EFFECTS AND DETERMINANTS OF MILD UNDERWEIGHT AMONG PRESCHOOL CHILDREN ACROSS COUNTRIES AND OVER TIME

by

Priya Bhagowalia, Susan E. Chen,
and William A Masters

Working Paper #09-13

October 2009

Dept. of Agricultural Economics

Purdue University

EFFECTS AND DETERMINANTS OF MILD UNDERWEIGHT AMONG PRESCHOOL CHILDREN ACROSS COUNTRIES AND OVER TIME

by
Priya Bhagowalia
Dept of Economics, TERI University
New Delhi, India
bhagowalia@alumni.purdue.edu
Susan E. Chen and William A. Masters
Dept. of Agricultural Economics, Purdue University
West Lafayette, Indiana 47907-2056
sechen@purdue.edu, wmasters@purdue.edu

Working Paper #09-13
October 2009

Abstract

Research on malnutrition typically focuses on severe cases, where anthropometric status falls below or above an extreme threshold. Such categorization is necessary for clinicians since mild cases may not justify intervention, but researchers could find that changes in mild malnutrition convey valuable information about mortality risk and health status. This paper focuses on changes in both mild and severe underweight in young children, as measured by 130 DHS surveys for 53 countries over a period from 1986 to 2007. We find that counting variance in all forms of underweight provides closer correlations with aggregate health outcomes (the under-five child mortality rate), and is more closely correlated to several influences of malnutrition (national income, gender equality and agricultural output). We conclude that the full distribution of nutritional status deserves greater attention, including in this case the prevalence of mild underweight among preschool children in developing countries.

Keywords: Underweight, weight-for-height, wasting, child mortality, FGT measures, DHS data

JEL Codes: I12, Q18

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, which is closely linked to other aspects of human welfare and economic development (Fogel 1994, Deaton 1997). 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 extreme underweight is being more than two standard deviations below the median of a reference population, as defined the World Health Organization (WHO 2006). In this study, we compare that kind of extreme underweight to milder variations in nutritional status, so as to consider all variance in child underweight below the reference median.

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 convey important information about changes in nutritional status, as a predictor of health outcomes and as a measure of program impacts. Among a sample of young children in Sudan, for example, 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 Figure 1. Other studies also find significant risks associated with sub-clinical undernutrition in different contexts: Pelletier (1994) summarizes analogous evidence from 28 epidemiological studies in 12 countries, drawing somewhat similar risk curves of varying shapes and slopes. More extreme values introduce higher risks, but there is typically some risk associated with mild underweight. As a result, counting the prevalence of mild underweight could improve nutrition monitoring, by conveying information about otherwise unobserved changes in health status.

The continuous nature of anthropometric data has been exploited by Sahn and Stifel (2002), Jolliffe (2004) and Madden (2006), to study the prevalence, depth and severity of both underweight and overweight. Their approach uses measures that were introduced by Foster, Greer and Thorbecke (1984) to study income shortfalls, but instead of a conventional poverty line they use standard thresholds for underweight and overweight. As shown by Sahn and Stifel (2002), comparisons among countries or over time are sensitive to the cutoff level used to define "malnutrition". Our approach in this paper uses the same Foster-Greer-Thorbecke (FGT) approach, extending the threshold all the way to the reference median so as to consider *all* underweight children, and test the significance of variation in the prevalence of mild as well as severe underweight across countries and over time.

Our data refer to a particularly vulnerable 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. Because of its obvious importance for social welfare, the socio-economic, geographic and economic determinants of child nutrition are 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, de Onis and Hanson 1997); and poor hygiene, inadequate feeding practices, and geographical location (de Onis, Frongillo and Blössner 2000).

In this paper we consider both the determinants of under-nutrition (in regressions of child underweight on income and other factors), and also its effects (in regressions of child mortality on child underweight and other factors), comparing results when counting mild as opposed to severe malnutrition. Each regression uses a variety of specifications including country fixed effects. Our central finding is that variance in mild underweight is closely linked to variance in child mortality and to key determinants of nutrition, even more so than variance in extreme underweight. Variance in mild malnutrition conveys information about mortality risk and nutritional status that is lost when we consider only extreme underweight, at least in this important sample of developing countries in recent years.

