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PROBABILITY SAMPLE SELECTION METHOD IN HOUSEHOLD SURVEYS WHEN CURRENT DATA ON REGIONAL POPULATION IS UNAVAILABLE

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ABSTRACT

Availability of the perfect sampling frame only exists in developed countries, which covers a very small proportion of the world countries. On the other hand, in developing countries lists of the latest population census counts are generally used as the sampling frame for sample surveys. Therefore, in developing countries surveys which are planned for future periods long after the census date, cannot be representative of the related time period if the same census counts are utilized. Instead, population projections and data adjustment methodologies must be used to provide a representative probability selection of the updated population. This article proposes a population projection and adjustment methodology in order to establish the ideal selection probability for household surveys. The method contains the correction on the differences of the sum of strata and aggregated values. Comparative examples are also provided to clarify the proposed methodology.

Key words: data adjustment, household surveys, population projection, projection methodology, sample selection, selection probability.

1. Introduction

The techniques used to make population projections can be classified as trend extrapolation models or curve fitting techniques and cohort component projection models. These models are useful when we only need to project the total and domain populations. Therefore, they use total population figures from the past to project future population levels. Among the possible alternative curve fitting methods like *linear, geometric, exponential* and *logistic*, the most widely used model for populations is the exponential model.

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There are two types of population estimation techniques, namely intercensal estimate (*between two censuses*) and postcensal estimate (*immediate*). Intercensal estimates are known as *interpolation* and postcensal estimates are referred to as *extrapolation*. Estimates and projections can be on the basis of either *de jure* (usual resident) or *de facto* (physically present) enumeration basis for populations. In most cases, they are based on *de facto* population basis.

The paper concerns the problem of limited importance in developed countries where updates of household population projections are relatively frequent between censuses and the proposed method can be unnecessary. However, the problem can be relatively frequent and worth studying in countries with poor population statistics. Therefore, the goal of this paper is to provide a population projection method and adjustment procedures in order to determine representative probability sample selection for household surveys in countries where the updated sampling frame does not exist. On the other hand, it can also be a useful example of the solution of the problem of conducting surveys in case of lack of recent data on population (the number of households by regions).

The paper has a review of the currently known population projection techniques. An overview of the population projection techniques is illustrated in the following section. An exponential model and adjustment procedures for the population projections are also proposed. A case study illustrated details of the adjustment methodologies which are supported by numerical applications.

2. Overview of population projection techniques

The techniques used to make population projections can be classified under two categories: curve fitting or trend models and cohort component projection models.

Curve Fitting Models are useful when we only need to project the total population. Therefore, they use total population figures from the past to project future population levels.

Cohort Component Models are more data intensive because they disaggregate total population figures into age/gender *cohorts*. Further, the different *components* of population change (births, deaths and migration) are taken into account and past figures for these components are applied to the current age/sex cohorts. The cohort component method is grounded in the *basic demographic equation* because there are three ways that a population can change in size and composition: births, deaths, and migration. Basically, the *cohort component method* survives each age-sex population subgroup at a certain time 1 forward to time 2, adds in the new births and in-migrants, and subtracts out-migrants. Clearly, to obtain more precise and more detailed information about the current and future population, the inclusion of age in the projection techniques is a necessary addition.

Information on the cohort component method has been given here because the method is an alternative to the curve fitting or trend models. Due to available data requirements, the cohort-component method is not finally used in this study.

Several population projection techniques and computer programs are available for general purposes in the literature (Davis 1995; Lutz, Vaupel and Ahlburg 1998; Shorter, Sendek and Bayoumy 1995; Stover 1990; United Nations 1989; van Imhoff and Keilman 1991; van Imhoff 1994; Groenwold and Navaneetham 1998).

Among these, early books on population projection methods and models are covered by Cox 1976; Hinde 1997; Newell 1988; Pollard, Yusuf and Pollard 1974; Shryock, Siegel and associates, 1976. Recent books on population projections covers the classical methodologies (Preston, Heuveline and Guillot 2001; Bongaarts and Bulatao 2000).

