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MULTILEVEL MODELING USING DHS SURVEYS: A FRAMEWORK TO APPROXIMATE LEVEL-WEIGHTS

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Multilevel Modeling Using DHS Surveys: A Framework to Approximate Level-Weights

Mahmoud Elkasabi
Ruilin Ren
Thomas W. Pullum

ICF
Rockville, Maryland, USA

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Corresponding author: Mahmoud Elkasabi, International Health and Development, ICF, 530 Gaither Road, Suite 500, Rockville, MD 20850, USA; telephone: +1 301-572-0950; fax: +1 301-572-0999; email: mahmoud.elkasabi@icf.com

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PREFACE

The Demographic and Health Surveys (DHS) Program is one of the principal sources of international data on fertility, family planning, maternal and child health, nutrition, mortality, environmental health, HIV/AIDS, malaria, and provision of health services.

One of the objectives of The DHS Program is to continually assess and improve the methodology and procedures used to carry out national-level surveys as well as to offer additional tools for analysis. Improvements in methods used will enhance the accuracy and depth of information collected by The DHS Program and be relied on by policymakers and program managers in low- and middle-income countries.

While data quality is a main topic of the DHS Methodological Reports series, the reports also examine issues of sampling, questionnaire comparability, survey procedures, and methodological approaches. The topics explored in this series are selected by The DHS Program in consultation with the U.S. Agency for International Development.

It is hoped that the DHS Methodological Reports will be useful to researchers, policymakers, and survey specialists, particularly those engaged in work in low- and middle-income countries, and will be used to enhance the quality and analysis of survey data.

Sunita Kishor
Director, The DHS Program

ABSTRACT

This report responds to the demand from The Demographic and Health Surveys (DHS) Program data users for sampling weights that correspond to each stage of sampling in DHS surveys. Such weights, described as level-weights, are required for multilevel modeling with data from complex surveys that involve multistage sampling, unequal sampling probabilities, and stratification. Like most survey datasets available for public use, level-weights are not included in DHS data because of concerns about disclosure risk. This report develops and illustrates a framework for estimating or approximating level-weights in DHS surveys. The proposed framework requires data that is included in the publicly available DHS datasets and final reports. The same framework can be used to approximate level-weights for other household surveys, such as the Malaria Indicator Surveys (MIS) and the Multiple Indicator Cluster Surveys (MICS).

1 BACKGROUND

The DHS surveys typically employ two-stage sampling designs. Primary sampling units (PSUs) or clusters are sampled in the first stage, and households in the second stage. A household respondent is interviewed first to obtain a household roster and information about the household as a unit. Eligible women and (usually) men are then interviewed. This design results in a multilevel dataset, with households, women, or men at level-1 and PSUs at level-2.

Multilevel models have been applied extensively to DHS data to study the effects of cluster-level variables on individual-level outcomes. DHS data users have used multilevel modeling to explore the effects of community characteristics on contraceptive use, breastfeeding, the nutritional status for under-5 children, and many other topics (Kasaye et al. 2019; Ogbo et al. 2018; Simiat 2018).

Rabe-Hesketh and Skrondal (2006) and Carle (2009) have proposed a pseudo-maximum-likelihood (PML) estimation approach in the context of generalized linear mixed models (GLMM) that requires a sampling weight for each level (a PSU-level, or level-2, weight and a household-level, or level-1, weight) and not simply the final survey weight, which is essentially the product of the two level-weights. The final weights for households, women, and men are sufficient for most analytical purposes, but not for multilevel modeling.

A major practical obstacle in applying multilevel modeling with DHS datasets and many other surveys is that sampling weights that correspond to the levels of the two-stage sampling design are not provided in the DHS datasets. Providing the exact cluster-level weight creates a risk in which someone with access to the sampling frame could identify specific clusters, specific households, or specific individuals within the clusters. To avoid disclosing the identity of any survey participant or the location of any sample cluster, only final survey weights are released in the public use datasets.

This report will outline a framework to approximate the sampling weights for the different levels by using publicly available data in the DHS datasets or final reports. Section 2 will briefly describe the sampling design of standard DHS surveys, outline the sampling parameters and information provided in the DHS datasets and final reports, and discuss confidentiality concerns. Section 3 describes the current procedures for calculating weights. Section 4 develops the framework for approximating the sampling weights at different design/data levels for DHS samples of households and women. Section 5 illustrates the framework with the Zimbabwe DHS 2015. We close the report with a discussion in Section 6.

2 SAMPLING DESIGN AND CONFIDENTIALITY

2.1 Sampling design

Most DHS surveys follow a two-stage stratified sampling design, where PSUs, also referred to as clusters, are selected in the first stage following a probability proportional to size (PPS) selection. In the second stage, residential households are selected with equal probability from an updated household listing of each selected PSU. The DHS samples are typically stratified by regions and urban/rural residence. In the first stage of sampling, PSUs are selected according to the allocation of the PSU sample over the sample strata. After the selection of the PSUs, a household listing operation is conducted in every selected PSU and a complete list of households is constructed. In the second stage, a fixed number of households is selected from each cluster. From the selected households, all women age 15–49 who slept in the household the night before the survey are eligible to complete a questionnaire designed for women. In addition, in all households or in a subsample, men of reproductive age (typically age 15–49, 15–54, or 15–59) are eligible to complete a questionnaire designed for men if a men's questionnaire was included in the design.

In most DHS surveys, a recent population census frame with enumeration areas (EAs) is used as a sampling frame for the first-stage selection. The EAs are selected as PSUs or clusters. An EA is a geographical area that serves as a counting unit for the population census, and is usually a city block in urban areas or a village in rural areas with 200-300 households. The census frame includes information about each EA that includes identification information and a measure of size (number of residential households enumerated in the last population census). Cartographic materials that delimit the location and boundaries of the EAs are also available.

