RRC adjusted counts is less than that in the 1991 RRC adjusted counts, as the methodology is similar. Overall, while this method provides a reasonable indication as to the level of intercensal incoherency of adjusted census counts, it provides little guidance as to how observed discrepancies should be corrected. At the same time, it is possible to relax the assumption of accurate 1986 RRC estimates by considering relative levels of net undercount rather than absolute figures. For example, the finding that coverage in 1991 was different than in 1986 is informative, even if exact coverage levels are not determined in either census.

1.3.3 Other Demographic Methods

There has been little research on the use of demographic techniques for evaluating census data

7 There has never been a study of the completeness of birth and death registration in Canada, apart from a limited study of the completeness of birth registrations in the 1930s undertaken by Enid Charles (1940). Exploratory research involving a few census tracts suggested incompleteness of 3%. Analysts of birth data in Canada believe that the registration system was already highly reliable when the introduction of the universal family allowance in the late 1940s added a significant incentive to register births. Recently, the universal family allowance has been replaced by a targeted child tax credit. It is uncertain whether this may have affected the incentive to register births.

beyond that mentioned above. Postcensal estimates as an immediate extension of Statistics Canada's population estimation program have long served in the evaluation of preliminary census results and will continue to be used for this purpose. Some interesting exploratory research has also been undertaken with previous censuses to examine the relevance of administrative data[8] in the evaluation process. While this appears promising at first glance, particularly for older ages, much more research is necessary to determine where potential problems lie in the use of administrative files. The collection and editing of most administrative data sets are the responsibility of each province. Their priorities differ and they provide varying resources to maintain data quality. As a result, there is evidence that the validity of data sets varies considerably by province.[9]

Over 25 years ago, an interesting line of research was initiated by Lapierre-Adamcyk (1970), to replicate demographic techniques initiated in the United States by Ansley Coale (1955) with Canadian data. Ansley Coale is generally considered the first to use demographic analysis in the evaluation of census coverage in the United States (Himes and Clogg, 1992).[10] In applying Coale's iterative procedure based on his "hypothesis of similar errors", Lapierre-Adamcyk provided alternative estimates by broad age group of net undercount for the native-born which were then compared to some of the early estimates available from the RRC. A major obstacle that she faced in her research was the uncertain quality of the vital statistics on births and deaths that entered into her estimates, and we continue to face the same problem in developing demographic estimates. The principal recommendation that came out of her research was the "necessity of studying the relative completeness of birth registration". If Statistics Canada had followed up on this recommendation, we would now be able to provide more precise estimates using straightforward techniques for those age groups most difficult to enumerate in the 1996 census, e.g., young adults.

Recognizing the imperfections of the data that enter into demographic estimates, C. Dionne has suggested further techniques building upon the basic cohort-component approach. He has attempted to give a multidimensional character to subsequent estimates through these techniques (Dionne, 1995; Dionne and Kerr, 1995a). By «multidimensional», Dionne refers to techniques by which various relationships between cohorts by sex, of varying levels of undercount, are simultaneously taken into account when estimating the relative size of age groups in a census year. The purpose of developing such models is to establish estimates of net undercount that are robust in the face of data

8 For example, Medicare data, tax files, family allowances for ages 0-14, old-age security for ages 65 and over, among others (Fortier and Raby, 1989; Michalowksi, 1992).

9 In addition to using administrative records in the evaluation of census data, the Administrative Record Comparison Project (ARC) at Statistics Canada has explored whether administrative data sets might be used as a substitute for census data (Statistics Canada, 1993). To construct an enumeration of the 1991 Canadian population, ARC began with tax files from Revenue Canada and imputed non-filers. Using this independent estimate, ARC made systematic comparisons to population counts from the 1991 census. After disclosing significant discrepancies at all levels of geography, ARC reached the conclusion that "administrative records represent a data source complementary to the Census of Population and not a replacement for it" (Statistics Canada, 1994). The difficulty lies with the non-universality of most administrative data sets in Canada, and the consequent need for the imputation of the omitted population.

10 Ansley Coale's research will be introduced in reviewing U.S. techniques.

quality problems. The most comprehensive of these multidimensional methods is an intergenerational model, with several empirical applications (Dionne and Kerr, 1995b). Research continues on the usefulness of such methods for the evaluation and possible correction of the age-sex distribution of the 1996 census.

In the evaluation of the 1996 census results, consistency across techniques may be used as a criterion in the correction of census data. Further research is necessary to establish the extent to which alternative techniques are robust in the face of data quality problems and to explain observed discrepancies.

2. The United States

2.1 U.S. Data-Collection Procedures

Prior to its mail-out-mail-back census, the U.S. Census Bureau expends considerable effort to assure that the enumeration lists compiled by itself, the U.S. Postal Service and several commercial mailing-list companies are as complete as possible. The starting point for the U.S. census thus differs from the Canadian, since Canada sends census enumerators directly into the field to establish and verify lists prior to Census day.

The U.S. has experienced considerably higher initial non-response mail back rates in recent censuses than Canada and has invested considerable resources to obtain as complete an enumeration as possible. With the goal of a universal de-jure count of all dwellings, households and individuals, the 1990 U.S. census involved over 300,000 census enumerators in non-response follow-up. As a direct result of the costs associated with non-response, plans for the 2000 U.S. census include greater use of statistical methods in the data collection process for those households which are the most difficult to enumerate. Specifically, the U.S. anticipates an initial non-response of about 60%. When 90% of these initial non-responses have been enumerated, the Census Bureau plans to resort to sampling techniques to estimate the characteristics of the remainder. This implies that about 10 to 15 million records will be imputed.

Sampling procedures along with improved quality checks, using both a post-enumeration survey and demographic analysis, are expected to provide a "one-number census", with all figures for each item adjusted for coverage. By following up only a sample of the hardest part of the population to enumerate, the U.S. Census Bureau hopes to free resources for more refined quality-control methods and so obtain a higher-quality enumeration at a lower cost.[11] It is uncertain what potential error will be introduced by the necessary sampling and imputation procedures.

