Appendix 1. Data, datasets, and selection criteria

Data have been retrieved from the DHS (http://www.dhsprogram.com) and MICS (http://www.childinfo.org/mics.html) reports in September 2014, where the results of the surveys are freely available, and from the DHS and MICS datasets, where the actual individual data can be obtained upon permission.
DHS and MICS surveys are the better source of demographic and health data of low- and middle-income countries. Data are comparable to each other, the MICS and DHS sampling procedures being harmonized. [1] They include birth registration rate (BR), calculated as the number of children whose births have been registered on the total number of children surveyed, and nutritional indices. According to WHO criteria, [2] reports use anthropometric indices of nutritional status (weight-for-age Z-scores: WAZ; height-for-age Z-scores: HAZ; weight-for-height Z-scores: WHZ) expressed in standard deviation units (s.d.) from the median of the reference population for the same sex and age, or height. Undernutrition is defined as an index below -2 s.d. from the median value of the standard: stunting (HAZ<2), underweight (WAZ<2), and wasting (WHZ<2).
The indices based on the WHO Child Growth Standards (http://www.who.int/childgrowth/) [3] were preferentially selected, using those based on the National Center for Health Statistics international growth reference (NCHS/CDC/WHO reference; http://www.cdc.gov/growthcharts/cdc_charts.htm) [4] only for 2006 or 2007 surveys and limited to within-country analyses.

The more recent DHS and MICS reports where birth registration rate (BR) and malnutrition levels were contextually present, and with the sample subdivision in wealth quintiles, have been used.
The subdivision in quintiles is based on the wealth index, i.e. “a composite measure of a household's cumulative living standard”. [5] This index does not provide absolute information on poverty, but is considered the best option to account for within-country socioeconomic variability. [6,7]
The analyses are focused on children under five years of age.

Selected reports, datasets, and variables

DHS and MICS reports
Thirty-seven sub-Saharan African countries have been included in the analyses (Table 1).
Eritrea and Malawi have not been considered because no birth registration data whatsoever were available. Other countries (Angola, Botswana, Cape Verde, Comoros, Djibouti, Mauritius, Seychelles, South Africa, Sudan) were not considered because surveys, or malnutrition levels, or wealth quintiles details were not available. Madagascar was considered only for stunting prevalence.
The analysis on the relationship between BR and malnutrition or wealth status was performed in a subset of 33 countries whose indexes of malnutrition were based on the WHO Child Growth Standards adopted in 2006, because the corresponding nutritional values are not directly comparable to those based on the previous NCHS/CDC/WHO references [8] used for reports on Ethiopia, Côte d'Ivoire, and Somalia. Guinea was also excluded because the report does not show the BR rate for wealth quintile.
A database has been assembled and made freely available at the Cagliari University institutional repository (http://ve-prints.unica.it/1119/). It comprises seven variables (detailed for the total sample and wealth quintiles), retrieved from the open access DHS and MICS reports: prevalence of stunting, underweight, and wasting; size of the sample used for nutritional assessment ('nutritional subsample'); prevalence of children registered at birth; size of the sample used for evaluating birth registration rate; survey (MICS or DHS, year).

DHS and MICS datasets
The datasets relative to 34 countries (thus excluding Guinea-Bissau, Equatorial Guinea, and Mauritania, where the datasets relative to the more recent surveys were not yet available) were asked for permission.
The total group of 34 countries was analysed for determining the sample composition used for nutritional analysis (number of registered and unregistered children) in each wealth quintile.
A sub set of 28 countries was analysed for comparing nutritional status in registered and unregistered children within wealth classes. The datasets of those countries where the great majority of children had been registered (BR≥90%: The Congo, Gabon) or not registered at birth (BR≤10%: Liberia, Somalia, Ethiopia) were excluded from this analysis. Madagascar was also excluded because only data on stunting were present.
Individual data from Swaziland were used to analyse the effect of non sampling errors on udernutrition.
In the case of DHS datasets, the Household Member Recode file was used, and variables HC70 (height for age standard deviation according to WHO), HC71 (weight for age standard deviation according to WHO), HC72 (weight for height standard deviation according to WHO), HV005 (household weight), HV270 (wealth index quintile), and HV140 (birth certificate / registered) selected. In the case of Ethiopia, whose report was published in 2006, the NCHS z-scores were used (HC5, HC8, HC11); in this dataset, the information on “birth certificate / registered” was reported in the variable