Many research projects have also been completed on population projections by various researchers (Groenwold and Navaneetham 1998; Davis 1995; Lutz, Vaupel and Ahlburg 1998; State Institute of Statistics 1995; United Nations 1989 and 1990).

Computer package programs are also developed and widely used on the population projections and some selected examples are covered by Leete 1990; Shorter, Sendek and Bayoumy 1995; Stover 1990; Van Imhoff 1994.

Projections based on growth rates assume constant arithmetic, geometric, or exponential growth to estimate populations between dates or to project numbers for a few years ahead. However, as the constant growth rate is seldom case in real life, projections based on growth rates are either limited to short time spans, or the growth rates are varied from one interval to another (Alho and Spencer 2005; Groenewold and Navaneetham 1998; Hinde 1997; Rowland 2003). All of the trend extrapolation models can be used to prepare intercensal and postcensal estimates.

3. Exponential model for population projection

There are many different techniques for the population projections. Among these, we would like to illustrate the use of the exponential model for the population projections. For this methodology, it is essential to obtain and use annual population growth rates. In practice, the recent past population growth rates are determined from the two latest population censuses (if available) for the related domains. For simplicity, we can call these as *data source* (*k*) *and* (*k+1*). The previous annual population growth rates for the corresponding domains can be obtained by using the population counts of the available data sources. Using the same domain dimensions, the future projected population can be labelled as *data source* (*k+2*), for convenience. Generally, the related population domains (or strata) will correspond to the *segregated class boundaries* in survey sampling methodology. Figure 1 illustrates the relationship among domains.

<table>
<tr><td colspan="2">Data source (k):
Previous census</td><td rowspan="4"></td><td rowspan="5">r_h
$\Rightarrow$
r</td><td colspan="2">Data source (k+1):
Latest census</td><td rowspan="4"></td><td rowspan="5">$\hat{r}_h$
$\Rightarrow$
$\tilde{r}$</td><td colspan="2">Data source (k+2):
Planned survey</td><td colspan="2" rowspan="2">Adjusted by</td></tr>
<tr><td>$N_1^{(k)}$</td><td></td><td>$N_1^{(k+1)}$</td><td></td><td>$\hat{N}_1^{(k+2)}$</td><td></td></tr>
<tr><td></td><td>$N_h^{(k)}$</td><td></td><td>$N_h^{(k+1)}$</td><td></td><td>$\hat{N}_h^{(k+2)}$</td><td rowspan="2">W_h</td><td rowspan="2">δ_h</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Total</td><td>$N^{(k)}$</td><td colspan="2">Total</td><td>$N^{(k+1)}$</td><td colspan="2">Total</td><td>$\hat{N}^{(k+2)}$</td><td>$\tilde{N}^{(k+2)}$</td></tr>
</table>

Figure 1. Graphical illustration of data sources and population structures.

The population domains are evaluated as statistical regions which are based on EUROSTAT's "*Nomenclature of Statistical Territorial Units*" (*NUTS*) classification. The overall population size (N) is equal to the sum of domain populations.

$$\sum_{h=1}^{H} N_h^{(k)} = N^{(k)} \quad \text{and} \quad \sum_{h=1}^{H} N_h^{(k+1)} = N^{(k+1)}$$

The following form of the exponential growth model is used for population projection of domains. For some designs, population domains may correspond to population strata.

$$N_h^{(k+1)} = N_h^{(k)} \; e^{r_h^{(k,\,k+1)} \; t_h^{(k,\,k+1)}} \quad \text{and}$$

$$\frac{N_h^{(k+1)}}{N_h^{(k)}} = \exp\left[r_h^{(k,\,k+1)} \; t_h^{(k,\,k+1)} \right]$$

The estimated annual growth rate of past population can be obtained by

$$r_h^{(k,\,k+1)} = \ln\left[\frac{N_h^{(k+1)}}{N_h^{(k)}} \right] \Big/ t_h^{(k,\,k+1)}$$