2.2 U.S. Micro-Level Approaches to the Evaluation of Census Coverage

While the U.S. has explored various micro-level approaches, the Census Bureau continues to rely on a post-enumeration survey as its principal coverage-measurement tool. This survey evolves with each enumeration. The 1990 Post Enumeration Survey (PES) is a revision of earlier post-enumeration surveys, of which the first was carried out nationally in 1950.[12] Although the U.S. explored

11 For further details, see U.S. Bureau of the Census, 1996.

12 For a comprehensive review of procedures used in the U.S. post-enumeration study, see the Journal of the American Statistical Association, Volume 88, No. 423, 1993.

the possibility of using a record-linkage study like the RRC, the conclusion was reached that such a procedure is inappropriate in a country that carries out only a decennial census. A record-linkage study relies heavily on tracing records sampled from the previous census, and the lapse of ten years would make this difficult. For the 1990 census, the U.S. relied upon a Post Enumeration Survey with a sample of about 166,000 housing units or 400,000 persons.[13] Of this total, 22,000 housing units were vacant, 144,000 were identified as occupied, and 142,000 were actually interviewed (Hogan, et al., 1993:1049).

The 1990 PES consisted of two basic samples: the P sample (a sample of the U.S. population obtained by area sampling) and the E sample (a sample of census enumerations from the census data base). The P sample represents the target population of the U.S. census and is based on the area sampling of geographic clusters (in 1990 a sample of 5,300 block clusters), whereas the E sample is of census records selected from the same clusters. The proportion of the P sample actually enumerated, which provides an estimate of gross undercoverage, is determined by the relisting of dwellings, the reinterview of households in selected blocks, and a follow-up interview and matching with census records. Automated matching techniques are applied to the E sample in order to obtain an estimate of overcoverage and a separate follow-up is undertaken to identify problem cases through individual interviews.

In 1990, the estimates of undercount and overcount from the P and E samples were combined in order to provide "dual-system estimates" of net undercount. As in Canada, this micro-level procedure is subject to both sampling and non-sampling errors. All efforts were made to minimize these errors by developing comprehensive imputation procedures for missing data, smoothing procedures and alternative post-stratification strategies. The U.S. Bureau has undertaken considerable work on the effect of various sources of error, including a sensitivity analysis of the effect of the imputation procedure designed for missing data. These errors were combined into an estimate of overall error using a Total Error Model (Mulry and Spencer, 1993). The purpose of this model is to allow for subsequent assessment of the effect of all sources of error in the PES, nationally and for state populations.

The U.S. Bureau produced three different sets of estimates for the 1990 census, largely as a result of methodological issues debated by its own statisticians and demographers.[14] The PES released its original estimates of net undercount in July 1991, revised them in January 1992, and revised them again in July 1992. The January 1992 estimates of net undercount were issued because of technical or computing problems with the July 1991 estimates, the high levels of sampling variance that accompanied them and questions concerning the smoothing techniques, used in large part to reduce sampling variability. The July 1992 revision differed significantly. The original 1,392 direct poststrata estimates were collapsed to 357 to reduce

13 A much smaller sample was selected for the RRC in Canada in 1991, about 56,000 persons. In comparing the size of the two samples, it is important to appreciate differences in the statistical efficiency of the two sampling designs. The design effect of the PES (i.e. the ratio of the sampling variance for a national estimate based on it to the sampling variance for the same estimate based on a simple random sample of the same size) is higher than that of the RRC, which would have to be about 15% larger if it were based on the same design (Dick, 1996).

14 Twelve different sets of dual-system estimates were reported by the 1980 U.S. post-enumeration study (Fay, et al., 1988).

sampling variability and eliminate the need for smoothing, and the basic PES data set was modified to reduce biases (see Hogan, et al., 1993:1052-53). The July 1992 revision provides the official estimates of net undercount presently used in the weighting of many U.S. Census Bureau surveys, including the Current Population Survey (CPS). In examining these alternative estimates derived from the PES, demographic analysis demonstrated inconsistencies in age-sex patterns, as well as in relative levels of net undercount by region. Also, the age-sex pattern of net undercount was not like that found in Canada. For example, in the July 1992 estimates, the net undercount of white children (0-17 years) was almost identical to that of young adults (18-29 years). In Canada, the net undercount of young adults was many times higher than that of children.[15]

As the 2000 U.S. census will make greater use of statistical methods in the data-collection process, further research is necessary to develop more refined quality-control methods. As indicated in *The Plan for Census 2000* (U.S. Census Bureau, 1996), a planned "second census" of 750,000 addresses will "include enough housing units in every state to assure the integrity of the apportionment process and the completeness of Census 2000". The reliance on sampling procedures in the actual data collection process has implications for the most appropriate procedures to be used to evaluate coverage. The U.S. Census Bureau is presently involved in research on the implications of this change for the search-and-match methodologies that have been used to estimate undercount. Preliminary results from the 1995 census test suggest the need for further research into dual-system estimation and revisions that will allow for more stable and unbiased estimates. Alternatives to the dual-system estimates have been tested unsuccessfully in the development of an Integrated Measurement Program for the 2000 census (Robinson, 1996).

15 The age-sex distribution was not consistent with those of the U.K. or Australia either.

2.3 U.S. Demographic Analysis and the Evaluation of Census Coverage Error

In addition to the PES, demographic methods have been relied upon for several decades for the evaluation of U.S. census coverage. The logic underlying the application of demographic methods is, as mentioned, straightforward, but the Bureau of the Census has faced several practical obstacles to obtaining estimates that are independent of both the PES and census procedures and that are of reasonable quality.

