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Effects and determinants of mild underweight among preschool children across countries and over time☆

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ABSTRACT

Research on malnutrition typically focuses on extreme cases which pose the greatest individual health risks, but researchers comparing populations might find that variation in mild malnutrition conveys valuable information about public health. This paper constructs and compares new measures of the prevalence, depth and severity of both mild and extreme underweight in children from three months to three years of age, as measured by 130 DHS surveys for 53 countries over a period from 1986 to 2006. We find that variance in mild underweight has a larger and more robust correlation with child mortality than variance in severe underweight, and is itself more closely correlated with local agricultural output, over a wide range of regression specifications. We conclude that the prevalence of mild underweight deserves greater attention as a useful signal of changing public health conditions among preschool children in developing countries.

1. Introduction

Anthropometric measures of weight and height are among the most practical means of comparing nutritional status among people. Economists use both individual observations and population-level statistics to model differences and changes in body size across populations, which is closely linked to other aspects of human welfare and economic development (Fogel, 1994; Deaton and Arora, 2009). Analyses typically focus on the prevalence and severity of extreme under- or over-nutrition, defined in terms of anthropometric measures that fall below or above conventional thresholds. For example, among children the most commonly used threshold for severe underweight is being more than two standard deviations below the median of a reference population, as defined by the World Health Organization (WHO, 2006). In this study, we compare that kind of extreme underweight to milder variations in bodyweight, so as to consider all variance in child nutritional status below the median of the WHO's reference population of healthy children.

For clinical and other purposes it may be necessary to classify observations into discrete categories, but the underlying anthropometric observations are clearly continuous in nature. Variations in bodyweight that do not exceed the clinical threshold may also convey important information, as a predictor of health outcomes and as a measure of program impacts. At the individual level,

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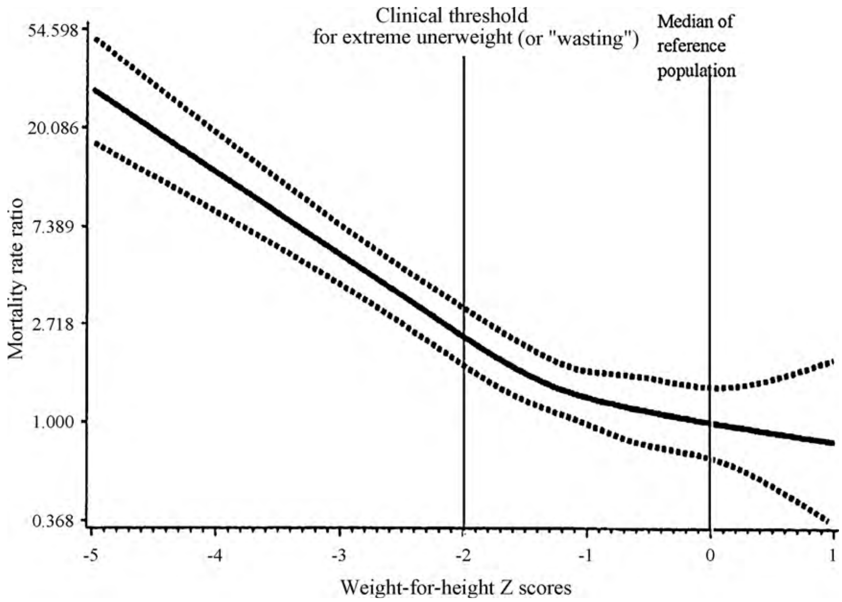

Fig. 1. Relationship between child underweight and child mortality in Sudan, 1988.Reprinted from Fawzi et al. (1997).

among a sample of young children in Sudan, Fawzi et al. (1997) find that lower weight-for-height is associated with rising subsequent mortality even between the clinical threshold and the reference median. This relationship is illustrated in Fig. 1. Pelletier (1994) summarizes analogous evidence from 28 epidemiological studies in 12 countries, drawing somewhat similar risk curves of varying shapes and slopes. In each case, risks increase with the degree of underweight, and even mild degrees of underweight are associated with small but potentially significant increases in health risks.

In this paper, we use individual data from DHS surveys to compute the population level extent of mild and extreme underweight among preschool children in developing countries. Each survey provides a nationally-representative sample of several thousand children, for one of 53 countries in various years between 1986 and 2006. There are a total of 130 such surveys, allowing us to test how both mild and extreme underweight (or wasting) vary with child mortality and other public health conditions at the national level. Our definition of underweight focuses on a child's weight-for-height, with "mild" underweight defined as all children who are thinner than the median of the WHO's reference population, and "extreme" underweight (or "wasting") defined in the conventional manner as all children who are two standard deviations or more below that median.

Our computation of country-level undernutrition measures uses the formulas of Foster et al. (1984), who proposed a family of index numbers with varying weights on each observation below the reference threshold. These Foster–Greer–Thorbecke (FGT) indices include the headcount prevalence (FGT0) for the proportion of children who are underweight, a depth index (FGT1) that sums all of their shortfalls below the reference threshold, and a severity index (FGT2) that sums the square of each shortfall. These index numbers were developed to compare the prevalence, depth and severity of income shortfalls below a poverty line, and have since been applied to anthropometric data on nutritional status by Sahn and Stifel (2002), Jolliffe (2004) and Madden (2006) among others. The thresholds used in these previous studies derive from clinical definitions of malnutrition, as reviewed by De Onis (2000). In our case, the clinical threshold for extreme underweight is a weight-for-height ratio that falls more than two standard deviations below the median of a healthy population. This paper compares results for this traditional definition of extreme underweight with a new measure for mild underweight, counting all shortfalls below the reference median.

Our new measure of mild underweight captures the small variation in individual health risks to the affected individuals that is illustrated in Fig. 1, and could also capture variation in public health conditions, such as exposure to infectious disease, that might affect bodyweight in some children and also affect mortality among others. Variation in mild underweight could also be informative for purely statistical reasons, to overcome errors in the measurement of each child's bodyweight at the extremes of the distribution where sample sizes are small. Both kinds of effects suggest that counting the prevalence of mild underweight could help improve nutrition monitoring.