SH20.
In the case of MICS, the following variables from the unit of analysis 'Mothers or primary caretakers of children under the age of five' were used: HAZ2 (height for age z-score WHO), WAZ2 (weight for age z-score WHO), WHZ2 (weight for height z-score WHO), FLAG (flag for anthropometric indicators), chweight (children's sample weight), windex5 (wealth index quintiles), BR1 (does [NAME] have a birth certificate?) and BR2 (has [NAME]'s birth been registered with the civil authorities?). A new variable (BR) was constructed that considered registered children with a birth certificate (BR1: both seen and not seen) and children with their birth registered (BR2: yes). In the case of Somalia, whose report was published in 2006, the variable BR2 was not present and the NCHS z-scores were used (HAZ, WAZ, WHZ). The same nutritional indices have been used for Côte d'Ivoire.
The analysis on the effect of age imprecision on undernutrition was performed using only the data from the MICS survey of Swaziland. The variables HL4 (sex), CAGE (age, months), AN3 (child's weight, kilograms), and AN4 (child's length or height, centimeters) were also included in the analysis.

Case selection and sample weight
Children who were flagged for out-of-range z-scores or invalid z-scores in any one of the three nutritional indicators have been excluded from the analysis. In MICS dataset the variable FLAG was used for this purpose while in the DHS the values defined as '999' or '9999' were used to select invalid data.
As to the variables related to BR, cases showing 'don't know' or 'missing' labels were excluded from the analysis.
Sample weight was applied using HV005 and chweight variables that represent the proportional part of the respective weights. This means that they have been normalised according to the specific group analysed.

Statistical analysis

Composition of the samples
DHS and MICS reports do not describe the composition of the sample used for nutritional analysis in terms of birth registration, i.e. what proportion of unregistered children was included in such sample. In order to quote such proportion, the total number of children under five years, the number of children examined for nutritional status, and the samples' composition in terms of birth registration were retrieved from the DHS and MICS datasets relative to 35 countries.
The difference between percentages of BR in the total sample and in the sample used for nutritional analysis has been assessed using a permutation test. For each of the 170 combinations of country/wealth class, we have calculated the difference between BR rates and the corresponding observed mean on the 170 differences. We have repeated the calculation 10000 times, where the labels 'total' and 'nutrition' sample have been randomly permuted. The obtained 10000 mean values represent the distribution of the mean under the hypothesis of no differences. Hence, we have calculated the probability of observing a mean difference larger than the observed one.

Effects of selection bias due to birth registration on undernutrition prevalence
This relationship has been explored using a logistic regression, i.e. a linear regression between the indicator of undernutrition, considered in the *logit* scale, that is $\text{logit}(Y)=\log(Y/(1-Y))$, and the explanatory variables: BR and the country. The variable Y represents the observed proportion of undernutrition in the wealth quintiles of the 33 countries (165 samples). The undernutrition proportions observed in the wealth quintiles across different countries allow the analysis of an independent sample conditionally on a specific wealth quintile, which is necessary because of country heterogeneity. We have assumed in the regression model that undernutrition levels variate independently among countries, and, hence, the undernutrition proportion of the same quintile for all countries is an independent sample.
In more detail, B and C represent BR and country, respectively, and $B.C$ indicates the interaction between BR and country; the model can be represented as follows:

$$\text{logit}(Y)=ß_0+ß_B B+ ß_C C+ ß_{B.C} B.C,$$

where we assumed that there exists a common (to all countries) undernutrition mean $ß_0$ and slope $ß_B$, plus a country specific mean and slope represented by parameters $ß_C$ and $ß_{B.C}$.
The goodness of fit of the model has been assessed by looking at the residuals and Cook's distances, in order to exclude the presence of outliers. The significance level has been assessed using the χ^2 test for the residual deviance.
The analysis was repeated for each nutritional indicator (HAZ, WAZ, WHZ) separately.
Considering the heterogeneity of the countries, the chosen regression model provided satisfactory results either in terms of interpretation and precision.

Further, in each wealth class of each country, we tested the hypothesis that the undernutrition proportion has the same mean in both groups of registered and unregistered children against the hypothesis that it is higher in the unregistered groups. The Student's t-test with Welch correction was used in order to account for heteroscedasticity, with an asymptotic correction justified by the large sample employed in each test (186821 children with a minimum of 187 children for a combination of country/wealth class).

This approach produced a multiplicity of repeated tests: 140 in total, 5 wealth classes in 28 countries. In order to avoid the possibility to reject the hypotheses just because of the large number of tests, a multiple testing correction was employed. We considered the most popular procedure to correct for multiple testing, the Benjamini-Hochberg procedure, [9] which consists of multiplying the set of ordered p-values, $p_{(1)} < \ldots < p_{(i)} < \ldots < p_{(m)}$, where m=140 tests, by the set of increasing sequence m/i, that is m, $m/2$, $m/3$, ..., 1. Such new or adjusted p-values, $mp_{(1)}, \ldots, m/ip_{(i)}$ are on the False Discovery Rate (*FDR*) scale. This scale is very useful because it is informative of the amount of FDR that we committed to when rejecting all hypotheses with an adjusted p-value lower than a chosen α (e.g. α=0.05). Such FDR is no larger than α in mean.

Effects of age bias and information error on undernutrition prevalence

The effect of age misreporting (information bias and information error) on the estimates of stunting and underweight was evaluated using the data from Swaziland, as an example.

We evaluated the effect of 1, 3, and 6 months of magnitude error in age, both in excess and in defect. Larger errors were considered improbable on the basis of pertinent literature. [10] Only children 24-60 months of age were considered in the analysis because an error of 6 months was considered less probable in children with a lower age, and because stunting is measured differently in children 0-24 months (length for age) than in older ones (height for age).

We considered the effect of systematic error (information bias, or age bias) on over- or underestimation of undernutrition equivalent to the prevalence of children of a certain age with a stature (or weight) comprised between the -2SD stature (or weight) value of their true age and the -2SD stature (or weight) value of the incorrect age. In fact, exemplifying, a 30-month-old male with a stature of 84.9 cm is stunted because such value is lower than the -2SD cut off (85.1 cm). However, if he is erroneously considered to be 29 months old, his stature would be within the normal range, as the cut off for stunting at this age is 84.5 cm. Similarly, all children aged 30 months with a stature comprised between 84.5 and 85.1 cm would be considered normal, underestimating their stunting, if their age were systematically biased of one month in defect.

In order to evaluate random error, the differential effect between excess and defect in assigning age on undernutrition evaluation has been empirically evaluated by looking at the 95% probability intervals on the distribution of the differences in undernutrition prevalence calculated with an incorrect age and with the exact age. The intervals have been calculated separately for each combination of HAZ/WAZ with sex and the order of magnitude (1, 3 and 6 months). They estimate the distribution of the compensated error on undernutrition prevalence and are informative about the hypothesis of perfect compensation between deviations in excess and in defect. Informally, such hypothesis is acceptable if the zero value is included into the interval. From a more formal perspective, the hypothesis of compensation has been evaluated using a Student's t-test between the absolute mean of increasing and decreasing in the undernutrition proportion.

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