The crux of the matter is whether or not it is possible to obtain population estimates of sufficient precision to provide valid insights into the extent and nature of census undercount. To have confidence in the quality of demographic estimates of net undercount, demographers need to be confident of the quality of the vital statistics and migration data that enter into such estimates. The history of the demographic analysis of census coverage in the U.S. has largely been a history of evaluating and adjusting time series on the basis of evidence on the internal consistency of demographic data between and across censuses. In the application of the basic demographic equation to American data, several adjustments have been made to the time series. For example, research on the completeness of birth registrations has led to systematic adjustments to the time series of births.

The first demographer to apply demographic analysis to American data was Ansley Coale (1955) in the evaluation of the 1950 census. Coale has been credited with laying the cornerstone of

demographic analysis of the U.S. census with his emphasis upon the demographic accounting identity (Himes and Clogg, 1992). In earlier U.S. research, a straightforward application of the basic component approach was unsatisfactory because no evidence existed on the completeness of birth registration data prior to 1940, nor was there conclusive evidence as to the quality of the other time series. As a result, direct demographic estimates of most cohorts suffered from the bias associated with underregistration of births, among other factors. Consequently, several techniques were developed to estimate population on the basis of imperfect data. Coale's research is representative of research undertaken during the 1950s and 1960s, although it has since been extended and revised by several demographers affiliated with the U.S. Census Bureau for the 1960, 1970 and 1980 censuses (Siegel and Zelnik, 1966; U.S. Bureau of the Census, 1977; Fay, Passel and Robinson, 1988).

When he first applied demographic techniques to the problem of the demographic analysis of census coverage, Coale had access to two tests of the birth-registration system undertaken in conjunction with the 1940 and 1950 censuses.[16] These indicated underregistration of the order of 7% to 8% of all births in 1940 and 2% to 3% in 1950. Such a degree of underregistration would have an obvious effect on all subsequent population estimates. With this information, Coale was able to estimate in a straightforward manner the size of the younger cohorts in 1950, while the quality of birth data associated with older cohorts at their origin remained unknown. Lacking information on the precision of birth data before 1940, Coale developed strategies to deal with the problem.[17] Among other techniques, Coale and Zelnik (1963) used backward-projection procedures for the native-born population. Cohorts from many censuses were projected backward with available life tables to obtain alternative estimates of the number of births associated with each cohort, which were then averaged, adjusted for underregistration and then "survived" to the present. Similar research has been done by Coale and Rives (1973) in an attempt to obtain new estimates of the Black population and by Whelpton (1950) to develop the estimates of births by race. These estimates have been relied upon by analysts at the U.S. Bureau in the evaluation of certain older cohorts (those aged 55-64) in the 1990 census.

While estimates developed by Coale, Whelpton and Zelnik among others were of fundamental importance for the earliest applications of demographic analysis to the evaluation of census coverage, with each subsequent census an increasing proportion of the American population has been estimated directly using the survival of births adjusted for underregistration.[18] Furthermore, due to the cumulation of errors when using demographic techniques in the estimation of older age groups, the U.S. Bureau has for several

16 This is in contrast to the situation faced by Lapierre-Adamcyck, who had virtually no information on the degree of birth underregistration.

17 An example is Coale's "working hypothesis of similar errors" from census to census. In working with imperfect data, estimates for older cohorts were obtained by assuming a constant pattern of net undercount across censuses by age and sex, expressed in terms of rates. Undercoverage rates estimated for the youngest cohorts in 1950 were applied in previous censuses to cohorts at the same ages. Revised counts were then "survived" to 1950 to obtain estimates for older ages. This process was iterated to the oldest ages. Unfortunately, there was an accumulation of errors at older ages.

18 By 1990, only Whelpton's estimates of births entered into demographic estimates of persons aged 55-64.

censuses relied upon administrative data[19] for persons aged 65 and older. By 1990, demographic estimates largely reflected the sum of births, deaths, legal immigration and emigration, supplemented by data on armed forces overseas, estimates of undocumented immigration and the aforementioned administrative data. With estimates derived nationally by age, sex and race, the direct application of the basic component approach allowed for estimates independent of the census.[20]

The results of demographic analysis differed considerably from the PES, just as they differed from results obtained in Canada. For example, in the U.S. 1990 census, demographic research estimated an overcount for ages 15-19 of +1.66% and for ages 20-24 of +0.02 (Robinson, et al, 1993). An estimated overcount for ages 20-24 contrasts sharply with the pattern that has been documented historically in Canada. For example, the RRC estimated a peak net undercount of 7% for the age group 20-24 in 1991. Both demographic analysis and the PES estimated higher levels of net undercount among children (0-17) relative to young adults (18-29). For example, the PES estimated an undercount of 3.2% among children compared to 3.0% among young adults while demographic analysis estimated undercounts of 2.3% and 1.1% respectively. In Canada, the RRC has always led to estimates where the net undercount for children is considerably lower than that for young adults (2% to 3% among children aged 0-9 compared to the aforementioned peak of 7% at ages 20-24). There is no obvious explanation of these differences, although differences in census operations and in the techniques and data used to measure net undercoverage may contribute. In addition, it is possible to speculate that omissions from the U.S. census are more likely to be offset by relatively large numbers of persons counted more than once, whether or not the age-sex pattern of overcoverage differs substantially in the two countries.

The Census Bureau has also been exploring ways to combine results from demographic analysis with dual-system estimates of net undercount obtained from the PES. As an example, Bell (1993) has attempted to modify the 1990 PES dual-system estimates using demographic estimates of national sex ratios by age. Specifically, alternative strategies of incorporating information on sex ratios have been tested, including procedures that relax a fundamental assumption of the PES, that of independence between the P and E samples. In fact, if the selection of the P and E samples meets the condition of independence, dual-system estimates are possible which are free of several sources of bias, including persons missed in both the census and the subsequent post-enumeration (correlation bias between the census and subsequent PES operations). A more realistic starting point, one in which this assumption is relaxed somewhat, is achieved by introducing what are considered highly accurate sex ratios by age. For example, independence can be assumed for females only, whose coverage is probably more reliable, while estimates for males are made using sex ratios derived from demographic analysis. Bell is extending previous research by Wolter (1990), who first used sex ratios to introduce systematic revisions of dual-system estimates. The U.S. Bureau, appreciating sex ratios as a robust tool in census evaluation and adjustment, is continuing such research in preparation for the 2000 census.