Our data refer to a particularly sensitive population: preschool children in developing countries. Their shortfalls in bodyweight are estimated by the World Health Organization (WHO, 2002) to be the underlying risk factor behind more than half of all child deaths in the world, killing nearly 6 million children each year. In this paper we consider the significance of mild underweight as a correlate of child mortality, including controls for per-capita income to capture a wide range of other influences on health. Improved nutrition and larger bodyweights have longer-term consequences as well. As long as bodyweights do not increase into the overweight range, larger children benefit from improved work capacity and intellectual performance (Martorell et al., 1992; Martorell, 1995). For all these reasons, the socio-economic, geographic and economic determinants of children's bodyweights have been widely studied. Among other factors, underweight prevalence and severity has been linked to per-capita income, infectious diseases, education (Pritchett and Summers, 1996); women's educational and social status, economic inequality, access to health services, ethnicity (Larrea and Kawachi, 2005; Hong, 2007); national per capita availability of food, access to safe water, government health expenditures (Frongillo et al., 1997); and poor hygiene, inadequate feeding practices, and geographical location (De Onis et al., 2000). Here we ask how closely each level of underweight is correlated with various influences on nutrition such as per-capita income, gender equality, income inequality, and local agricultural output. Each regression is conducted at the country level, and uses a variety of specifications including country fixed effects to isolate changes over time.

2. Methods

2.1. Nutritional status and individual-level z-scores

To compare the extent of child underweight across populations, we begin with individual data on the weight-for-height of preschool children. This variable is of particular interest because it tracks whether these children have recently absorbed enough nutrients to build and maintain bodyweight given their genetic growth potential, disease burden and activity level. Researchers studying older children often consider height-for-age and weight-for-age, to capture cumulative deficits in linear growth over a longer time span. Researchers who wish to focus on shorter-term changes in bodyweights among older children and adults would use the Body Mass Index (BMI), defined as weight per height squared, to account for the nonlinear relationship between healthy weight and height. As shown by De Onis et al. (2006), healthy levels of BMI also vary by age, so comparisons over a wide age range might use a measure of BMI-for-age. Our focus on the weight-for-height (or length) ratios of very young children is motivated by the findings of Shrimpton et al. (2001), who show that the onset of underweight typically occurs after three months of age, with a sharp decline in weight-for-length that hits bottom around 12–24 months. The extent and timing of recovery varies widely, but their data show on average a return to near-normal levels in Latin America and Asia by 36 months. To capture the extent of this preschool shortfall, we focus on preschool children in the most vulnerable age range, from 3 to 36 months.

We compare the weight-for-height of a particular child against their growth potential, using z-scores relative to a healthy population as advocated by the World Health Organization (WHO, 2008). These measures express each child's observed weight-for-height ratio, y_i, as its difference from the weight-for-height of the median healthy child in a reference population, y_{50}, in terms of standard deviations, σ_y in that reference population $z_i \equiv y_i - y_{50}/\sigma_y$. The WHO's reference population is designed to be globally representative, capturing the full range of genetic and cultural variability in the development of healthy children, as described in WHO (2006) and De Onis et al. (2006); computational procedures are encoded in the *igrowup* package of Stata programs to convert the observed weight, height and age of any given child into a z-score.

2.2. Aggregate conditions and population-level underweight measures

The underweight measures that we calculate depend on the shape of the weight-for-height distribution in each country. Those distributions are used to compute three distinct population-level measures for each country, using Foster–Greer–Thorbecke (FGT) indices of order 0, 1 and 2, respectively. The first measure is an underweight headcount index, counting the fraction of all children whose bodyweights fall below the reference threshold. The second is an underweight depth index, using the FGT formula of order 1 to sum the gaps by which those underweight children fall below the threshold. The third is an underweight severity index, using the FGT of order 2 to sum the squared gaps, so that larger gaps are weighted more heavily in the index. Each of these underweight measures corresponds to a different damage function, counting variation below the threshold in different ways: the headcount index ignores all variation in the degree of shortfall, the depth index corresponds to a linear damage function, and the severity index corresponds to a quadratic increase in damages as the shortfall worsens. In practice, however, the usefulness of higher-order FGT indices may be limited by measurement error among extreme values as found by Moradi and Baten (2005); this kind of error creates erroneous extreme values which would be magnified by higher powers at order 1 or 2. At order 0, measurement errors affect estimated prevalence only in the vicinity of the threshold.

Shortfalls in bodyweight can be computed relative to any threshold. The conventional approach is to use a clinical criterion, counting individuals as underweight only if their condition is associated with unambiguous health risks for that particular person. Typically, the World Health Organization and others define such extremes of underweight as two standard deviations below the median of the reference population (a z-score beyond -2). This paper compares that conventional approach with the prevalence of *all* underweight, defined as any shortfall below the reference median (a z-score below 0). The difference is *mild* underweight, which counts children whose z-scores are between 0 and -2. Small shortfalls below the reference median may be associated with small individual risks, but they are used here primarily as a potentially-useful signal of public health conditions such as disease prevalence that affect bodyweights of some children, and may also affect mortality among others. As shown by Mokyr and Gráda (2002), differences in disease prevalence and other public health factors play a large role in differential mortality during periods of food shortage, even in times of outright

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famine. Capturing changes in public health conditions using changes in mild underweight could offer an informative signal about all health risks facing children, even if being mildly underweight imposes little additional risk in itself.

Using our notation, the three FGT indexes over both definitions of underweight can be defined in a single equation as:

$$\mathrm{FGT}^o \equiv \frac{1}{N}\sum_{i=1}^{N}(t - z_i)^o I(z_i \le t), \quad (1)$$

where t is a threshold that defines the level of underweight (either 0 or −2), z_i is our anthropometric measure of bodyweight for the ith child, N is the number of children in the population, and $I(z_i \le t)$ is an indicator variable that takes on the value of 1 if z_i is lower than the user defined threshold and 0 otherwise. The order parameter (o) takes on values of 0, 1 and 2, as exponents on the shortfall associated with each observation. Eq. (1) is a standard FGT formula, except that it uses z-scores as the raw data and so we do not need to perform the customary standardization of dividing by t (Sahn and Stifel, 2002). We also use an additional modification to isolate mild cases, by setting the indicator I to unity only if z_i falls between our two thresholds ($0 \le z_i \le -2$).