2.2 Sampling parameters in DHS data files and final reports

The data collected in DHS surveys are made available for data users in many formats, such as SPSS, SAS, and Stata. In addition to the health and demographic data collected in interviews, some important sampling information is included in the final dataset. The standard sampling data included in the DHS recode data files include:

- Cluster (HV001/V001/MV001)
- Stratum (HV022/V022/MV022 or HV023/V023/MV023)
- Sampling weight (HV005/HV028/V005/D005/MV005/HIV05)
- Survey domain (HV024/V024/MV024 and HV025/V025/MV025)

Detailed information on the sample design is provided in the survey final report. The appendix of the survey sampling design, typically Appendix A, provides summary tables from the sampling frame, the sample design, and the sample allocation. The sampling design appendix contains tables that describe:

- Distribution of residential households by region and type of residence (urban/rural) according to the census frame

- Distribution of EAs and their average size in the number of households, by region and type of residence, according to the census frame

- Sample allocation of selected EAs and households by region and type of residence

2.3 Confidentiality

Confidentiality is a major concern because all data collected in DHS surveys are available to users. To protect survey participants' identity and privacy, the released data should not allow for potential identification of any household or individual in the data file. In DHS surveys, strict rules are imposed at various steps during survey implementation to prevent the direct or indirect disclosure of the identity of individual respondents, their households, or clusters. Cluster ID codes are scrambled and geographic information system (GIS) information is geo-masked with displacement to prevent potential disclosure. All information that could identify a cluster, household, or individual is omitted from the data file. This includes the cluster's selection probability. The sampling variables released in the data file are sufficient to describe the data structure and allow users to uniquely identify the clusters and households for data analysis, data management, or tabulation purposes, but are not sufficient to disclose the location or identity of any cluster, household, or individual.

The DHS final data files should identify the true sampling strata, which is important for the sampling error calculation in many statistical analyses. However, if a stratum is small and has only a few clusters selected, confidentiality constraints may not permit inclusion of the true sampling stratum identifier. In such cases, a higher-level stratification identifier is included. This alternative should be close to the true stratification and not have a substantial effect on calculation of standard errors.

Since the final survey weights are sufficient for most data analysis purposes, DHS releases these weights but not the selection probabilities for the sampling units at different stages, the design weight (the inverse of the overall selection probabilities), the intermediate weights (design weights adjusted for non-response), or any of the adjustment factors used to calculate the final survey weights. The omitted information could potentially be used to identify a cluster or a household, especially by someone with access to the population census records. The final survey weights are not informative, in this sense, especially after correction for non-response and normalization.

3 WEIGHTING PROCEDURES IN DHS SURVEYS

To ensure that statistical estimates based on DHS data are valid, sampling weights should be used in the analysis. These weights compensate for different probabilities of selection within the samples, and different levels of non-response. By including the survey weights in the analysis, each interviewed unit becomes representative of similar units in the target population. This section presents the different weights calculated for DHS surveys, and the steps for calculating each weight. We focus on the household weight and the woman's weight because the other weights can be calculated with similar steps.

3.1 Calculating the design weight

The calculation of survey weights in DHS surveys begins with calculating the design weight, which accounts for the selection probabilities of the sampling units at different sampling stages. The design weights are then adjusted for non-response at the levels of the cluster, household, or individual to calculate the final survey weights for households (HV005), women (V005), and men (MV005).

If the sample is selected with the standard two-stage stratified cluster sampling design described above, the calculation of design weights is based on the separate sampling probabilities for each stage. The sampling probabilities for the two stages are:

- P_{1hi}: first-stage or cluster sampling probability of cluster *i* in stratum *h*
- P_{2hij}: second-stage or household sampling probability for household *j* within cluster *i* in stratum *h*

Since the sample clusters are selected with probability proportional to size (PPS), the first-stage sampling probability P_{1hi} can be calculated as:

$$P_{1hi} = \frac{a_h M_{hi}}{M_h} \tag{1}$$

where a_h denotes the number of clusters selected in stratum *h*; M_{hi} denotes the measure of size of the cluster *i* used in the first stage selection (in a typical DHS survey, this is the number of households in the cluster based on the census frame); and M_h denotes the total measure of size in stratum *h*. If there is no cluster-level non-response, the inverse of the first-stage sampling probability P_{1hi} is the *cluster weight* ***(Level-2 weight)*** and can be written as:

$$w_2 = w_{2hi} = \frac{1}{P_{1hi}} \tag{2}$$

In the second stage, a sample of households is selected with equal probability systematic sampling within each cluster *i*, and the second-stage sampling probability P_{2hi} for any household *j* can be calculated as:

$$P_{2hij} = \frac{s_{hi}}{L_{hi}} \tag{3}$$

where L_{hi} denotes the number of households listed in the household listing operation in cluster *i* in stratum *h*, and s_{hi} denotes the number of households selected in the same cluster. In cases where a large EA *i* was grouped into segments (clusters), and only one segment was PPS-selected and listed, P_{2hi} should be calculated as follows:

$$P_{2hij} = b_{hi}\frac{s_{hi}}{L_{hi}} \quad (4)$$

where b_{hi} is the proportion of households in the selected segment compared to the total number of households in EA i. The household design weight is then calculated as the inverse of the overall selection probability (product of the two selection probabilities of the two stage) as follows:

$$d_{hij} = \frac{1}{P_{1hi}P_{2hij}} \quad (5)$$

The household design weight is a cluster-level weight in the sense that all interviewed households from the same cluster share the same weight.

3.2 Correction for non-response

One of the critical functions of survey weights is to adjust for unit non-response among the sampled units if they could not be accessed/contacted or did not cooperate, and thus did not complete the survey. Such non-response might happen for sampled clusters, households, or individuals. Unfortunately, non-response in some or all of these levels is inevitable in almost all surveys. Therefore, the design weight calculated in the first step should be adjusted for non-response so that responding units represent all selected units. The purpose of the non-response adjustment is to inflate the design weights for the completed units to compensate for the non-completed units. Such inflation can be done with several methods. The DHS Program uses the *Weighting Class Adjustment* method, in which homogeneous response groups are formed, and a response rate is calculated within each group and used to inflate the design weight. Since sampling strata are created to be homogenous with respect to the survey variables, DHS uses the sampling strata as response groups. Within each sampling stratum, a weighted response rate is calculated, and the inverse of this rate is multiplied by the design weight to produce a survey weight that is adjusted for non-response within that stratum (Kott 2012).