2.3.1 U.S. Demographic Estimates and

19 Medicare data with adjustments for under-enrollment.

20 Due to the weakness of internal migration data in the U.S., methodological research continues on the potential use of demographic estimates and administrative data in the evaluation of census coverage at the level of states and large counties (see Robinson, 1995).

Uncertainty

Since the reliability of demographic estimates is diminished by the uncertainty of the underlying components, analysts at the U.S. Bureau decided to address this issue by developing what Das Gupta (1991) has called an uncertainty model of demographic analysis. The purpose of this model is to develop interval estimates of population and net undercount[21] based on pseudo-statistical theory involving interval estimates analogous to, yet qualitatively different from, conventional frequentist confidence intervals. These intervals are considered useful in judging the precision of demographic estimates without being directly derived from them from the point of view of statistical probability.

To document this uncertainty model, the U.S. Bureau has prepared a series of reports which presents an evaluation of the uncertainty associated with the measurement of each component of their demographic estimates (Robinson, 1991a, 1991b, 1991c, 1991d; Woodrow, 1991a, 1991b; Robinson and Lapham, 1991; Robinson, Woodrow and Ahmed, 1991; Robinson, Ward and Spencer, 1991). The goal was to develop interval estimates for each component based on a consensus of the views of Census Bureau experts in measurement error and estimation methodology. A study undertaken by Robinson (1991) is representative of this research. In it, sensitivity analysis was employed to examine the effect of hypothetical sources of error in birth-registration data. As all births are adjusted for incomplete registration, it was logical for Robinson to consider various sources of error in the tests of birth registration themselves, including both sampling and non-sampling error.[22] The question asked was, "what level of sampling and non-sampling error can be considered reasonable, or realistic, and if so, what is the impact of such error on overall estimates of births?" The combined effect of such errors provides an upper and lower boundary for input into the overall model.[23] The replication of similar simulations and judgements concerning other components leads to overall measures of the uncertainty of the final estimates of net undercount.

The confidence interval associated with birth registration was relatively narrow, of course, as were those associated with intercensal deaths and their distribution by age, sex and race. On the other hand, migration was subject to relatively large errors in estimation, given the difficulties in deriving indirect estimates of immigration, emigration and especially non-documented residents. After establishing the uncertainty intervals with demographic analysis, it was found that certain PES estimates of undercount fell outside them. Now that these discrepancies have been identified, the goal of further research will be to reconcile the differences obtained using different methodologies. Das Gupta (1990) has also extended this research to assign confidence intervals to estimated sex ratios by age.

Despite the recommendation of the Census Bureau based on considerable research on the issue

21 The probability is very high (95% or 99%) that the true U.S. population and net undercount fall within the intervals.

22 Matching bias, correlation bias between the data sets involved, extrapolation or interpolation bias for years where specific birth registration tests were not available, etc.

23 As a result of his many simulations, Robinson arrived at intervals for white births with a range from 1.3% in 1965-70 to 6.6% in 1935-40. The intervals were considerably wider for black births, reaching a high of 16.7% in 1935-40.

of census coverage in the United States, the Department of Commerce decided against adjustment of the 1990 census. Subsequently, the director of the Census Bureau decided in 1992 not to adjust the postcensal population estimates for undercount. However, this left open the possibility that the Bureau of Labour Statistics might adjust the population estimates for the purpose of survey controls, most notably for the Current Population Survey, which it did in January 1994. Hence, for the first time in the United States, an official set of population estimates adjusted for net undercount was available, the national and state controls for the CPS.

3. The United Kingdom

3.1 British Collection Procedures

With a goal of a universal count, the decennial British census has historically involved both basic methods of enumeration, i.e., de jure (usual residence) and de facto (present on census night). In the 1991 census, enumerators collected information by usual place of residence. In the past, Britain has relied upon drop off/pick up for its full population operations. This method has been abandoned in Canada, and the United States and Britain are presently reviewing their procedures. In its Census Test in 1997, the United Kingdom plans to test new enumeration procedures, including the provision of pre-printed address lists for field staff and the delivery and mail-back of census questionnaires. In addition, in one small remote area, a full postal methodology is being tested.

In 1991, enumerators were responsible for locating and listing all relevant properties, as well as the direct collection of census questionnaires. Several checks on completeness were carried out as part of field operations, including follow-up by phone and in person and the verification of lists. In 1991, for the first time in Britain, efforts were also made to include "in situ" households, all of whose members were absent on census night. This was done either by allowing for the first time the late completion of census forms after the household had returned to their address, or by imputation by copying a record of a matched household which voluntarily completed a form. As with other countries, the estimates of net undercount obtained directly from post-enumeration studies do not include those who were missed but were then added to the census base through such imputation procedures. The U.K. level of imputation remained high, more than three times the initial estimate of undercoverage documented through the post-enumeration survey. For further details, see the British 1991 Census User's Guide (Dale and Marsh, 1993).

3.2 Micro-Level Approaches to the Evaluation of British Census Coverage

The British have carried out a post-enumeration study for every census since 1961, although their earliest efforts did not go uncriticised. Among the technical difficulties encountered in the earliest post-enumeration studies were small sample size, difficulties in accurate data collection, delays in implementation and an apparent lack of complete independence between data collection procedures in the census and the post-enumeration study. Because of these technical difficulties, considerable work went into verifying these estimates through demographic analysis and comparison with administrative records. The official position of the Office of Population

Censuses and Surveys (OPCS, now the Office for National Statistics, ONS) is that the estimates of undercoverage obtained from micro-level analyses prior to 1991 are accurate as well as consistent with macro-level analyses.