The structure of the paper is as follows. First, we outline the methodology that we use to measure nutritional status at the country level. Second, we summarize and describe the data used in this analysis. Third we compare the performance of mild as opposed to severe malnutrition as a correlate of infant mortality, and then compare the precision with which mild as opposed to severe malnutrition is correlated with various socioeconomic factors. We close with a discussion of the potential merits of considering mild underweight as a health indicator, in addition to conventional measures of severe malnutrition.

Methods

Nutritional status and individual-level z scores

To measure the prevalence of child underweight at the population level, we begin with individual data. Our variable of interest is a child's weight for height, which is relatively sensitive to whether they have recently absorbed enough nutrients to build and maintain bodyweight given their age, genetic growth potential, disease burden and activity level. The measure is particularly relevant among children aged 3-35 months, whose weight-for-height levels can fall sharply below their potential growth path when nutrient intake falls below the child's needs (Shrimpton et al. 2001).

To compare the anthropometric status of a particular child against their growth potential, we use *z* scores as advocated by the World Health Organization. These express the child's weight-for-height, y_i, as its difference from the median weight-for-height of a reference population, y_{50}, in terms of standard deviations, σ_y of the reference population:

$$z_i \equiv \frac{y_i - y_{50}}{\sigma_y} \tag{1}$$

The standard reference population for these measures is from WHO (2006), as encoded in the igrowup package of Stata programs (WHO 2008) which applies this formula to convert the observed weight and height of each child to their corresponding z score. Unlike previously used reference populations, such as the National Child Health Statistics (NCHS) reference which is based on a sample of US children, the WHO reference is designed to have globally-representative genetic variability in addition to cultural variation in how children are nurtured.

Aggregate conditions and population-level FGT measures

Individual data are aggregated to the population level using Foster-Greer-Thorbecke (FGT) measures, which add up the extent to which bodyweights fall below the reference level in a given country and year, with flexible weights on the degree of shortfall below the reference value. An FGT measure of order 0 is a headcount index, capturing only prevalence – the proportion of people who fall below the cutoff. An FGT measure of order 1 captures the depth of the shortfall, in the sense of a cumulative gap by which those people fall below the threshold. Finally, an FGT of order 2 captures the severity of the problem, weighting extreme values more heavily by adding up the square of each person's distance from the threshold. Using our notation, all three measures can be defined in a single equation as:

$$FGT^{o} \equiv \frac{1}{N}\sum_{i=1}^{N}\left(t - z_i\right)^{o} I(z_i \leq t)\,, \qquad (2)$$

where t is the user defined threshold, z_i is our anthropometric measure for the i^th^ child, N is the number of children in the population, and $I(z_i \leq t)$ is an indicator variable to include each observation with a z score which is lower than the user defined threshold. The order parameter (o) takes on values of 0, 1 and 2, as exponents on the shortfall associated with each observation. Equation (2) differs from most FGT formulas in that z-scores are already standardized across populations, so we do not need to perform the customary standardization of dividing by t (Sahn et al, 2002).

The conventional threshold used by the World Health Organization and others to classify children as severely underweight ("wasted") is a weight-for-height ratio more than two standard deviations below the median of the reference population (z < -2). Our approach compares such severe underweight with the prevalence of *all* underweight, defined as any shortfall below the reference median (z < 0). In this context, "mild" underweight refers to z scores between 0 and -2.

Variation in the prevalence of mild underweight could be important for its direct impact on health risks, or for its information content as a readily-measured signal of other risk factors. For example, the prevalence of mild underweight could fall due to a reduced burden of parasitic or infectious diseases, which reduces mortality risk and also allows children to stay on their potential growth path during early childhood. The resulting correlation between mortality risk and mild underweight may be like Figure 1, roughly linear below the reference median, but as shown by Pelletier et al. (1995) the shape and position of these risk curves can vary across space and time. The lowest-risk level of bodyweight could depend on the other risk factors to which children are exposed: for example, a higher weight in early childhood might be helpful for children at risk of later energy deficits, while a lower weight could reduce risks among those who are more nutritionally secure. For a worldwide sample of children, the most plausible minimum-risk bodyweight would be the median of the WHO's reference population, which is the threshold for our FGT measure counting all kinds of underweight.