2.3. Regression specifications and control variables

Our conceptual framework is a model in which inputs for the health production function are subject to resource constraints. In this case, the variables of interest occur at the population level, and so may be influenced by public health investments and other country-level determinants of health and nutrition, in addition to household-level factors. A first set of regressions pertain to underweight as a determinant of health outcomes, and a second set pertain to other socio-economic variables as determinants of underweight prevalence.

Our first set of hypotheses test for correlation of child underweight with child mortality under age five. Child mortality rates are among the most widely reported measures of population health, and could be directly influenced by child underweight, or could be caused by other factors such as disease burdens which incidentally also affect children's growth potential. Regression specifications are of the following form:

$$\mathrm{CMR}_{j,t} = \alpha^{o\cdot r} + \beta^{o\cdot r}\mathrm{FGT}^{o\cdot r}_{j,t} + \gamma^{o\cdot r}X_{j,t} + \varepsilon^{o\cdot r}_{j,t} \quad (2)$$

Here, $\mathrm{CMR}_{j,t}$ is the under-five child mortality rate for the jth country in year t. Separate regressions are conducted to test its correlation with underweight children aged 3–35 months in that country and year, as measured by the three different nutritional indices that we calculate for each country. These are denoted by $\mathrm{FGT}^{o,r}_{j,t}$, with superscripts for each order parameter (o) and reference levels of underweight (r). The orders are 0, 1 and 2 for underweight prevalence, depth and severity, respectively. The reference levels are denoted *extreme* for the conventional definition of underweight ($z < -2$), *all* for the full set of underweight observations ($z < 0$), and *mild* for only the intermediate cases ($-2 < z < 0$). In some regressions we include measures of both mild and extreme underweight variables, and we use a variety of control variables for each country and year ($X_{j,t}$). These include country fixed effects to absorb any time-invariant national characteristics, and real per-capita income as a determinant of both household purchasing power and the country's ability to provide public goods.

We also consider whether underweight prevalence itself is closely correlated with standard determinants of child nutritional status. The regression specification is:

$$FGT^{o,r}_{j,t} = \alpha^{o,r} + \beta^{o,r}X^{o,r}_{j,t} + \varepsilon^{o,r}_{j,t} \quad (3)$$

where the regressors (X) include real income, other variables and country fixed effects as explained in the following section.

3. Data

We construct each of our measures from the underlying weight and height of individual children aged 3 through 35 months, reported in 130 Demographic and Health Surveys (DHS) from 53 developing countries over various years from 1986 through 2006, sourced from Macro International (2008). About half the sample is from Africa (69 surveys from 27 countries), and about one-fifth is from Latin America (28 surveys from 10 countries), with the remainder from South, Southeast and Central Asia (Table 1).

Descriptive statistics in Table 2 reveal that the prevalence of extreme, mild and all underweight differ greatly in magnitude if measured by the headcount index (FGT0). The higher-order nutritional measures are more similar across the three categories of underweight, since by definition there are smaller gaps between observed and reference values for mild as opposed to extreme cases.

To explore the correlation between child underweight and child mortality we use data on under-five child mortality rate per thousand live births, obtained from UNICEF (2008), regressed on the prevalence of in underweight using a log–log specification. This allows coefficients to be interpreted as percentage elasticities. In some of these regressions, we control for national income using log real GDP per capita in PPP terms, measured in constant 2000 international dollars, from the Penn World Tables as reported in the World Bank's World Development Indicators (WDI). To control for all time-invariant national characteristics using country fixed effects, we drop the 13 countries with only one survey year so our final sample size in these regressions is 117 observations over 40 countries.

To explore the correlates of child underweight, we draw on an extensive literature concerning the determinants of child malnutrition across countries and over time (Smith and Haddad, 2002), focusing on the most important variables that have been collected in a consistent manner across our sample of countries and years. This rules out some potential determinants such as health care investments, but does allow us to consider four main ways in which socio-economic conditions might influence underweight

Table 1
List of Demographic and Health Surveys used to construct underweight measures.

Regions	No. of countries	No. of Surveys	Countries and years surveyed
Africa	27	69	Benin (1996, 2001), Burkina Faso (1998, 1992, 2003), Burundi (1987), CAR (1994), Cameroon (1991, 1998, 2004), Chad (1996, 2004), Comoros (1996), Cote d'Ivoire (1994, 1998), Ethiopia (1992, 1997), Gabon (2000), Ghana (1988, 1993, 1998, 2003), Guinea (1999, 2005), Kenya (1993, 1998, 2003), Madagascar (1992, 1997, 2003), Malawi (1992, 2000, 2004), Mali (1987, 1995, 2001), Mozambique (1997, 2003), Namibia (1992, 2000), Niger (1992, 1998, 2006), Nigeria (1990, 1999, 2003), Rwanda (1992, 2000, 2005), Senegal (1986, 1992, 2005), Tanzania (1991, 1996, 1999, 2004), Togo (1988, 1998), Uganda (1988, 2000, 2006), Zambia (1992, 1996, 2001), Zimbabwe (1988, 1992, 1994, 1996, 2005)
Asia	7	13	Bangladesh (1996, 1999, 2004), Cambodia (2000, 2005), India (1992, 1998, 2005), Nepal (1996, 2001), Pakistan (1990), Sri Lanka (1987), Thailand (1987)
Central Asia	5	9	Armenia (2000, 2005), Kazakhstan (1995, 1999), Kyrgyz Republic (1997), Turkey (1993, 1998, 2003), Uzbekistan (1996)
Latin American and the Caribbean	10	28	Bolivia (1989, 1993, 1998, 2003), Brazil (1986, 1996), Colombia (1986, 1995, 2000, 2004), Dominican Republic (1986, 1991, 1996, 2002), Guatemala (1987, 1995, 1998), Haiti (1994, 2000, 2005), Nicaragua (1997, 2001), Paraguay (1990), Peru (1991, 1996, 2000, 2005), Trinidad & Tobago (1987)
Middle East	4	11	Egypt (1988, 1992, 1995, 2000, 2003, 2005), Morocco (1987, 1992, 2003), Tunisia (1988), Yemen (1991)

prevalence: national income, income inequality, gender inequality and local agricultural output. In a few cases, values were imputed from immediately adjacent years, but otherwise the data are left missing. Our final sample size with these four variables is thus restricted to 114 observations over 40 countries.