Estimates of undercount from these earlier studies were conservative. Although more recent post-enumeration surveys are more rigorous in terms of research design and data-collection methodology, the level of reported undercount continues to be relatively low. For example, in 1991 the estimate obtained directly from the post-enumeration study was only about one half of one percent, a surprisingly low figure. It should be noted, however, that this figure does not include missing and imputed households added directly to the census base; if such imputations were included, the net undercount would have been many times higher.

One factor suggested as a partial explanation of these conservative estimates of undercoverage is the fact that the British post-enumeration study is a dependent re-enumeration, as opposed to an independent re-enumeration (Diamond, 1994). It takes the census as its starting point and then moves on to check census procedures. The immediate consequence of the British method is that it becomes "very difficult to make sensible estimates of those who are missed both by the census and by the post-enumeration study" (Diamond, 1994:135). This method can be contrasted with the U.S. capture-recapture post-enumeration survey, where a sample of the population is initially selected which is entirely independent of the census. In the U.S., dual-system estimates were specifically designed with this difficulty in mind, to describe the population missed in both the census and post-enumeration study.[24]

The 1991 British post-enumeration survey began with a multi-stage sample of approximately 1,200 enumeration districts for systematic follow-up. The census enumerators' record books were then used as the sampling frame for selecting households for verification. The dependent nature of the re-enumeration is reflected in the fact that it verified the census enumerators' record books and information gathered in census questionnaires.[25] The important question is thus whether, by using as its reference point the enumeration record book and census questionnaire, the post-enumeration study biases results. If the post-enumeration interviewer obtains information consistent with the initial record book or census form, there is little incentive to question its accuracy. For example, if highly mobile members of a household are missed initially, the probability of discovering them through the post-enumeration study may also be small.

To the extent that persons are missed in both the census and the post-enumeration study,

24 While the sample for the U.S. PES was selected independently of the census, it should be appreciated that the actual capture probabilities were not always totally independent. For example, evidence of correlation bias was disclosed through demographic analysis with respect to Black men, with a significant number possibly missed both in the census records and in the PES interviews.

25 The British post-enumeration study lists sample enumeration areas to compare with the initial enumerators' record book, checks buildings listed as non-residential, checks the classification of households as "census absent" and "census vacant", reinterviews households where the record book indicated "census forms returned", comparing systematically with the initial questionnaire, and checks households initially classified as multi-occupier households.

subsequent estimates of undercount will be biased downwards. In its final estimates of net undercount in 1991, the agency estimated much higher figures than the initial ones because demographic techniques demonstrated that the level of undercount estimated through the post-enumeration study was too low, with as many as an additional million persons missed in the census. Because there is little evidence of similar problems in 1981, there has been considerable speculation as to why greater difficulties were experienced by enumerators in the 1991 census and postcensal study. These speculations include the effect of the British poll tax, increased mobility among younger cohorts and increased alienation. Again, evidence consistent with this shift was obtained using demographic analysis (Wiggins, 1993).

3.3 Demographic Approaches to the Evaluation of British Census Coverage

While debate in the U.S. over the appropriate adjustment of census figures has led to volumes of sometimes contradictory evidence (and considerable litigation), in Britain certain demographic techniques have been relied upon successfully to evaluate and adjust official population figures. They are the classic balancing equation along with basic information on expected sex ratios. Recent British censuses have been systematically appraised using a variety of procedures, including a systematic comparison of census counts with corresponding postcensal estimates obtained by "surviving" the previous census, fully adjusted, using intercensal events. Overall, the official 1971 and 1981 census counts, adjusted by post-enumeration studies, were judged to be highly accurate, largely because such comparisons established a high degree of intercensal coherence.

The OPCS found a significant discrepancy when the 1991 census was compared to postcensal estimates based on the 1981 census. The relevant estimates exceeded by 1,047,000 persons the 1991 census figures adjusted for undercount on the basis of the post-enumeration survey (Office of Population Censuses and Surveys, 1995:113). This discrepancy, which suggests an undercount of about 2.2%, was significantly greater than the post-enumeration-study estimate of fewer than 300,000 missed, or 0.4%. To explain the closure error observed in 1991, several sources of potential error warranted a second look, including possible difficulties in the 1981 census and post-enumeration survey, possible problems in the measurement and estimation of the components relied upon to obtain the postcensal estimates for 1981 to 1991, and possible problems in the 1991 census and post-enumeration survey.

Postcensal estimates can only be relied on to evalute census coverage if it is possible to identify problems in data collection or estimation. In explaining the discrepancy of approximately 1,000,000 persons in 1991, the OPCS (1993) explored the possibilities that the 1981 census had a significant overcount, that the 1991 census and post-enumeration study missed a comparable number, and that the net effect of intercensal events (deaths, births and migration) was substantially overstated. That both the 1981 and 1991 post-enumeration studies understated the true level of net undercount, while acknowledged as a possibility, was never officially accepted.

The OPCS has rejected the likelihood of significant error in the coverage studies for the 1981 census. Furthermore, the working assumption concerning vital statistics is that registration is complete, although there is no mention of a birth or death registration study. With respect to the least reliable component of the demographic estimates,

international migration, the official OPCS position is that, if anything, the expected bias is in the opposite direction to what is implied by the error of closure. If the observed error of closure were wholly due to misreported net international migration, then a net inflow of approximately 400,000 persons over the period 1981-91 would necessarily be replaced by a net outflow of over 600,000. The consensus among analysts in Britain is that immigration is more likely to be slightly understated than overstated.