The adjustment for non-response begins by adjusting for any non-response at the level of the sampling cluster. Let a_h^c be the number of clusters completed in stratum h. DHS surveys use a simple response rate to correct for cluster-level non-response:

$$RR_h^{CL} = a_h^c/a_h \quad (6)$$

For the completed clusters, the non-response-adjusted design weight for cluster i in stratum h can be computed as:

$$d_{hi}^{CL} = d_{hi}/RR_h^{CL} \quad (7)$$

The adjusted design weight can then be adjusted for household non-response. Let $R_j = 1$ if household j was completed and $R_j = 0$ otherwise. Within each stratum h, the household weighted response rate is calculated as:

$$RR_h^{HH} = \sum_{j \in h} R_j d_j^{CL} \Big/ \sum_{j \in h} d_j^{CL} \tag{8}$$

where d_j^{CL} is the adjusted design weight of household j as calculated in (7). For the completed households in cluster i, the non-response-adjusted household weight is computed as:

$$d_{hi}^{HH} = d_{hi}^{CL} / RR_h^{HH} \tag{9}$$

This weight can be used as a survey weight for completed households, where the conditional **Level-1** weight that accounts for the selection and non-response of households is calculated as:

$$w_{1|2}^{HH} = w_{1hi}^{HH} = \frac{d_{hij}^{HH}}{w_{2hi}} \tag{10}$$

where w_{2hi} is the level-2 weight defined in (2).

However, according to the DHS standard approach, a normalized version of d_{hij}^{HH} is released instead. The normalized weight is calculated by multiplying the sampling weight by a constant at the national level. This constant, or the normalization factor, is the estimated household-level total sampling fraction, or the total number of completed households divided by the total weighted number of completed households, or the summation of the weights over all completed households. Therefore, the household survey weight (HV005) for all households in cluster i can be calculated as:

$$HV005_{hi} = d_{hi}^{HH} \frac{m^c}{\sum_h \sum_{j \in h} d_j^{HH}} \tag{11}$$

where m^c is the total number of completed households in the survey and d_j^{HH} is the cluster-level non-response-adjusted household weight d_{hi}^{HH} defined in (9).

To calculate the individual weight for a woman age 15-49, the denormalized household weight d_{hi}^{HH} should be adjusted for individual-level non-response. Let Rk = 1 if individual k completed the survey, and Rk = 0 otherwise. Within each stratum h, the individual weighted response rate is calculated as:

$$RR_h^{WM} = \sum_{k \in h} R_k d_k^{HH} \Big/ \sum_{k \in h} d_k^{HH} \tag{12}$$

where d_k^{HH} is the adjusted design weight of individual k as calculated in (9). For the responding individuals in cluster i, the non-response-adjusted design weight is computed as:

$$d_{hi}^{WM} = d_{hi}^{HH} / RR_h^{WM} \tag{13}$$

The normalized version of the woman weight (V005) for all women in cluster i can then be calculated as:

$$V005_{hi} = d_{hi}^{WM} \frac{n^c}{\sum_h \sum_{k \in h} d_k^{WM}} \tag{14}$$

where n^c is the total number of completed interviews with women age 15-49 in the survey, and d_k^{WM} is the cluster-level non-response-adjusted design weight d_{hi}^{WM} defined in (13). Note that the de-normalized weight d_{hi}^{WM} can be used to calculate the conditional **Level-1** weight that accounts for the selection and non-response of households and non-response of individuals:

$$w_{1|2}^{WM} = w_{1hi}^{WM} = \frac{d_{hi}^{WM}}{w_{2hi}} \tag{15}$$

3.3 Other DHS weights

The survey weights for households selected for the men's survey and for men can be calculated with the same approach described above. If men are only interviewed in a subsample of households, the overall selection probability must be adjusted to account for the subsample selection.

There are other special weights for the domestic violence module (D005) and HIV testing module (HIV05). In the domestic violence module, only one eligible woman is randomly selected from each sampled household to complete the domestic violence questionnaire. To account for the within-household selection and for the non-response for the module, the design weight must be adjusted to take into consideration the within-household selection probability and the response rates for the domestic violence module. For the HIV weight, the design weight must be adjusted for non-response for the HIV test. The sampling weights for HIV testing are calculated separately for women and men, but follow the same methodology. The standard weight for HIV testing is normalized for women and men together. More details about the calculation of weights for domestic violence and HIV can be found in the DHS Sampling and Household Listing Manual (ICF International 2012).

4 LEVEL-1 AND LEVEL-2 WEIGHTS

4.1 Steps to calculate level-1 and level-2 weights

If all information described in Section 3 is available, the calculation of separate level-1 and level-2 weights is straightforward. Table 1 describes the calculation of separate weights for households (as level-1) and clusters (as level-2) using the survey weight HV005 and a minimal amount of additional information about cluster i in stratum h. The same steps can be used to calculate the separate weights for women (as level-1) and clusters (as level-2) using V005 and minimal additional information.

Table 1 Steps to calculate level-1 and level-2 weights from the DHS household survey weight (HV005)

Steps	Formula	Requirements	Accessible/ Available	Where
1. De-normalize the final survey weight	$d_{hi}^{HH} = HV005_{hi} \frac{\sum_h \sum_{j \in h} d_j^{HH}}{m^c}$	$HV005_{hi}$	Yes	Public-use datasets
		$\sum_h \sum_{j \in h} d_j^{HH}$	No	
		m^c	Yes	Public-use datasets
2. Calculate the level-2 weight	$w_{2hi}^{HH} = \frac{1}{P_{1hi}} = \frac{M_h}{a_h M_{hi}}$	a_h	Yes	Appendix A
		M_h	Yes	Appendix A
		M_{hi}	No	
3. Calculate the level-1 weight	$w_{1hi}^{HH} = \frac{d_{hi}^{HH}}{w_{2hi}}$	d_{hi}^{HH}	Yes	Step 1
		w_{2hi}^{HH}	Yes	Step 2

Unfortunately, as indicated in Table 1, some required information is not available through the DHS public use data/materials, such as the cluster measure of size M_{hi} and the estimated total number of households, $\sum_h \sum_{j \in h} d_j^{HH}$, for the household weight (HV005), or the estimated total number of women 15-49, $\sum_h \sum_{k \in h} d_k^{WM}$, for the woman weight (V005).