Variables used in our child underweight regressions start with national income (*realgdp*) as defined above. We also include the Gini coefficient (*gini*) of income inequality from the World Income Inequality data base (UNU/WIDER, 2008). The inequality data have substantial limitations, so we might expect a relatively high degree of measurement error in this variable (Atkinson and Brandolini, 2009).

To capture the extent of discrimination against girls and women, we measure gender equity (*geneq*) as female minus male life expectancy, normalized by male life expectancy. These data are drawn from the UN's Population Projections, as reported in the World Development Indicators (World Bank, 2009). The *geneq* variable is usually positive, since potential life expectancy is higher for females, but *geneq* can be negative when gender discrimination severely limits opportunities for girls and women. Differences in life expectancy hardly capture all of the salient issues in gender relations, but offer an important summary measure of cumulative biases due to gender discrimination across countries and over time (Klasen and Wink, 2002).

Table 2
Descriptive statistics for all variables ($N = 130$).[a].

Variable	Mean	Std	Min	Max	Definition	Source
Extreme underweight						
Headcount	9.43	6.57	0.62	29.00	FGT index of order 0 (share of people) for $z < -2$	DHS[b]
Depth	0.27	0.19	0.02	0.93	FGT index of order 1 (cumulative gap) for $z < -2$	DHS[b]
Severity	0.82	0.59	0.05	3.09	FGT index of order 2 (sum of sq. gaps) for $z < -2$	DHS[b]
All underweight						
Headcount	52.24	16.57	20.84	82.55	FGT index of order 0 (share of people) for $z < 0$	DHS[b]
Depth	0.62	0.30	0.14	1.36	FGT index of order 1 (cumulative gap) for $z < 0$	DHS[b]
Severity	1.24	0.73	0.17	3.66	FGT index of order 2 (sum of sq. gaps) for $z < 0$	DHS[b]
Mild underweight						
Headcount	42.80	11.54	18.74	69.05	FGT index of order 0 (share of people) for $-2 < z < 0$	DHS[b]
Depth	0.35	0.13	0.12	0.68	FGT index of order 1 (cumulative gap) for $-2 < z < 0$	DHS[b]
Severity	0.42	0.18	0.12	0.87	FGT index of order 2 (sum of sq. gaps) for $-2 < z < 0$	DHS[b]
Realgdp	0.26	0.20	0.05	1.04	Real GDP per capita in PPP terms (US$1000s)	World Bank (2009)
Geneq	0.06	0.04	−0.05	0.18	Gender equity in life expectancy = (female − male)/male	World Bank (2009)
Gini	46.51	9.89	28.70	73.90	Gini coefficient for income	UNU/WIDER (2008)
Agout[c]	0.29	0.24	0.05	1.62	Agricultural output per rural person	FAO (2009)
CMR	117.44	59.34	22.60	292.82	Child mortality (under 5), per 1000	UNICEF (2008)

[a] All variables have 130 observations, except for the Gini variable which has 89 and *agout* which has 114.
[b] Author's calculation using data from Demographic and Health Surveys (DHS).
[c] The *agout* data are compiled by the FAO from national reports of production by commodity, subtracting outputs that are also used as seed or feed to obtain net production of each commodity, and weighting that by a world price to obtain the total value of output.

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To capture local food production, we use the FAO estimate of total agricultural output (*agout*), defined as net farm production in 1999–2001 international dollars (FAO, 2009). Almost all countries also import food, for which purchasing power is already captured in *realgdp* and *gini*. We normalize total food production by the UN Population Projections' estimate of rural population to obtain output per rural person, and use the result in log form. This variable is undoubtedly subject to considerable measurement error, but does offer a potentially valuable indicator for all countries and years.

4. Results

To describe our results we begin with graphical illustrations of the data, and then turn to regression results.

4.1. Probability density functions

The underlying source of differences in results when using mild as opposed to extreme underweight is shown using nonparametric kernel estimates of the relevant probability density functions (PDFs) for three example countries (Fig. 2). The case of Guinea shows a rightward shift in the distribution from 1999 to 2005, while Togo shows a leftward shift from 1988 to 1998, and Morocco shows a rightward shift from 1987 to 1992 followed by an expansion in both underweight and overweight. These shifts in national PDFs over time are significant for all three countries. For Guinea the Kolmogorov–Smirnov (KS) test statistic is 0.054 and the Mann–Whitney–Wilcoxon (MWW) test statistic is −2.89. Both tests reject the null that the samples were drawn from the same distribution. Similar results were found for Togo and Morocco (Fig. 2).

Our three kinds of underweight measure count all observations to the left of $z = -2$ (for extreme underweight), between −2 and 0 (for mild underweight), and to the left of 0 (for all levels of underweight). The distinction leads to large differences in empirical results. For example, in Guinea the headcount index of extreme underweight fell very slightly between 1999 and 2005, from 14.5 to 14.3, whereas for all underweight it declined sharply from 63.2