Other evidence suggestive of problems in the 1991 figures surfaces in the reported sex ratios by age for both the unadjusted and adjusted census figures. Reported sex ratios of young adults appear implausible in light of what is known of the sex ratio at birth and the mortality and migration of young men and women. While both the 1981 census counts and the 1991 postcensal estimates had sex ratios much in line with expectations, much lower sex ratios than expected were found for persons in their early to mid 20s in the 1991 census. This is consistent with the conclusion that the post-enumeration study failed to detect all the coverage error for young men. The consensus among OPCS staff was that the accuracy of the 1991 census-based count was inadequate, and the OPCS made the unprecedented decision not to re-base national population figures on the 1991 census.

For the age group 0-44, the whole of the difference observed between the postcensal estimates and the census was attributed to problems in the 1991 census and postcensal study (OPCS, 1993b:25). To justify why a portion of the error was not attributed to the 1981 census or to the intercensal components, it was argued that the size of such errors was "unquantifiable, and any allowances would be arbitrary". Despite the absence of empirical evidence as to what portion of the observed error was due to problems in 1981 or to error in the migration data, as opposed to the 1991 census figures, the postcensal estimates were accepted for these age groups. Again, this adjustment was justified by the evidence for intercensal coherence between census data and observed sex ratios. For older age groups (aged 45-79), the census figures adjusted by the postcensal study were accepted. For those aged 80 and older, the demographic approach showed a deficit in the census adjusted by the survey results (Heady, Smith and Avery, 1993:39) and the figures of the demographic approach were adopted.

The age-sex pattern of net undercount in British postcensal estimates has more in common with the Canadian RRC results than with the U.S. results. Among young adults, the level of net undercount peaks for young women in their early 20s and for young men, who have higher levels, in their late 20s. For both males and females, the level of undercount was comparable to the levels observed in Canada for these ages. At older ages (except for those over age 80), negligible undercount was observed for either sex while the net undercount for children lay somewhere between that of older age groups and young adults.

As in the U.S. and Canada, sub-national estimates of net undercount by age and sex have yet to be estimated using the same demographic methods applied nationally, primarily because of imprecision in internal migration data.[26] It is also not possible to assume that the level and age-sex pattern of undercount observed nationally can be applied at the sub-national level.[27] Consequently,

26 As will be seen below, the same generalization hold in Australia.

27 For a complete description of the methods used to generate population estimates adjusted for undercount at the sub-national level, see OPCS, 1993b.

other procedures are necessary to distribute the estimated undercount among local areas. Specifically, a pro-rata distribution of the number of each age-sex group across all local areas was used to obtain preliminary estimates, then, using information on the sex ratios by age for the nation as a whole and for certain local areas in 1971, 1981 and 1991, systematic adjustments of pro-rated figures were made to avoid implausible sex ratios (OPCS, 1993).

4. Australia

4.1 Australian Collection Procedures

As in Canada, the Australian census is carried out every five years. While it is conducted on a de-facto basis using drop-off/pick up operations, some data are available on a de-jure basis. To make an enumeration of the population according to people's location on census night, the Australian Bureau involves enumerators in the listing of dwellings, making direct contact with all occupied dwellings, providing residents with census forms for self-enumeration and then collecting all forms. In order to ensure as complete an enumeration as possible, several checks were included in the field operations, including follow-up of enumerators by phone and in person and the verification of lists by the enumerator's supervisors (Castles, 1989).

4.2 Micro-Level Approaches to the Evaluation of Australian Census Coverage

As in Britain, the adjustment of census figures has not been a matter of controversy in Australia, and the Australians have used a post-enumeration survey, in conjunction with demographic analysis, for all estimates of the population since 1971. The design of the survey has been relatively constant over time. Basically, it involves multi-stage area sampling of the Australian population in order to obtain a sample of private dwellings as independent of census operations as possible. The Australian PES is designed to identify both undercoverage and overcoverage from the area sample involved.

In terms of Diamond's (1994) distinction between dependent and independent re-enumeration, the Australian post-enumeration survey falls closer to the latter. All efforts are made to reduce the interaction between the census and the post-enumeration survey. For example, the Australian post-enumeration survey, like the American, does not involve census field staff nor does it begin with census enumeration lists and questionnaires. To the extent that the post-enumeration study and the census are statistically independent, "those factors that led to a person being missed or over-counted in the census may or may not be present in the PES, resulting in biased estimation of the underenumeration".

In 1991, a sample of about 40,000 private dwellings was drawn. Data were collected from the selected households through personal interview three weeks after Census night. People resident in the country on census night were asked their usual place of residence as well as their census-night address and any other address which might have been included on a census form. Systematic matching procedures of the post-enumeration sample to the census allowed for estimates of both the number of persons who should have been counted in the census and the number who were actually counted. As the Australian post-enumeration survey was designed to estimate both the number of persons missed and the number of persons over-enumerated, national estimates after post-stratification were made by age and sex. At lower levels of geography the sampling error of estimates was obviously higher, particularly for detailed age-sex categories. Imputation procedures were introduced to deal with cases involving vague

addresses which were not able to be matched to relevant census forms (Madden, 1995).

While the earliest post-enumeration studies in Australia detected very low levels of undercount, by 1976 rates had risen to levels comparable to those in Canada and the United States. By 1991, the total net undercount for Australia was estimated at about 1.8%, down negligibly from 1.9% in 1986. With respect to the age-sex pattern of undercoverage, the 1991 figures demonstrate a pattern of net undercount very similar to Canada's, i.e., peaking at about 4.4% at ages 20-24 for both males and females, although the actual level is not nearly as high as in Canada (Australian Bureau of Statistics, 1995). Results from the post-enumeration study have been systematically compared with administrative data sources, such as family-allowance and Medicare files. Where evidence exists based on administrative data or demographic analysis, appropriate adjustment is made to particular post-enumeration survey age/sex cells.