4.2 Steps to approximate level-1 and level-2 weights

This section presents steps to approximate level-1 and level-2 weights from the final survey weights with information available from DHS. We approximate the level-weights from the household weight (HV005) and the woman weight (V005) by following the steps outlined in Table 1. To execute the approximation, the following inputs are required:

1. The household weight (HV005) from the household recode (HR) dataset, or the woman weight (V005) from the woman recode (IR) dataset.

2. The total number of completed/interviewed clusters a_h^c (clusters with at least one interviewed household) in stratum h for all strata. In surveys where all selected clusters were interviewed, the number of selected clusters a_h can be used. In a typical DHS survey, a_h for all strata can be found in Table A.3 in Appendix A on the sampling design. The number of interviewed clusters a_h^c should be calculated from the household (HR) dataset or the woman (IR) dataset.

3. The total number of households M_h in stratum h for all strata. In a typical DHS survey, this can be found in Table A.1 in Appendix A on the sampling design.

4. The total number of households M in the entire country according to the census. In a typical DHS survey, this can be found in Table A.1 in Appendix A on the sampling design.

5. The total number of households M_{hi} in cluster i for each cluster. These numbers are not available in the datasets or the final report. However, these numbers can be approximated with the average number of households per cluster within sampling strata according to the census data $\bar{M}_h$. In a typical DHS survey, this can be found in Table A.2 in Appendix A on the sampling design.

6. The total number of households that completed the survey, m^c, or the total number of interviewed women, n^c.

7. The projected number of households, $\hat{M}$, in the entire country at the time of the survey, or the projected number of women age 15-49, $\hat{N}$, in the entire country at the time of the survey. These projected numbers may be accessible through sources such as the country's statistical office, the United Nations Population Division's (UNPD) World Population Prospects, or the United Nations Population Fund (UNFPA).

An approximation can be executed with the three steps outlined in Table 2. More details about how the equations in Table 2 were derived is provided in Appendix A of this report.

Table 2 Steps to approximate level-1 and level-2 weights from household or individual weights

Steps	Household weight	Individual weight
1. De-normalize the final weight, using approximated normalization factor	$d_{hi}^{HH} = HV005_{hi} \dfrac{\hat{M}}{m^c}$	$d_{hi}^{WM} = V005_{hi} \dfrac{\hat{N}}{n^c}$
2. Approximate the level-2 weight	$w_2^{HH} = w_{2hi} = \frac{A_h}{a_h^c} f^\alpha$, $f = d_{hi}^{HH} / \left(\frac{A_h}{a_h^c} \times \frac{\bar{M}_h}{s_h}\right)$ and $0 \leq \alpha \leq 1$	$w_2^{WM} = w_{2hi} = \frac{A_h}{a_h^c} f^\alpha$, $f = d_{hi}^{WM} / \left(\frac{A_h}{a_h^c} \times \frac{\bar{M}_h}{s_h}\right)$ and $0 \leq \alpha \leq 1$
3. Approximate the level-1 weight	$w_{1\|2}^{HH} = w_{1hi} = \frac{d_{hi}^{HH}}{w_{2hi}}$	$w_{1\|2}^{WM} = w_{1hi} = \frac{d_{hi}^{WM}}{w_{2hi}}$

The variation factor f in the second step contributes with different degrees to w_2 and $w_{1|2}$, depending on the specification of the exponent α, $0 \leq \alpha \leq 1$. The factor is fully assigned to w_2 when $\alpha = 1$, and fully assigned to $w_{1/2}$ when $\alpha = 0$. The variation factor is equally assigned to the two weights when $\alpha = 0.5$. When the extreme values are used, all the weight variation is attributed to one of the two level-weights, the level-1 or level-2 weight. If all variation is assigned to w_2 , with $\alpha = 1$, then $w_{1/2}$ has a constant value $\frac{\bar{M}_h}{s_h}$ within each sampling stratum h. At the other extreme, if all variation is assigned to $w_{1/2}$ with $\alpha = 0$, then w_2 is assigned a constant value $\frac{A_h}{a_h^c}$ within each sampling stratum h. Given the DHS sampling design described earlier, extreme values for α, such as 0 and 1, should be avoided. The easiest option is the equal split, $\alpha = 0.5$. The user may explore different values of α and evaluate the results to judge if cluster-level variations or household-level variations have the most influence on the model and then decide an appropriate α (Stata code for this sensitivity analysis is provided in Table 3).

The de-normalization step restores the original scale of the survey weight but is not meant to produce accurate population counts. De-normalization can also be done approximately, based only on information available within the survey data and Appendix A of the final report. An approximate sampling fraction can be used to de-normalize the household weight or the woman individual weight. The de-normalized weights in the first step of Table 2 can be approximated as:

$$d_{hi}^{HH} = HV005_{hi} \times \frac{M}{m^c} \tag{16}$$

$$d_{hi}^{WM} = V005_{hi} \times \frac{M}{m^c} \tag{17}$$

where M is the total number of households in the country provided in the tables in Appendix A.

5 ILLUSTRATIONS

This section presents two illustrations. Illustration 1 is an example of how the level-weights can be approximated from the household weight. Illustration 2 shows how the level-weights can be used in a multilevel model of modern contraception use among married women age 15-49. Data from the Zimbabwe DHS 2015 (ZDHS 2015) are used for both illustrations.

5.1 Illustration 1: Approximate level-weights

The estimation of level-1 and level-2 weights based on the household weight (HV005) from the household (HR) standard recode file of the ZDHS 2015 follows three steps:

1. Data needed for calculations are extracted from the HR dataset and from Appendix A of the final report (Zimbabwe National Statistics Agency and ICF International 2016).

2. Level-weights are calculated with the equal split approach.

3. A sensitivity analysis is conducted where level-weights are recalculated based on different values of α.

Table 3 presents the three stages in more detail and with Stata code. Figure 1 gives a partial listing, for observations 23–32, of the DHS household weight, the variation factor, and the equal-split level-weights.