Several alternative scenarios can also be used for determining the future growth rate of the population. Unless there is no special reason (like *migration* or *mortality*) of population change for the future period, the past annual growth rate of the population may also be used as a future population growth rate. That is,

$$r_h^{(k,\,k+1)} \Rightarrow \quad \hat{r}_h^{(k+1,\,k+2)}$$

Taking the future domain growth rate as $\hat{r}_h^{(k+1,k+2)}$, the future population growth of the domains can be projected by the use of the following model. The total population projection can be obtained as:

$$\hat{N}_h^{(k+2)} = N_h^{(k+1)} \exp\left[\, \hat{r}_h^{(k+1,\,k+2)}\; t_h^{(k+1,\,k+2)} \right]$$

$$\text{and finally} \;\; \sum_{h=1}^{H} \hat{N}_h^{(k+2)} = \hat{N}^{(k+2)} .$$

4. Proposed population adjustment methodology

Total population refers to the household population (*members of household*), institutional population (*armed forces, dormitory, hospital, prison, etc.*) and mobile population (*homeless, nomadic tribes, etc*). For a representative household based sample survey, the target population is considered to be equal to the household population.

When the information is available on the amount of institutional population [$N_h^{(INS)}$] and mobile population [$N_h^{(MOB)}$], these amounts has to be subtracted from the adjusted total population [$\tilde{N}_h^{(k+2)}$] in order to obtain the household population [$\hat{N}_h^{(HH)}$] for each domain (Ayhan and Ekni 2003). This simple relation is given below:

$$\hat{N}_h^{(HH)} = \tilde{N}_h^{(k+2)} - \left[N_h^{(INS)} + N_h^{(MOB)} \right]$$

Ayhan and Ekni (2003) also provided real numerical count data on the “institutional population” which was based on 5 regional estimates of the 1990 General Population Census of Turkey.

If these information is available, then it has to be used, otherwise the component can be neglected and taken as zero for practical purposes. Recent developments towards the collection, release and use of special information created some drawbacks. Nowadays, there may also be some political and/or strategic reasons for not stating/releasing some of the institutional population information components for small domains. Under such circumstances, the *de jure* based household population enumeration may not be possible.

For the illustration of the proposed methodology, the information provided for the *data sources* (*k*) and (*k+1*) corresponds to the two previous population census results of the related domains. Therefore, domain totals and overall total information will be identical. On the other hand, information which is based on population projections for *data source* (*k+2*), will not have the same desired properties. In other words, the sum of domains will be equal to the existing domain total, but this will not be equal to the total projection estimate of the overall population.

In order to balance the relationship between the domain totals and the overall total, an adjustment is required. This can be called as the *total population projection adjustment*. This adjustment will correct the difference between the *sum of the projected domain populations* and *total population projections*.

The sum of domain populations will be equal to the existing domain total of $\sum_{h=1}^{H} \hat{N}_h^{(k+2)} = \hat{N}^{(k+2)}$. But this will not be equal to the total projection estimate of the overall population. That is,

$$\sum_{h=1}^{H} \hat{N}_h^{(k+2)} = \hat{N}^{(k+2)} \neq \tilde{N}^{(k+2)} = \mathrm{N}^{(k+1)} \exp\left[\mathrm{r}^{(k+1,\, k+2)}\, t^{(k+1,\, k+2)}\right]$$

assuming that, $r^{(k,\, k+1)} \Rightarrow \tilde{r}^{(k+1,\, k+2)}$ as before.

In order to balance the relationship between the domain totals and the overall total, an adjustment is required. This can be called as the "total population projection adjustment". This adjustment will correct the difference between the "sum of the projected domain populations" and "total population projections". That is, $\hat{N}^{(k+2)} \Rightarrow \tilde{N}^{(k+2)}$.

Let us show the difference between the above total projections as:

$$\Delta = \tilde{N}^{(k+2)} - \hat{N}^{(k+2)} \quad \text{where} \quad \hat{N}^{(k+2)} = \sum_{h=1}^{H} \hat{N}_h^{(k+2)}$$

$$\delta_h = \left(\frac{\hat{N}_h^{(k+2)}}{\hat{N}^{(k+2)}} \right) \Delta = W_h\, \Delta \quad \text{where} \quad W_h = \hat{N}_h^{(k+2)} \Big/ \hat{N}^{(k+2)}$$

$$\tilde{N}_h^{(k+2)} = \hat{N}_h^{(k+2)} + \delta_h$$

Then, the sum of the adjusted projection totals for domains will be equal to

$$\sum_{h=1}^{H} \tilde{N}_h^{(k+2)} = \tilde{N}^{(k+2)}.$$

5. A case study

The latest Population Census of Turkey (October 2000) is used as a reference time location of population projections for an intended sample survey which is planned for October 2012.