In the estimation of total net undercount for sub-national populations (states and territories), the sampling error associated with estimates by age and sex was considered unacceptably high. As a result, the Australian Bureau relied upon an iterative proportional fitting procedure (Purcell and Kish, 1989; Purcell, 1979; Bagnall, 1983) to estimate net undercount for states and territories by age and sex. This procedure uses national population estimates by age and sex adjusted using the post-enumeration survey, adjusted state and territory estimates for each sex, and unadjusted census figures for each state and territory by age and sex. The unadjusted census figures are adjusted to fit the other two sources of information using the iterative proportional fitting algorithm.[28] A constraint imposed was that no age group should experience overcoverage. In 1991, the same procedure was relied upon for state and territorial estimates of coverage.

4.3 Demographic Approaches to the Evaluation of Australian Census Coverage

Using the National Demographic Data Bank maintained by the Australian Bureau of Statistics, including births, deaths and international migration since 1926, demographic estimates can be compiled independently of the 1991 census for ages 0-64. Using a lengthy time series on births with detailed information on mortality and overseas arrivals and departures by age and sex, older age groups were "survived" to 1991. The assumption was made that the historical time series on births and deaths in Australia is substantially complete, without errors of omission (Hall, 1969). With what is assumed to be reliable information on international migration, demographic estimates by age and sex have been taken into account for several censuses for the evaluation of post-enumeration-study estimates of net undercount.

The quality of these demographic estimates declines for older ages as a longer time series is involved in estimation.[29] Australia is one of the few countries with an even higher proportion of its population foreign-born than Canada.[30] It is therefore not surprising that the basic demographic method breaks down for older ages. Detailed

28 Details on this procedure were first described by the Australian Bureau in a 1983 technical paper on population estimates (Bagnall, 1983).

29 This was particularly true for females in 1991.

30 By June 1995, 23% of the Australian population was born overseas.

comparisons with the postcensal survey and administrative data (e.g., family allowance, Medicare), has led to the conclusion that the postcensal survey results are more likely to be valid both in terms of total net undercount and undercoverage for most older age-sex categories.

As in Canada, adjustments have been made to recent official population estimates on the basis of demographic analysis. For example, the 1986 post-enumeration estimates led to a sex ratio among children considered unacceptable in light of what was known of the sex ratio at birth and the sex differentials in the mobility and migration of the very young. As a result, the estimated number of males missed in the age group 0-4 was increased slightly toward the demographic estimate. For similar reasons, figures for other age groups were modified slightly, revising the number of young men and women in the light of sex ratios provided by demographic analysis. In 1991, a systematic evaluation of census undercount involved the post-enumeration survey, the demographic estimates described above and the sex ratios established by Medicare data. The Australians continue to have considerable confidence in the postcensal estimates of coverage, with certain adjustments made for specific age groups. In the final set of estimates for 1991 some weight was given to each data source, such that "none was allowed to override the others where adjusting might have led to unrealistic results" (McLennan, 1995:16). In summarizing the reliability of the post-enumeration study, Madden (1995:4) indicates that adjustments were made to the post-enumeration study estimates for males aged 60-64 years and for females aged 35-39, 40-44, 65-69 and 75 years and older.[31]

5. Discussion

The current age-sex distribution of net undercount obtained using the Reverse Record Check (RRC) is similar to results obtained in Britain and Australia, with particularly high levels of net undercount among young adults, and among young men in particular. In international comparisons, the American data were anomalous in that the level of undercount among young adults, as documented by both demographic analysis and the post-enumeration survey, was relatively low. Any number of factors might explain this discrepancy, including differences in census operations such as the manner in which information is gathered from households, the way in which lists are established, the specific imputation procedures involved in dealing with missing data, the relative level and nature of non-response experienced, the strategies taken in terms of reducing such non-response, correlation bias where similar persons are missed from both the PES and census, etc. Overall, international comparisons of census coverage are extremely complex because of all these possible sources of difference as well as others, including the size and living arrangements of families and households, the public relations of government statistical agencies, the level of public apathy or alienation, the general level of literacy in a population, etc.

31 Both Canada and Australia have adjusted their estimates of net undercount on the basis of demographic analysis. This differs from the practice in the United States, where such adjustments were not made despite some clear inconsistencies between the PES and demographic estimates for detailed age-sex-race groups.

As the RRC can be considered an independent re-enumeration of Canada's population[32], it is not likely to suffer from the problems experienced in Britain in 1991 due to the interdependence of the census and the subsequent re-enumeration, leading to persons missed in both operations. To the extent that the sampling frames of the RRC are complete and established independently of census procedures, a negligible number of persons should be missed by both the census and RRC. While the strengths of this methodology are obvious, less has been published evaluating the conceptual, theoretical and practical limitations to the RRC check method, for example, on the effects of difficulties in tracing and matching records or the effects of subsequent imputation procedures. In this context, U.S. research, developing a total-error model for their post-enumeration study, is particularly informative (Mulry and Spencer, 1993). The U.S. Bureau has devoted considerable resources to the systematic assessment of both sampling and non-sampling error in the post-enumeration study, nationally and for state populations.[33]

While the RRC is accepted as the most reliable and valid measure of net undercount in Canada, it has, however some limitations. The main source of error relates to the sampling error of the RRC methodology, which increases with the level of dissaggregation. Hence, one of the principal advantages of demographic analysis is its potential for providing more refined estimates of population by detailed age and sex categories. Such refinements have been the outcome of research carried out in all the countries whose programs have been reviewed, from the adjustments in Canada and Australia, for example, because of the unacceptable sex ratios for persons aged 0-4, to the decision of the British OPCS not to rebase their 1991 census on the basis of the census and post-enumeration evaluation. In the U.S., the outcome of demographic analysis was to provide a benchmark to judge the post-enumeration-study results in 1990. Recently, demographic analysis has been relied upon in evaluating the success of the U.S. 1995 census test in preparation for Census 2000 (Robinson, et al., 1996).