Table 3 Stages and steps to approximate level-1 and level-2 weights from the household weight with Stata code

Stages	Steps	Stata code
Stage 1	**Compile inputs for level-weights calculations** 1. Calculate the total number of completed clusters a_h^c in stratum h for all strata. 2. Add the total number of census clusters A_h in stratum h for all strata. The numbers can be found in Table A.3 in the final report of the ZDHS 2015. 3. Add the average number of households per cluster by sampling strata according to the census data $\bar{M}_h$. The numbers can be found in Table A.3 in the final report. 4. Calculate the total number of completed households m^c. 5. Add the total number of households according to the census frame. This number can be found in Table A.2 in the final report. 6. Add the number of households selected per cluster. This number can be found in the in the text of Appendix A of the final report. 7. Prepare the DHS household weight.	use "ZWHR72FL.DTA", clear *** 1 *************************** gen a_c_h=. quietly levelsof hv022, local(lstrata) quietly foreach ls of local lstrata { tab hv021 if hv022==`ls', matrow(T) scalar stemp=rowsof(T) replace a_c_h=stemp if hv022==`ls' } *** 2 *************************** gen A_h = 0 replace A_h = 673 if hv022 == 1 ... replace A_h = 1682 if hv022 == 19 *** 3 *************************** gen M_h = 0 replace M_h = 108 if hv022 == 1 ... replace M_h = 98 if hv022 == 19 *** 4 *************************** quietly summarize hv001 gen m_c=r(N) *** 5 *************************** gen M = 2976119 *** 6 *************************** gen S_h = 28 *** 7 *************************** gen DHSwt = hv005 / 1000000
Stage 2	**Approximate level-1 and level-2 weights** 1. De-normalize the final weight, using approximated normalization factor. 2. Approximate the level-2 weight based on equal split method (α=0.5). 3. Approximate the level-1 weight.	*** 1 *************************** gen d_HH = DHSwt * (M/m_c) *** 2 *************************** gen f = d_HH / ((A_h/a_c_h) * (M_h/S_h)) scalar alpha = 0.5 gen wt2 = (A_h/a_c_h)*(f^alpha) *** 3 *************************** gen wt1 = d_HH/wt2

Stage 3	**Sensitivity analysis**
	Calculate level-weights based on the following 7 scenarios of α: 0, 0.1, .25, .50, .75, 0.90 and 1.
		local alphas 0 0.1 .25 .50 .75 0.90 1
		local i = 1
		foreach dom of local alphas{
		gen w2_`i' = (A_h/a_c_h)*(f^`dom')
		gen w1_`i' = d_HH/w2_`i'
		local ++i
		}

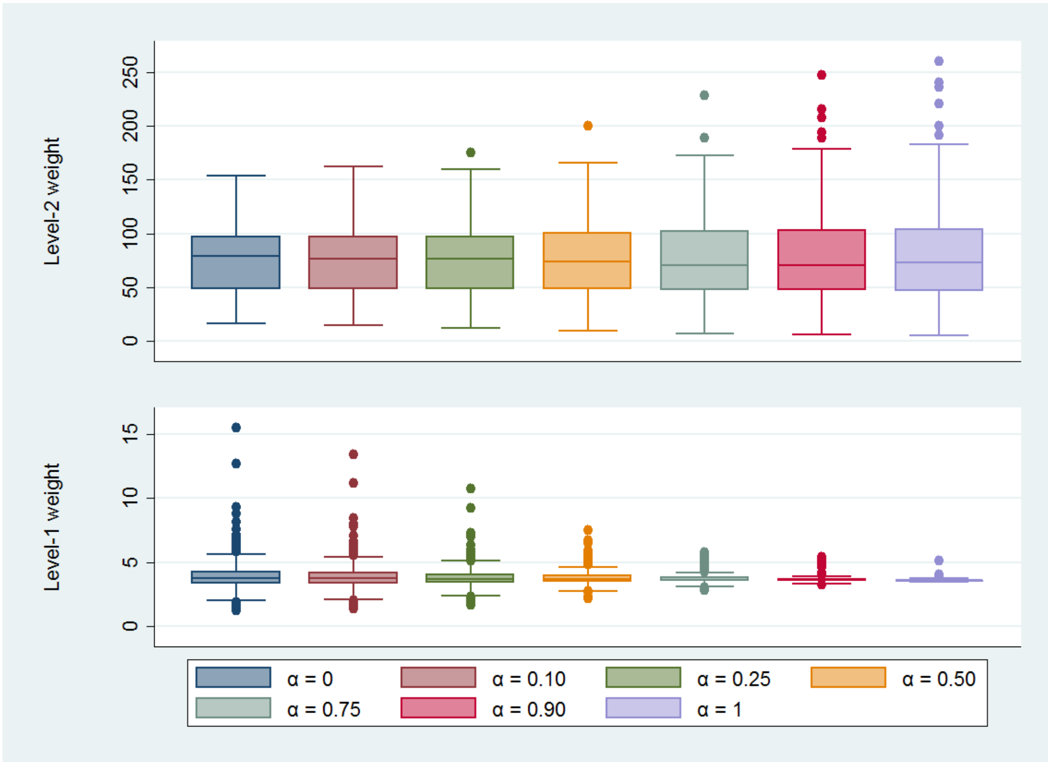
Figure 1 **Level-weights for observation numbers 23–32 calculated with the equal-split approach (α = 0.5)**

	hhid	DHSwt	d_HH	f	wt2	wt1
23.	1 25	1.807388	510.6324	1.488201	119.5941	4.269714
24.	1 26	1.807388	510.6324	1.488201	119.5941	4.269714
25.	1 27	1.807388	510.6324	1.488201	119.5941	4.269714
26.	1 28	1.807388	510.6324	1.488201	119.5941	4.269714
27.	1 29	1.807388	510.6324	1.488201	119.5941	4.269714
28.	2 1	1.440993	407.1166	1.164747	104.5778	3.892953
29.	2 2	1.440993	407.1166	1.164747	104.5778	3.892953
30.	2 3	1.440993	407.1166	1.164747	104.5778	3.892953
31.	2 4	1.440993	407.1166	1.164747	104.5778	3.892953
32.	2 6	1.440993	407.1166	1.164747	104.5778	3.892953

As indicated in Figure 2, the equal split (α=0.50) seems like a good choice for the allocation of variation in weights to the level-1 and level-2 units, at least in this example. Figure 2 shows boxplots that describe the dispersion in the level-2 weights in the upper panel of the figure and the dispersion of the level-1 weights in the lower panel, for each of the seven scenarios. In general, high dispersion in weights is undesirable and inefficient because the results depend much more on the units with high weights than the units with low weights. As described earlier, α=0 allocates all the variation to the level-1 weight and α=1 allocates all of the variation to the level-2 weight. If all the variation is allocated to the level-1 weight, that is, to households or women, then the results will depend much more on the level-1 cases (households or women) with high weights. If all the variation is allocated to the level-2 weight, that is, to clusters, then the results will depend much more on the level-2 cases (clusters) with high weights.