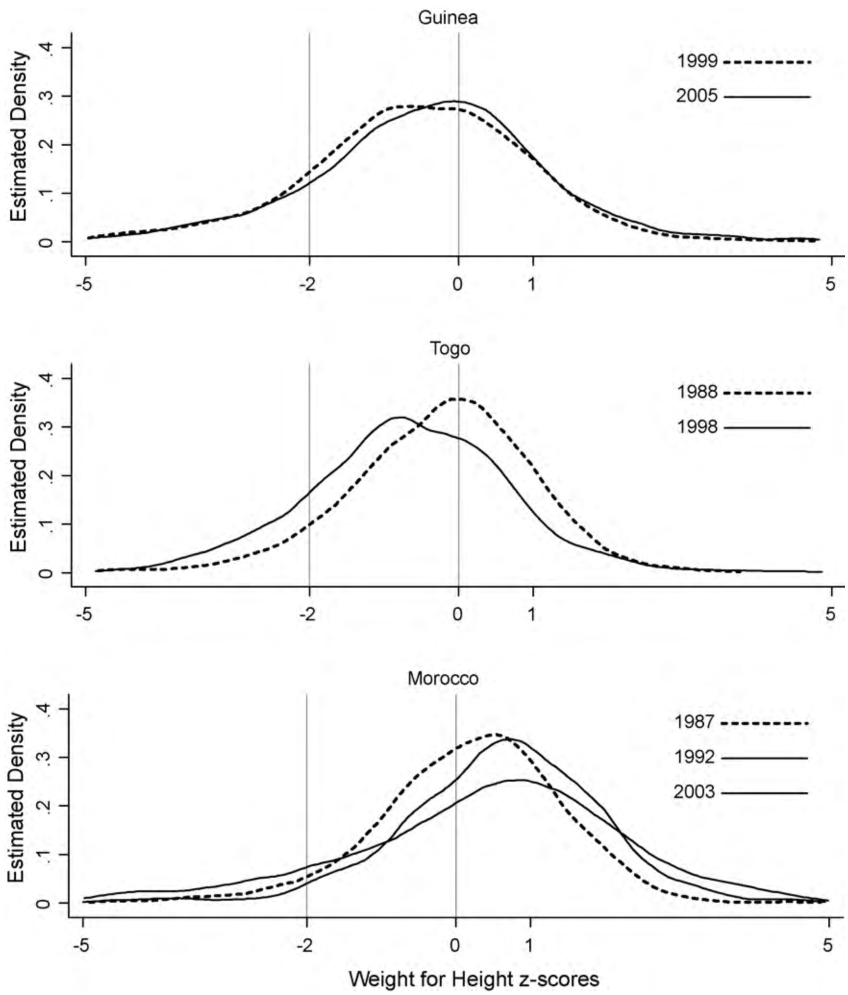

Fig. 2. Estimated distributions of weight-for-height *z*-scores for selected countries. *Note*: Kolmogorov–Smirnov (KS) and Mann–Whitney–Wilcoxon (MWW) tests for the equality of distributions for each of the countries are Guinea, KS: 0.054*, MWW: −2.89*; Togo, KS: 0.18*, MWW: 12.15*; Morocco for 1987 and 1992: KS:0.15*, MWW: −12.18* and 1992 and 2003; KS:0.1*, MWW: 2.57 where $^{*}p < 0.5$.

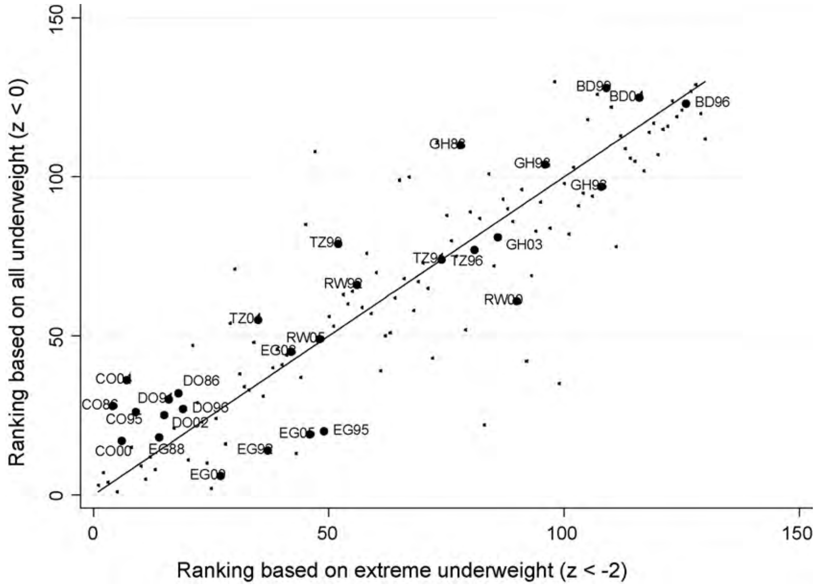

Fig. 3. Country rankings using headcount indices, all versus extreme underweight.Table 3. CO – Colombia, DO – Dominican Republic, GH – Ghana, BD – Bangladesh, TZ – Tanzania, RW – Rwanda and EG – Egypt. The last two numbers represent the calendar year of data used to calculate the rank.

to 54.4. In Morocco between 1987 and 2003 even the direction of change differs, as the headcount index of extreme underweight rose from 4.7 to 10.4 while for all underweight it declined from 40.5 to 34.6.

4.2. Country rankings

The extent to which we obtain different rankings when counting mild underweight in addition to the extreme cases is illustrated in Fig. 3 for the headcount indices, Fig. 4 for the depth indices, and Fig. 5 for the severity indices. In each chart, ordinal rankings from conventional measures are plotted on the horizontal axis, while rankings from new measure of all underweight are on the vertical axis. Rankings range from 1 (the least underweight) to 130 (the most underweight). A 45-degree line through the origin represents equality between the two rankings.

The labeled points reveal, for example, that Colombia (CO) has a consistently higher (less desirable) ranking in terms of all underweight on the vertical axis, than it has using the traditional measure of extreme underweight on the horizontal axis. In Egypt (EG) the opposite is generally