The sample design which is based on the Classification of Statistical Regions NUTS1–Level refers to 12 regions of Turkey and is taken as the "reporting domains" in the survey literature. The regions are not planned to represent any geographical or socio-economical breakdown of the country, in this case. The population projections for the year 2012 are achieved on the basis of the information provided from two previous population censuses of Turkey, which is given in Table 1.

Table 1. Recent population censuses of Turkey and population projections for domains

Domains *h*	Previous population census *October 1990* $N_h^{(k)}$	Latest population census *October 2000* $N_h^{(k+1)}$	Annual growth rate of population *2000-2012* $\hat{r}_h^{(k+1,\,k+2)}$	Projected population for planned survey *October 2012* $\hat{N}_h^{(k+2)}$	Domain weights of projected population for 2012 W_h	Amount of population adjustments for domains δ_h	Adjusted projection for planned survey *October 2012* $\tilde{N}_h^{(k+2)}$
1	7195773	10018735	0.0330963	14903745	0.174663	- 155094	14748651
2	2589490	2895980	0.0111863	3312021	0.038815	- 34466	3277555
3	7594977	8938781	0.0162912	10868772	0.127376	- 113104	10755668
4	4688514	5741241	0.020256	7321001	0.085798	- 76184,9	7244816
5	5204217	6443236	0.0213562	8325348	0.097568	- 86636,5	8238712
6	7026489	8706005	0.0214326	11259408	0.131954	- 117169	11142239
7	3818444	4189268	0.0092683	4682095	0.054871	- 48723,5	4633371

Table 1. Recent population censuses of Turkey and population projections for domains (cont.)

Domains h	Previous population census *October 1990* $N_h^{(k)}$	Latest population census *October 2000* $N_h^{(k+1)}$	Annual growth rate of population *2000-2012* $\hat{r}_h^{(k+1,\,k+2)}$	Projected population for planned survey *October 2012* $\hat{N}_h^{(k+2)}$	Domain weights of projected population for 2012 W_h	Amount of population adjustments for domains δ_h	Adjusted projection for planned survey *October 2012* $\tilde{N}_h^{(k+2)}$
8	4889323	4895744	0.0001312	4903460	0.057466	- 51027,1	4852433
9	2852806	3131546	0.0093224	3502214	0.041044	- 36445,3	3465769
10	2354030	2507738	0.0063252	2705493	0.031707	- 28154,3	2677338
11	3101812	3727034	0.0183626	4645803	0.054446	- 48345,8	4597457
12	5157160	6608619	0.0247989	8899198	0.104293	- 92608,1	8806589
Total	**56473035**	**67803927**	**0.0182857**	**85328559** **84440600**	**1.010516**	**- 887959**	**84440600**

Source: Partly based on T.S.I. (2003).

The difference between the *overall total projection* and the *sum of the domain projections* simply arises from the fact that in (*k+1*) the fast growing components (*h*) have become bigger than they were in (*k*); hence, assuming (r_h) values to be constant from (*k+1*) to (*k+2*) will always give larger sum of the domain projections compared to assuming (*r*) to be constant (which gives overall total projection). This mathematical necessity hardly needs numerical illustration of this type, unless the discrepancy is analysed e.g. as a function of the variation in r_h (if r_h = constant = r, then the two total projections will be identical).

5.1. Comparison of overall selection probabilities for households

Overall selection probabilities for households can be determined from the household based information of the population information for each domain. This information can be obtained by dividing the total population of each domain by the corresponding average household size for this domain.