Canada and Australia differ from the U.S. and Britain in one important respect, the effect of international migration over the last several decades. Weaknesses in the measurement of international migration make it more difficult to apply the basic demographic method. As previously indicated, the consequence in both Canada and Australia is that estimates of net undercount using the basic demographic method are inadequate for older ages. Although estimates of international migration for any specific period may be reasonable, the effect of cumulative errors on estimates of the size of older age groups destroys their precision. On the other hand, while the United States does not have the same immigration levels, there are certain segments of the American population that are very difficult to enumerate, in particular the non-documented resident population. This is not an insignificant population and there is little reliable information on it, particularly with respect to its age-sex distribution. Britain, similar to

32 This statement should be qualified as an "independent re-enumeration" of the "current census", as obviously the RRC draws a large part of its sample from persons enumerated in the previous census.

33 The problems faced by the PES in the United States led to great efforts being devoted to biases stemming from tracing and non-sampling error. Problems such as movers, temporary residents, vacant dwellings, etc., are all significant. Since the Canadian RRC has individuals as the sampling unit, they are simply traced until a resolution can be made. However, there are biases in the RRC, and they are certainly concentrated in the untraced persons. At the same time, similar problems are found in the U.S. PES.

the U.S. in the proportion foreign-born, does not have the same problem with non-documented population, removing a major obstacle to demographic estimates.

There is a need for further research on the use of demographic techniques in Canada for the purpose of census evaluation. Concerning the suitability of administrative data for this purpose, further research is necessary as to their quality and how to use them for evaluation. As demonstrated in the U.S., it becomes particularly difficult to obtain reliable demographic estimates for older ages given the effect of cumulative error on the components of growth. As a result, the U.S. used adjusted Medicare files to evaluate the coverage of age groups 65 years and older. Further research on similar applications of administrative data in Canada appears advisable, particularly for older age groups. The question remains as to whether the necessary adjustments and imputations needed to work with these data sets can be justified in the Canadian context.

Certain recommendations put forward by Lapierre-Adamcyk (1970) over 25 years ago apply equally well today, as there is a need for further research into the quality of the data that enter into our demographic estimates, notably the accuracy of vital statistics on births and deaths and administrative data on international migration. This has long been a priority in the United States, where impressive research has been carried out. For example, Das Gupta's (1991) uncertainty model represents the application of considerable effort to evaluate the precision of demographic components over time. The question remains as to how applicable such research is in the Canadian context.

It is in this context that Dionne (1995) proposed the use of multidimensional models to estimate population and evaluate census coverage. By establishing a structure of intergenerational relations using primarily vital statistics, the goal is to obtain robust estimates of net undercount independently of the RRC. The extent to which such a procedure will be successful depends on the sensitivity of such models to data-quality problems. In working with imperfect data, the issue is whether reasonable estimates of net undercount can be obtained, how such estimates differ for different methodologies including different demographic methods, and the reasons for observed discrepancies. Research continues on these topics.

This review of the methods relied upon in other countries is far from comprehensive, as many countries in Western Europe have undertaken post-enumeration studies to evaluate their censuses. In a review of the methods used in Western Europe, Begeot et al. (1993) refer to census-coverage studies in Belgium, Greece, Spain, France, the Irish Republic, Italy, Luxemburg, Portugal, Austria, Norway, Sweden and Switzerland. Furthermore, outside Europe, New Zealand is planning to adjust its census count for net undercount in 1996. In these countries the most common procedure employed is the post-enumeration survey, while many Western European countries also have the advantage of systematic comparisons with population registers. Of the countries mentioned, only the Republic of Ireland relied exclusively on demographic methods, using postcensal estimates to assess census results.

6. Conclusion

Several procedures, developed by both demographers and statisticians, have historically played an important role in evaluating the coverage of census data. The purpose of the present report is to review such procedures in Canada, the United

States, the United Kingdom and Australia. Data-collection procedures were described briefly for each country, then micro-level procedures (record linkage and search) were outlined. Finally, demographic procedures, the focus of interest, were examined. The importance of demographic methods as opposed to other techniques varies from country to country, from near total reliance, as in the estimation of the 1991 population of Britain, to their use to evaluate and adjust in the case of Australia, the results obtained from micro-level procedures.

In conclusion, the author suggests that the following research be pursued in order to improve Statistics Canada's estimates of census coverage.

1) The available time series on births, immigration, emigration, returning Canadians, non-permanent residents, and deaths, should be more thoroughly evaluated, including a study of the completeness of birth and death registration.

2) The results obtained by the RRC and demographic techniques should be more systematically appraised and compared, including the inconsistencies disclosed using only demographic methods.

3) Further research is required on alternative demographic methods that might be relatively robust in the face of data quality problems (e.g., the intergenerational model).

4) The usefulness of additional sources of administrative data should be systematically examined, particularly for evaluating the coverage of older age groups (including such sources as Medicare files, tax files and social security);

5) The use of sex ratios should be more thoroughly explored, since they are a robust tool for the evaluation of census data.

6) Further research into potential problems with the Reverse Record Check should be undertaken, particularly with respect to non-sampling error and the possible use of sensitivity analysis to evaluate its effects.

7) An evaluation of census edit and imputation procedures should be undertaken to investigate possible resulting distortions in the age-sex distribution.

The importance of collaborative research on census coverage by both statisticians and demographers has been recognized in Canada, as elsewhere. Demographic methods can help evaluate the success of the RRC by providing an independent estimate of the population by age and sex. In general, the strength of demographic methods rests in the consistencies that they provide for specific cohorts from one census to the next, whereas the strength of the census figures adjusted by the coverage studies rest in totals, both nationally and for the provinces. Obtaining similar results from different methodologies adds to the credibility of our official estimates of population. Given the reasonable cost of demographic analysis, an integral element of Statistics Canada's population estimation program, further resources appear justified for the development or demographic indicators of census-coverage problems.

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