Efficiency is a criterion in the design of DHS surveys. The value of α that comes closest to replicating the true design of the survey will generally be the one that simultaneously minimizes both the dispersion of the level-1 and level-2 weights. The boxplots in Figure 2 suggest that the optimal design is best approximated with the middle value, α=0.50.

Figure 2 Boxplots for level-weights based on different values of α



5.2 Illustration 2: Multilevel models using approximated level-weights

In this illustration, the use of modern contraceptive methods is modeled based on data from the ZDHS 2015. We fitted several mixed-effects logit regression models on 5,149 married women (age 15-49) nested within 400 clusters. All models share the same specifications, except the level-weights, with the binary variable *cumodern* as the outcome variable, with a value of 1 that indicates modern contraceptive use and 0 otherwise. The model covariates include age in years (*age*), education (*secondary*: 0 = primary or less; 1 = secondary or more), place of residence (*urban*: 0 = rural; 1 = urban), and number of children (*children*: 0 = no children; 1 = 1 child; 2 = 2 children; 3 = 3 children; 4 = 4 or more children). Consider a two-level random-intercept model to model $\pi_{ij} = Pr(cumodern_{ij} = 1)$ for woman *i* in cluster *j*, where random effects are modeled for each sampling cluster as follows:

$$logit(\pi_{ij}) = \beta_0 + \beta_1 age_{ij} + \beta_2 secondary_{ij} + \beta_3 urban_{ij} + \beta_4 1.children_{ij} + \beta_5 2.children_{ij} + \beta_6 3.children_{ij} + \beta_7 4.children_{ij} + u_j$$

for *j* = 1, …, 400 clusters, with *i* = 1, …., n_j women in cluster *j*, where $u_j \sim N(0, \sigma^2)$.

The regression models were fitted with the *svy: melogit* command in Stata-16 (StataCorp 2019). All Stata code can be found in Appendix B, including code to calculate level-weights based on the woman weight (V005). We fitted seven models with level-weights calculated with the following values of α: 0, 0.1, 0.25, 0.50, 0.75, 0.90 and 1. An eighth model was fitted with the level-1 weight declared as 1 (a common practice used when level-weights are not available). Since results from models 1 to 7 are very similar, we present results from models 1, 4, 7 and 8 in Table 4.

Table 4 **Multilevel logistic regression modeling modern contraceptive use among married women using different level-weights**

	Model 1 (α = 0) Coef. (Std. Err.)	**Model 4 (α = 0.50)** Coef. (Std. Err.)	**Model 7 (α = 1)** Coef. (Std. Err.)	**Model 8 ($w_{1\|2}$ = 1)** Coef. (Std. Err.)
Age	-0.08***(0.01)	-0.08***(0.01)	-0.08***(0.01)	-0.07***(0.01)
Education				
Primary or less (ref)				
Secondary	0.46***(0.11)	0.47***(0.11)	0.47***(0.11)	0.50***(0.11)
Place of residence				
Rural (ref)				
Urban	0.47***(0.13)	0.46***(0.13)	0.45***(0.13)	0.38***(0.11)
Number of children				
0 children (ref)				
1 child	3.92***(0.34)	3.92***(0.34)	3.92***(0.34)	3.60***(0.30)
2 children	4.86***(0.35)	4.86***(0.35)	4.85***(0.35)	4.48***(0.31)
3 children	5.04***(0.38)	5.03***(0.38)	5.03***(0.38)	4.64***(0.34)
4 children or more	5.36***(0.38)	5.35***(0.38)	5.35***(0.38)	4.91***(0.34)
Intercept	-1.47***(0.35)	-1.48***(0.35)	-1.48***(0.34)	-1.45***(0.31)
Random effects				
Estimate intercept variance (standard error)	0.84 (0.10)	0.82 (0.10)	0.79 (0.10)	0.32 (0.10)

*** p-value =<0.001

In Table 4, the estimated coefficients and their standard errors are very similar for all values of α in the full range of 0 to 1. However, in general, the coefficients in Model 8 are attenuated (closer to 0) and their standard errors are smaller. As shown in the bottom row of Table 4, when using level-weights, the estimated variance of the intercept at level-2 ranges between 0.79 and 0.84, which is more than twice the variance of 0.32 that is estimated when the level-1 weight is declared as 1 in Model 8. This observation suggests that the variation between clusters in the use of modern contraception is underestimated if level-weights are not used.

6 DISCUSSION

In this report we proposed a framework to approximate level-weights for multilevel models. We proposed an approximation method that uses the available data and information provided by the DHS Program in the survey datasets and final reports. The approximation method includes a powered variation factor that contributes to slicing or allocating the final survey weight between level-1 and level-2 weights. The proposed approximation approach is valid for other household surveys, such as the Malaria Indicator Survey (MIS) and the Multiple Indicator Cluster Survey (MICS), if the inputs for the method are available as with DHS surveys.

We also used a specific DHS survey, conducted in Zimbabwe in 2015, to illustrate how level-weights can be calculated from the household weight or the woman weight in the data files, and then illustrated how those level-weights can be used when fitting multilevel models. Stata code is provided for these illustrations. We compared different models in which the proposed approximation method is used or not used. According to the results of the comparisons, omitting level-weights may lead to underestimating the variation between level-2 units.

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APPENDIX A DERIVATIONS OF FORMULAS

A.1 Level-weights from the household weight

This appendix gives the derivations of the equations to approximate the level-weights based on the household weight. We first assume there is no non-response at the cluster level or among households. In the next section, the derivations will be extended to allow for non-response in the different sampling levels.