Here $\frac{\hat{N}_h^{(k+2)}}{\overline{H}_h} = \hat{M}_h \quad \forall h$ where average household size is $\overline{H}_h = S^{-1}\sum_{i=1}^{S}\overline{H}_{hi}$ where S is the number of subdomains. The overall selection probability of the domains will be equal to the overall sampling fractions. That is

$$Pr\left(F_h^{(DU)}\right)^{-1} = f_h^{(DU)} = \frac{m_h}{\hat{M}_h} \quad \forall h$$

Overall sample selection probabilities for households can be determined by obtaining household based information from the population information for each domain. This information can be obtained by dividing the total population of each domain by the corresponding average household size for this domain, which is given in Table 2. The overall selection probability of the domains will be equal to the overall sampling fractions. In this study, overall selection probabilities are compared for projected and non-projected populations. The results have indicated under-representation in the probabilities of selection for non-projected populations, and consequently the selected sample estimates will also be biased.

Table 2. Comparative estimates of several population sizes

Domains H	Latest census population 2000 $N_h^{(k+1)}$	Household survey population 2012 $\hat{N}_h^{(k+2)}$	Average size of households $\overline{H}_h$	No. of Population households 2012 $\hat{M}_h$
1	10018735	14903745	3.85	3871103
2	2895980	3312021	3.56	930343
3	8938781	10868772	3.81	2852696
4	5741241	7321001	4.03	1816626
5	6443236	8325348	4.17	1996486
6	8706005	11259408	4.60	2447697
7	4189268	4682095	4.97	942071
8	4895744	4903460	4.78	1025828
9	3131546	3502214	5.11	685365
10	2507738	2705493	6.01	450165
11	3727034	4645803	6.44	721398
12	6608619	8899198	6.55	1358656
Total	**67803927**	**85328559**	**4.50**	**18961902**

When information for institutional population and mobile populations are not available, then unfortunately the projected total survey population and household survey population has to be taken as equal. That is,

$$\hat{N}_h^{(k+2)} = \tilde{N}_h^{(k+2)} - \left[N_h^{(INS)} + N_h^{(MOB)} \right] = \tilde{N}_h^{(k+2)} - 0 = \hat{N}_h^{(k+2)}$$

Computed sample sizes of domains for fixed sampling fractions are given in Table 3.

Table 3. Computed sample size of domains for a fixed sampling fraction of $f_h = 0.001$

Domains h	Sample size based on latest census of 2000 $n_h^{(k+1)}$	Sample size of household survey population for 2012 $n_h^{(k+2)}$	Sample size of households for 2012 m_h
1	10019	14904	3871
2	2896	3312	930
3	8939	10869	2853
4	5741	7321	1817
5	6443	8325	1996
6	8706	11259	2448
7	4189	4682	942
8	4896	4903	1026
9	3132	3502	685
10	2508	2704	450
11	3727	4646	721
12	6609	8899	1359
Total	**67805**	**85329**	**18962**

5.2. Alternative sampling fractions

A. For a fixed overall sampling fraction

(1). Based on the population from the latest (2000) population census results.

$$f_h^{(k+1)} = \frac{n_h^{(k+1)}}{N_h^{(k+1)}} = \frac{1}{F_h^{(k+1)}} \quad \text{and} \quad f^{(k+1)} = \frac{67805}{67803927} = \frac{1}{1000} = 0.001$$

(2). Based on the population from the adjusted population projection (2012) results.

$$f_h^{(k+2)} = \frac{n_h^{(k+2)}}{\hat{N}_h^{(k+2)}} = \frac{1}{F_h^{(k+2)}} \quad \text{and similarly}$$

$$f^{(k+2)} = \frac{85329}{85328559} = \frac{1}{1000} = 0.001$$

When there are no values for institutional and mobile population, the resulting values will be the same estimates for all strata.

(3). Based on the number of dwelling units (or households) from the estimated household population (2012) results.

$$f_h^{(DU)} = \frac{m_h}{\hat{M}_h} = \frac{1}{F_h^{(DU)}} \quad \text{and} \quad f^{(DU)} = \frac{18962}{18961902} = \frac{1}{1000} = 0.001$$

The *gain* and *relative gain* from alternative sample sizes can be examined by using the following formulation.