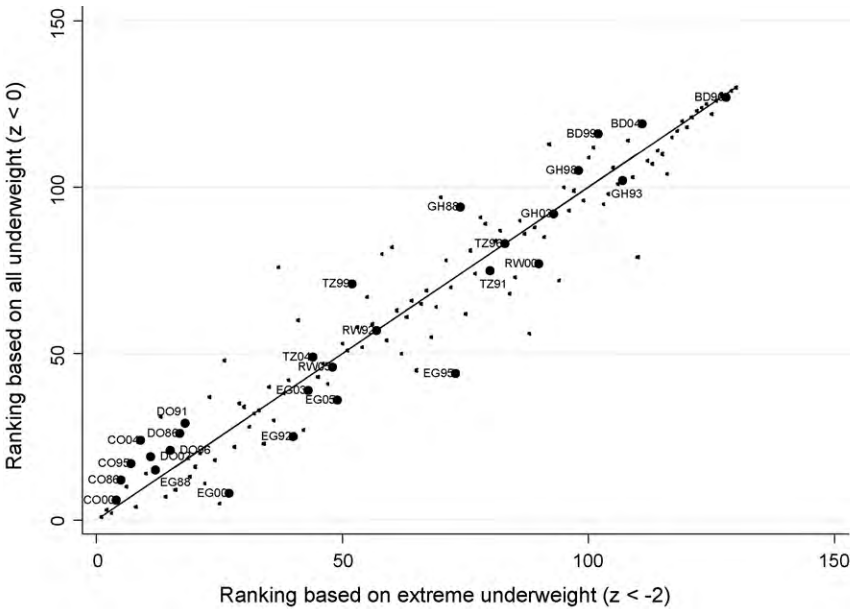

Fig. 4. Country rankings using depth indices, all versus extreme underweight.Authors' calculations. Labels are as for Fig. 3.

true. Changes within a country sometimes cause even more extreme change in rankings. Using the headcount indices in Fig. 3, from 1991 to 1999 Tanzania (TZ) saw an improvement in its ranking by extreme underweight, but its ranking in terms of all underweight worsened. From 1992 to 2000, Rwanda (RW) experienced the opposite

Table 3
Rankings based on prevalence of extreme ($z<-2$) and all ($z<0$) underweight.

Country	Year	All $z<0$	Extr. $z<-2$
Peru	2000	1	5
Armenia	2000	2	25
Paraguay	1990	3	1
Turkey	2003	4	3
Peru	1996	5	11
Egypt	2000	6	27
Peru	2005	7	2
Bolivia	2003	8	13
Bolivia	1998	9	10
Morocco	1992	10	24
Peru	1991	11	20
Bolivia	1989	12	12
Armenia	2005	13	43
Egypt	1992	14	37
Zimbabwe	1988	15	8
Kyrgyz Rep	1997	16	28
Colombia	2000	17	6
Egypt	1988	18	14
Egypt	2005	19	46
Egypt	1995	20	49
Brazil	1986	21	17
Morocco	2003	22	83
Kazakhstan	1999	23	23
Brazil	1996	24	26
Dominican Rep	2002	25	15
Colombia	1995	26	9
Dominican Rep	1996	27	19
Colombia	1986	28	4
Nicaragua	2001	29	22
Dominican Rep	1991	30	16
Kazakhstan	1995	31	36
Dominican Rep	1986	32	18
Nicaragua	1997	33	33
Guatemala	1998	34	32
Nigeria	1999	35	99
Colombia	2004	36	7
Bolivia	1993	37	44
Turkey	1998	38	31
Malawi	2004	39	61
Morocco	1987	40	38
Turkey	1993	41	40
Uzbekistan	1996	42	92
Zimbabwe	1999	43	72
Gabon	2000	44	41
Egypt	2003	45	42
Guatemala	1995	46	39
Guatemala	1987	47	21
Tunisia	1988	48	34
Rwanda	2005	49	48
Zimbabwe	2005	50	62
Cameroon	2004	51	63
Malawi	2000	52	79
Zimbabwe	1994	53	51
Uganda	1988	54	29
Tanzania	2004	55	35
Cameroon	1991	56	50
Kenya	2003	57	59
Cameroon	1998	58	68
Mozambique	2003	59	57
Uganda	2000	60	54
Rwanda	2000	61	90
Zambia	2001	62	64
Haiti	2000	63	53
Zambia	1996	64	55
Malawi	1992	65	71
Rwanda	1992	66	56
Kenya	1993	67	69
Uganda	1995	68	66
Haiti	2005	69	93
Zambia	1992	70	60
Trinidad & Tob.	1987	71	30
Comoros	1996	72	85
Kenya	1998	73	70
Tanzania	1991	74	74
Uganda	2006	75	77
Togo	1988	76	58
Tanzania	1996	77	81
Yemen	1991	78	111
Tanzania	1999	79	52
CAR	1994	80	76
Ghana	2003	81	86
Guinea	2005	82	101
Mozambique	1997	83	94
Nigeria	2003	84	97
Senegal	1986	85	45
Senegal	1992	86	89
Namibia	1992	87	82
Cote d'Ivoire	1998	88	75
Senegal	2005	89	80
Haiti	1994	90	88
Pakistan	1990	91	103
Benin	2001	92	95
Cote d'Ivoire	1994	93	87
Ethiopia	1997	94	106
Guinea	1999	95	104
Namibia	2000	96	91
Ghana	1993	97	108
Nigeria	1990	98	100
Burundi	1987	99	65
Madagascar	1992	100	67
Madagascar	1997	101	84
Madagascar	2003	102	117
Togo	1998	103	102
Ghana	1998	104	96
Benin	1996	105	115
Niger	2006	106	114
Chad	2004	107	120
Thailand	1987	108	47
Mali	2001	109	113
Ghana	1988	110	78
Cambodia	2005	111	73
Burkina Faso	2003	112	130
Ethiopia	1992	113	112
Cambodia	2000	114	118
Burkina Faso	1992	115	121
Chad	1996	116	122
India	1998	117	119
Mali	1987	118	105
Burkina Faso	1998	119	124
Mali	1995	120	129
India	1992	121	125
Nepal	1996	122	110
Bangladesh	1996	123	126
India	2005	124	123
Bangladesh	2004	125	116
Nepal	2001	126	107
Niger	1992	127	127
Bangladesh	1999	128	109
Niger	1998	129	128
Sri Lanka	1987	130	98