A.1.1 No non-response

Assuming full response among all sampling units, including sampling clusters and households, the design weight in (5) can be used as a survey weight. As illustrated earlier, with the multistage stratified cluster sampling design used in the DHS surveys, the household design weight can be written as:

$$d_{hi} = \frac{M_h}{a_h M_{hi}} \frac{L_{hi}}{s_h} = \frac{A_h}{a_h} \frac{\bar{M}_h}{s_h} \frac{L_{hi}}{M_{hi}} \tag{A.1}$$

where A_h denotes the total number of clusters in stratum h according to the census frame. If the number of households listed is exactly the number of census households in all clusters, that is, $L_{hi} = M_{hi}$, then the DHS samples are self-weighting at the stratum level since the household design weight is a constant across the sampling stratum. Then the last term in equation (A.1) is equal to one and the household design weight converges to:

$$d_{hi} = \frac{A_h}{a_h} \frac{\bar{M}_h}{s_h} \tag{A.2}$$

$\bar{M}_h$ and A_h are known and are given in Appendix A of the DHS final reports, as are a_h (number of selected clusters from stratum h) and s_h (number of selected households per cluster). The first term in the equation (A.2) is the main part of the level-2 weight, which would be the exact level-2 weight if clusters were selected with equal probability selection instead of PPS sampling. The second term in the equation (A.2) is the main part of the level-1 weight if the average number of households listed per cluster is close to the average cluster size of the stratum. In practice, this ideal situation never happens. The cluster size varies and the number of households listed is different from the census number. Using the main part of the level weights, the true level-2 and level-1 design weights can be written as the constant main part multiplied by a variation factor:

$$w_2^{HH} = w_{2hi} = \frac{M_h}{a_h M_{hi}} = \frac{A_h}{a_h} f_{2hi}, \quad f_{2hi} = \frac{\bar{M}_h}{M_{hi}} \tag{A.3}$$

$$w_{1|2}^{HH} = w_{1hi} = \frac{L_{hi}}{s_h} = \frac{\bar{M}_h}{s_h} f_{1hi}, \quad f_{1hi} = \frac{L_{hi}}{\bar{M}_h} \tag{A.4}$$

The average variation of the level-2 weight comes from the variation of the cluster size compared to the average cluster size by stratum, whereas the average variation of the level-1 weight comes from the variation of the number of listed households compared to the average cluster size. The overall variation factor of the household design weight f_{hi} is the product of the two factors as follows:

$$f_{hi} = f_{2hi} f_{1hi} = \frac{L_{hi}}{M_{hi}} \tag{A.5}$$

The variation factors f_{2hi} and f_{1hi} are unknown since the denominator of f_{2hi} and the numerator of f_{1hi} are unknown. However, their product, the overall variation factor f_{hi}, is known and, from equation (A.1), can be calculated as:

$$f_{hi} = d_{hi} \Big/ \left(\frac{A_h}{a_h} \frac{\bar{M}_h}{s_h} \right) \tag{A.6}$$

The overall variation factor can then be equally shared between the level-2 weight and level-1 weight as follows:

$$f_{2hi} = f_{1hi} = \sqrt{f_{hi}} \tag{A.7}$$

The equal variation split is a special case of a more general power split, where the overall variation factor is allocated to the level-2 weight and level-1 weight based on an exponent or power value $\alpha, 0 \le \alpha \le 1$, as follows:

$$f_{2hi} = f_{hi}^{\alpha} \tag{A.8}$$

$$f_{1hi} = f_{hi}^{1-\alpha} \tag{A.9}$$

Therefore, the approximated level-2 and level-1 weights are given by:

$$w_2^{HH} = w_{2hi} = \frac{A_h}{a_h} f_{hi}^{\alpha} \tag{A.10}$$

$$w_{1|2}^{HH} = w_{1hi} = \frac{d_{hi}}{w_{2hi}} \tag{A.11}$$

A.1.2 Including non-response

We now derive the level-weights from the household weight allowing for non-response among clusters and households. Again, the final weight is normalized. Correcting for cluster-level non-response is equivalent to recalculating the first-degree selection probability based on the number of clusters interviewed a_h^c as $P_{1hi} = a_h^c \, M_{hi}/M_h$. The correction will be explicit in the equation of the level-2 weight, where the number of selected clusters a_h is replaced by the number of interviewed clusters a_h^c. The correction for household-level non-response is absorbed into the overall variation factor f_{hi}. Since the final household weight is normalized, a denormalized version of the weight must be used to derive the level-1 weight. The final approximated level-2 and level-1 weights given in (A.10 and A.11) are:

$$w_2^{HH} = w_{2hi} = \frac{A_h}{a_h^c} f_{hi}^{\alpha} \tag{A.12}$$

$$w_{1|2}^{HH} = w_{1hi} = \frac{d_{hi}^{HH}}{w_{2hi}} \tag{A.13}$$

where $f_{hi} = d_{hi}^{HH} / \left(\frac{A_h}{a_h^c} \frac{\bar{M}_h}{s_h} \right)$, $0 \le \alpha \le 1$ and d_{hi}^{HH} is the denormalized version of the household weight HV005.

A.2 Level-weights from the individual weight

This section describes the calculation of level-weights from an individual weight, specifically the woman weight, allowing for non-response in different sampling stages and using a final normalized weight. Since there is no woman selection within household (all women age 15-49 in the household are eligible for the individual interview), the main part of the level-1 and level-2 weights for women are the same as for the household. The only difference is a correction for individual non-response at the stratum level. The correction factor can be absorbed into the overall variation factor. Equations (A.12) and (A.13) can be used directly to approximate the level-1 and level-2 weights based on the de-normalized individual weight as follows:

$$w_2^{WM} = w_{2hi} = \frac{A_h}{a_h^c} f_{hi}^{\alpha} \tag{A.14}$$

$$w_{1|2}^{WM} = w_{1hi} = \frac{d_{hi}^{WM}}{w_{2hi}} \tag{A.15}$$

where $f_{hi} = d_{hi}^{WM} / \left(\frac{A_h}{a_h^c} \frac{\bar{M}_h}{s_h} \right)$ and d_{hi}^{WM} is the de-normalized version of the woman weight V005.