The gain in sample size:

$$G(n) = \frac{n^{(k+1)}}{n^{(k+2)}} = \frac{67805}{85329} = 0.795$$

The relative gain in sample size:

$$RG(n) = \left[n^{(k+2)} - n^{(k+1)} \right] / n^{(k+2)} = [85329 - 67805] \,/\, 85329$$
$$= \frac{17542}{85329} = 0.205$$

This reflects 20.5% under-representation of sample selection probability over the twelve year period. As an alternative, it is possible to compare alternative selection probabilities for the case of a fixed sample size.

All this merely says that if a sample is selected (only) from past lists of elementary units, a nominal (f) would give smaller (n) or to get a given (n) would need larger (f) – compared to if the same procedure were applied to updated lists. The elaborated and often repeated computations add little to this basic point. Projected population (if accurate) tells us by how much:

$$\frac{n_1}{n_2} = \frac{f_2}{f_1} = \frac{N^{(k+1)}}{N^{(k+2)}} \,.$$

B. For a fixed sample size

(1). Fixed sample size is used from the latest (2000) population census results.

$n_h^{(k+1)} = f_h^{(k+1)} N_h^{(k+1)}$ and $n^{(k+1)} = f^{(k+1)} N^{(k+1)}$ = (0.001) (67803927) = 67805

For this case, the same fixed sample size $n^{(k+1)}$ = 67805 is used in future sample selections. The *gain* and *relative gain* from fixed sample sizes can be examined by using the following relation. The gain in sampling fraction is:

$$G(f)=\frac{f^{(k+1)}}{f^{(k+2)}}=\frac{0.001}{0.000795}=1.2579$$

The relative gain in sampling fraction is $RG(f)=\left[\ f^{(HH)}-f^{(k+1)}\right]/f^{(HH)}$

$$RG(f)=[0.000795-0.001]\ /\ 0.000795=\frac{0.000205}{0.000795}=\frac{1}{3.878}=0.2579$$

where $f^{(k+1)}=\frac{n_h^{(k+1)}}{N_h^{(k+1)}}=\frac{67805}{67803927}=\frac{1}{1000}=0.001$

$$f^{(HH)}=\frac{n_h^{(k+1)}}{\hat{N}_h^{(k+2)}}=\frac{67\,805}{85328559}=\frac{1}{1258}=0.000795$$

(2). Expansion factor can also be used for comparison.

The relative gain in expansion factors;

$$RG(F)=\left[\ F^{(k+2)}-F^{(k+1)}\right]/F^{(k+2)}$$

$$RG(F)=[1258-1000]\ /\ 1258=0.205$$

Again, the comparison reflects 20.5% under-representation for sample selection probability over the specified period.

6. Conclusions

This study reflected the results of the importance of the updated population counts as the basis for representative sample selection. The earlier computations based on census data reflects the population under-coverage error when compared to results which are based on latest adjusted methodologies. Comparison of relative gains can be interpreted differently for a fixed sample size and for a fixed sampling fraction. In both cases, the latest and more refined information provides better representation of the population coverage.

Rather than using updated population projections, the use of the latest population counts are very common in developing countries. These figures are creating under-coverage error and serious bias for population representation.

Sample allocation into sub-domains can also be made by taking the urban/rural proportions of the latest population census as weights for the proportional allocation within the stated domains (*population size of 20000 was taken as boundary value for urban/rural domains*). For the sample design there may be other requests to have independent urban and rural domains for inference objectives. In this case, separate population projections have to base on urban and rural breakdowns. In addition, sample allocations in sub-domains will also be taking care of the "size groups of settlements".

The findings from comparative results of the case study indicated that for a fixed overall sampling fraction the gain in sample size was 0.795, and the relative gain in sample size reflects 20.5% under-representative sample selection probability over the twelve-year period. The gain and the relative gain in sampling fraction are found to be 0.2579. On the other hand, the gain due to the comparison of the expansion factors was 0.205. These results clearly show that the use of new probabilities (*latest overall sampling fractions*) will reflect better representation of the population when compared to old selection probabilities.

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