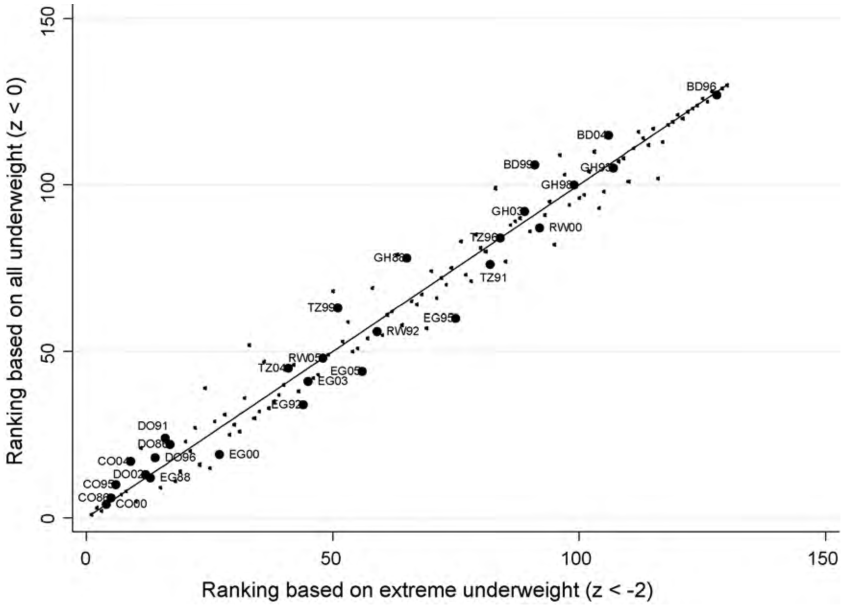

Fig. 5. Country rankings using severity indices, all versus extreme underweight.Authors' calculations. Labels are as for Fig. 3.

shift. Ghana (GH) oscillated in one direction then the other from 1988 to 1993 then 1998, before improving in both rankings in 2003. For Bangladesh (BD), almost all the change has been in rankings by extreme underweight, with little change in the ranking by total underweight.

The scatter plots of country rankings deviate from the 45-degree line most when using the headcount index (Fig. 3). The rankings are closer to the 45-degree line when using the higher-order FGT formulas in Figs. 4 and 5, reflecting the fact that these depth and severity indices put greater emphasis on the extreme values which both measures have in common. This emphasis is clearly visible in the case of Bangladesh: with our new measure of all underweight, from 1996 to 1999 its ranking relative to other observations worsened in Fig. 3, but improved in Figs. 4 and 5. During this period, Bangladesh made little progress against mild underweight, even as it successfully reduced the incidence of more extreme cases.

4.3. Correlation with child mortality

Empirical tests of Eq. (2) presented in Table 4 reveal whether our new measures of mild underweight provide a useful signal of changes in public health. The dependent variable is child mortality, which we regress on successive measures of mild, extreme or all underweight in a variety of specifications. The first three columns offer horse-race regressions to test whether variance in child mortality is more closely linked to extreme or mild underweight, when controlling for income and country fixed effects. It turns

Table 4
Specification testing for the child mortality regression.

	1	2	3	4	5	6
	(Headcount)	(Depth)	(Severity)	(Headcount)	(Headcount)	(Headcount)
Extreme cases	0.006 (0.085)	−0.052 (0.084)	−0.065 (0.084)	0.035 (0.090)		
All cases					0.389* (0.184)	
Mild cases	0.416* (0.198)	0.403* (0.168)	0.343* (0.152)			0.419* (0.185)
Real GDP per capita	−0.871*** (0.162)	−0.879*** (0.158)	−0.885*** (0.158)	−0.916*** (0.165)	−0.872*** (0.166)	−0.871*** (0.161)
Constant	2.299** (0.715)	4.220*** (0.193)	4.080*** (0.321)	3.597*** (0.277)	2.341** (0.745)	2.300** (0.716)
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.898	0.899	0.897	0.891	0.898	0.900
$\beta_1 = 0$	[0.946]	[0.54]	[0.439]			
$\beta_2 = 0$	[0.039]	[0.019]	[0.027]			
$\beta_1 = \beta_2$	[0.095]	[0.0418]	[0.0542]			
All $\alpha_i = 0$	[0.000]	[0.000]	[0.000]			

The dependent variable for all regressions is under-five child mortality rate per thousand live births. All variables are in natural logarithms, with 117 observations over 40 countries. The Huber White sandwich estimator of variance is used for standard errors (in parentheses). Significance levels shown are $^*p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$. *p*-Values are in square brackets, where β_1 is the coefficient on the headcount index of extreme cases, β_2 is the coefficient on the headcount index of mild cases, and α_i are coefficients for the country fixed effects. Without country fixed effects and income in specifications (1)–(4) the extreme underweight measures were significant. Results for a specification for child mortality interacted with sub saharan Africa indicator were not significant.

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Table 5
Results for conventional and new headcount measures of child underweight, regressed on standard influences.

Dependent variable:	Extreme cases			All cases			Mild cases		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Real GDP per capita	−3.182** (1.054)	−3.691 (2.462)	−3.476** (1.094)	−9.098*** (2.608)	−1.126 (4.398)	−5.631* (2.435)	−0.142** (0.046)	0.077 (0.104)	−0.061 (0.046)
Gender equality	−111.173*** (28.550)	4.392 (34.763)	−59.971* (29.970)	−220.098*** (59.211)	5.486 (67.476)	−39.123 (48.257)	−2.444** (0.918)	−0.369 (1.167)	−0.706 (0.805)
Gender equal. sq.	502.869*** (142.833)	3.768 (251.248)	243.723 (172.348)	1111.869*** (302.635)	356.610 (377.364)	335.242 (286.649)	16.190** (5.081)	11.126 (6.871)	6.659 (5.174)
Ag. output index	−2.122* (0.992)	1.331 (2.102)	−1.315 (0.915)	−7.120* (2.789)	−8.807* (4.325)	−8.688*** (2.606)	−0.155** (0.056)	−0.285* (0.112)	−0.202*** (0.059)
Constant	5.526** (1.943)	0.553 (2.375)	4.678** (1.693)	34.509*** (4.516)	31.047*** (4.617)	31.699*** (4.165)	3.315*** (0.084)	3.456*** (0.097)	3.338*** (0.095)
Country fixed effects	No	Yes	No	No	Yes	No	No	Yes	No
Random Effects	No	No	Yes	No	No	Yes	No	No	Yes
R-squared	0.414	0.830		0.498	0.915		0.436	0.803	
N	114	114	127	114	114	127	114	114	127
Ramsey RESET test	[0.092]	[0.031]		[0.005]	[0.296]		[0.001]	[0.199]	
Hausman test			[0.016]			[0.064]			[0.546]

All variables are in natural logarithms except for gender equality and the Gini coefficient. The number of observations is shown below each regression. There are 40 countries in the 114-observation sample, and 53 countries in the 127-observation sample used in the random effects models. The Huber White sandwich estimator of variance is used for standard error (in parentheses). The *p*-values for the observed significance level of the Ramsey RESET test and the Hausman test is in square brackets. Significance levels shown are $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$. A similar pattern of results was obtained with the higher-order FGT indices for the depth and severity of underweight in each range.

out that only mild underweight is significant, and the estimated elasticity of child mortality with respect to it is 0.42 for the headcount index, 0.40 for the depth index, and 0.34 for the severity index.