APPENDIX B STATA CODE

```
use "ZWIR72FL.DTA", clear

* keep currently married women
keep if v501==1

* drop currently pregnant and declared infecund
drop if v213==1 | v605==7

* recode model variables
recode v313 (0/2 = 0 "traditional or not using") (3 = 1 "modern use"), gen(cumodern)
gen age=v012
recode v106 (0/1=0 "noedu/primary") (2/3=1 "secondary+") (8/9=.), gen(secondary)
recode v025 (2=0 "rural") (1=1 "urban"), gen(urban)
recode v218 (0=0 "0 children") (1=1 "1 children") (2=2 "2 children") (3=3 "3
children") (4/12=4 "4 children or more"), gen(children)

**********************************************************************
* Stage A *** Compile parameters/inputs for Level-weights calculations
**********************************************************************
* a_c_h completed clusters by strata
gen a_c_h=.
quietly levelsof v022, local(lstrata)
quietly foreach ls of local lstrata {
tab v021 if v022==`ls', matrow(T)
scalar stemp=rowsof(T)
replace a_c_h=stemp if v022==`ls'
}

* A_h total number of census clusters by strata
gen A_h = 0
replace A_h = 673  if v022 == 1
replace A_h = 3340  if v022 == 2
replace A_h = 162 if v022 == 3
replace A_h = 2451 if v022 == 4
replace A_h = 463  if v022 == 5
replace A_h = 2843 if v022 == 6
replace A_h = 839 if v022 == 7
replace A_h = 2298 if v022 == 8
replace A_h = 165 if v022 == 9
replace A_h = 1343 if v022 == 10
replace A_h = 218 if v022 == 11
replace A_h = 1280 if v022 == 12
replace A_h = 981 if v022 == 13
replace A_h = 2230 if v022 == 14
replace A_h = 372 if v022 == 15
replace A_h = 2907 if v022 == 16
replace A_h = 4920 if v022 == 17
```

```
replace A_h = 198 if v022 == 18
replace A_h = 1682 if v022 == 19

* M_h average number of households per cluster by strata
gen M_h = 0
replace M_h = 108  if v022 == 1
replace M_h = 102  if v022 == 2
replace M_h = 98 if v022 == 3
replace M_h = 100 if v022 == 4
replace M_h = 99  if v022 == 5
replace M_h = 98 if v022 == 6
replace M_h = 101 if v022 == 7
replace M_h = 100 if v022 == 8
replace M_h = 113 if v022 == 9
replace M_h = 106 if v022 == 10
replace M_h = 97 if v022 == 11
replace M_h = 99 if v022 == 12
replace M_h = 99 if v022 == 13
replace M_h = 99 if v022 == 14
replace M_h = 100 if v022 == 15
replace M_h = 101 if v022 == 16
replace M_h = 104 if v022 == 17
replace M_h = 144 if v022 == 18
replace M_h = 98 if v022 == 19

* m_c total number of completed households (added from the HR dataset)
gen m_c= 10534

* M total number of households in country
gen M = 2976119

* S_h households selected per stratum
gen S_h = 28

gen DHSwt = v005 / 1000000

**********************************************************************
* Stage B *** Approximate Level-weights ***
**********************************************************************
* Steps to approximate Level-1 and Level-2 weights from Household or Individual
Weights
*Step 1. De-normalize the final weight, using approximated normalization factor
gen d_HH = DHSwt * (M/m_c)

*Step 2. Approximate the Level-2 weight
* f the variation factor
gen f = d_HH / ((A_h/a_c_h) * (M_h/S_h))

* Calculating the level-weights based on different values of alpha
local alphas 0 0.1 .25 .50 .75 0.90 1
local i = 1
```

```
foreach dom of local alphas{
gen wt2_`i' = (A_h/a_c_h)*(f^`dom')
gen wt1_`i' = d_HH/wt2_`i'
local ++i
}

**********************************************************************
* Stage D *** Fit Random intercept models ***
**********************************************************************
svyset v001, weight(wt2_1) strata(v022) , singleunit(centered) || _n, weight(wt1_1)
svy: melogit cumodern age secondary urban i.children || v001:
estimates store model1

svyset v001, weight(wt2_2) strata(v022) , singleunit(centered) || _n, weight(wt1_2)
svy: melogit cumodern age secondary urban i.children || v001:
estimates store model2

svyset v001, weight(wt2_3) strata(v022) , singleunit(centered) || _n, weight(wt1_3)
svy: melogit cumodern age secondary urban i.children || v001:
estimates store model3

svyset v001, weight(wt2_4) strata(v022) , singleunit(centered) || _n, weight(wt1_4)
svy: melogit cumodern age secondary urban i.children || v001:
estimates store model4

svyset v001, weight(wt2_5) strata(v022) , singleunit(centered) || _n, weight(wt1_5)
svy: melogit cumodern age secondary urban i.children || v001:
estimates store model5

svyset v001, weight(wt2_6) strata(v022) , singleunit(centered) || _n, weight(wt1_6)
svy: melogit cumodern age secondary urban i.children || v001:
estimates store model6

svyset v001, weight(wt2_7) strata(v022) , singleunit(centered) || _n, weight(wt1_7)
svy: melogit cumodern age secondary urban i.children || v001:
estimates store model7

* assign levels-weight for model 8 (Level-1 weight = 1 and Level-2 weight = survey
weight)
gen wt2_=d_HH
gen wt1_=1

svyset v001, weight(wt2_) strata(v022) , singleunit(centered) || _n, weight(wt1_)
svy: melogit cumodern age secondary urban i.children || v001:
estimates store model8

esttab model1 model2 model3 model4 model5 model6 model7 model8 using
"C:\Users\......\melogti_results.csv", b(2) se(2) replace ///
title(Mixed effects models_Zimbabwe DHS 2015)       ///
nonumbers mtitles("alpha = 0" "alpha = 0.10" "alpha = 0.25" "alpha = 0.50" "alpha =
0.75" "alpha = 0.90" "alpha = 1" "w1 = 1")
```