The last three columns in Table 4 drop one of the two undernutrition measures, and show headcount indices only. Again the measure of extreme underweight is not correlated with child mortality, whereas mild underweight is linked to it with an elasticity of 0.42, and the combined measure of all cases has an elasticity of 0.39. In robustness tests not presented here, without fixed effects we found that both extreme and mild underweight were significant correlates of child mortality, and without income the magnitude of the coefficient on mild underweight was larger and remains significant. Also, the specifications reported in columns 4–6 were repeated using the higher-order indices for depth and severity, and again the only significant measures were those that counted cases of mild underweight. Finally, concerns about heterogeneity across regions were addressed by using an indicator variable for observations from Sub-Saharan Africa (SSA) which accounts for about half our sample. We found that it had no significance in its interaction with any of the underweight measures, suggesting no difference in the correlations between mortality and underweight.

In summary, results for Eq. (2) show robust significance for variation in mild underweight as a correlate of child mortality, across and within countries and controlling for per-capita income. The elasticity is such that each percentage increase in mild or all underweight is associated with a 0.4% increase in child mortality. This correlation does not imply that mildly underweight individuals face large individual health risks, but it does suggest that their bodyweights convey useful information about public health.

4.4. Correlation with determinants of child underweight

Our tests of Eq. (3) address the factors that influence mild as opposed to extreme underweight. Results are shown in Table 5 for the headcount index only. Robustness tests using the higher-order depth and severity indices have similar results and are not shown. Each set of three columns uses one of the three definitions of underweight: the first set uses the conventional measure of extreme underweight, while the second and third use our new measures of all underweight and mild underweight only. All are regressed on the same independent variables: real income, gender equality and its square, local agricultural output and a constant. All variables are in logs, except for gender equality which offered a closer fit using a quadratic specification. Results shown omit the Gini coefficient as a regressor, because it is available for only a subset of our data ($N = 88$) and when included is not significantly correlated with underweight in any of our specifications. Within each set of three columns, the first column presents results across the entire pooled dataset, the second column adds country fixed effects to isolate changes over time, and the third column uses random effects to control for any common shocks across countries such as the relative cost of food on world markets. (Random effects are not reported in Table 4, due to the absence of common shocks to child mortality.)

All three measures of underweight prevalence turn out to be significantly correlated with all of the independent variables, but this holds only in the pooled cross-section. When we control for country fixed effects, extreme underweight is no longer correlated with any of these plausible influences, whereas mild and all underweight remain significantly correlated with local agricultural production. In summary, our results for Eq. (3) show that mild underweight differs from extreme underweight mainly in that it is more closely correlated with local agricultural output. That relationship survives country fixed effects as well as random effects specifications in Table 5, and also holds for higher-order FGT indices.

5. Conclusions

The literature on malnutrition focuses primarily on extreme cases of under- or overweight, using conventional thresholds of severity. This is entirely appropriate in a clinical setting or when working with individual data, since more extreme cases involve greater health risks. But for population-level studies, where the entire distribution of measured bodyweights is available, focusing only on the extremes misses information that might be provided by variation in mild cases. For example, the prevalence of mild underweight might be correlated with otherwise-unobserved changes in disease exposure or other public health conditions. Tracking mild underweight could also help overcome measurement error and small sample sizes among the extreme cases.

We focus on underweight among children in developing countries, at their most vulnerable stage between three months and three years of age. We use individual data from all available DHS surveys to construct new population-level measures that count both extreme and mild cases of underweight, using weight-for-height ratios relative to the WHO's reference population at each age and sex. Whereas conventional measures count only children who fall more than two standard deviations below the reference median, our approach includes a much larger number of children whose weight-for-height ratio falls anywhere below that median. The resulting distributions are summarized by FGT-type indices for the headcount, depth and severity of underweight, which apply exponents of 0, 1 or 2 as increasingly large weights on the gap between observed and reference values.

Comparing various measures across 130 DHS surveys from 53 countries, we find that including mild underweight leads to different country rankings than if only conventionally-defined extreme underweight were included. This difference turns out to be highly informative. In a series of regression tests, we show that our measures of mild underweight have larger and more robust correlations with under-five child mortality rates than traditional measures of extreme underweight. In our preferred specification we also control for changes in per-capita income, and find an estimated elasticity of child mortality with respect to mild underweight of about 0.4, for within-country variance over time. In contrast, the conventional elasticity is not significantly different from 0.

Many factors could influence the extent of mild as opposed to extreme underweight, and account for its more robust correlation with child mortality rates. We provide suggestive evidence that mild and extreme underweight both respond in expected ways to standard influences on nutrition. The main difference is that mild underweight is more significantly correlated with local agricultural production, even with country fixed effects or using random effects to control for common shocks such as world food prices.

In summary, a focus on extreme cases may not be entirely appropriate for nutrition monitoring and economic analysis, where the full distribution of anthropometric status is available to the researcher. We find that counting mild instead of just extreme cases of child underweight makes population-level measures more closely correlated with child mortality rates, and is itself more closely correlated with local agricultural production. These results consider only child underweight in developing countries, but the approach could readily be applied to other anthropometric measures, making greater use of data on mild as well as extreme malnutrition to inform health policy and improve health outcomes.

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