Whatever threshold is used, the FGT order could be chosen to reflect the functional form by which underweight is linked to health risks. An FGT of order 0 would correspond to a stepwise loss function, while order 1 would imply that risk rises linearly with underweight, and order 2 would imply that risk rises with its square. In practice, the usefulness of higher-order FGT measures in this context may be limited by measurement errors that introduce more extreme values, as found for example by Moradi and Baten (2005). This kind of error would flatten the distribution, creating erroneous extreme values that are more heavily weighted at order 1 or 2. At order 0, measurement errors affect estimated prevalence only in the vicinity of the threshold.

Regression specifications and control variables

Our conceptual framework for studying child under-nutrition is based on a standard neoclassical model where inputs in 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 concern underweight as a determinant of health outcomes, and a second set concern other socioeconomic variables as determinants of underweight prevalence. In both kinds of regression our innovation is to consider the entire distribution of underweight levels, instead of just the severe cases used in conventional measures.

Our first set of hypotheses test for correlation of child underweight with child health outcomes, defined in terms of 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 things such as reduced disease burdens which incidentally also help children fulfill their growth potential. Regression specifications are of the following form:

$$CMR_{j,t} = \alpha^{o,r} + \beta^{o,r} FGT_{j,t}^{o,r} + \gamma^{o,r} X_{j,t} + \varepsilon_{j,t}^{o,r} \tag{3}$$

Here, $CMR_{j,t}$ is the under-five child mortality rate for the jth country in year t. Separate regressions are conducted to test its correlation with child underweight in that country and year, as measured by different FGT measures. These are denoted by $FGT_{j,t}^{o,r}$, with superscripts for each order parameter (o) and reference levels of underweight (r). The orders are 0, 1 and 2 for prevalence, depth and severity respectively. The reference levels are denoted *severe* 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 use additional 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.

Our second set of hypotheses asks whether underweight prevalence itself is closely correlated with standard determinants of child nutritional status. Here, the regression specification is:

$$FGT^{o,r}_{j,t} = \alpha^{o,r} + \beta^{o,r} X^{o,r}_{j,t} + \varepsilon^{o,r}_{j,t} \tag{4}$$

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

Data

We construct each of our FGT 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 2007, sourced from Macro International (2008). As shown in Table 1, 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.

Descriptive statistics for all variables are shown in Table 2. Mild and severe underweight differ greatly in magnitude, at least when measured by the headcount ratio (FGT^0). For conventionally-defined extreme underweight, this prevalence ($FGT^{0,severe}$) has a mean of 9.43 percent and a standard deviation of 6.57, whereas our new variable ($FGT^{0,mild}$) has a mean of 42.80 percent and a standard deviation of 11.54, and all kinds of underweight together ($FGT^{0,all}$) has a mean of 52.24 percent and standard deviation of 16.57. The higher-order measures (FGT^1 and FGT^2) are more similar in magnitude between mild and severe underweight, since mild underweight has a greater prevalence but smaller gaps between observed and reference values.

The data used to test our first set of hypotheses involve under-five child mortality rate per thousand live births, obtained from UNICEF (2008), regressed on the prevalence of underweight. Following Waldman (1992), we use 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 countries with only one survey year so our final sample size in these regressions is 117 observations.

For the data used to test our second set of hypotheses, we draw on an extensive literature concerning the determinants of child malnutrition across countries and over time (e.g. 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 socioeconomic conditions might influence underweight 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.

Variables used in our child underweight regressions start with national income (*realgdp)* as defined above. Since income may be unequally distributed, however, we also include the Gini coefficient (*gini*) of income 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 as detailed by 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. The gap also depends on the absolute level of average life expectancy so we normalize by male life expectancy. 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 (e.g. Klasen and Wink 2002).

To capture local food productivity, we use agricultural output per rural person (*agout*), defined as net farm production in 1999-2001 international dollars divided by the rural population, from FAOStat (FAO 2009). This variable measures local availability of food for on-farm consumption or sale to others; almost all countries also import food, for which purchasing power is already captured in *realgdp* and *gini*. 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. We then normalize this sum 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.

Results

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

Probability density functions

The underlying source of differences in our FGT measures for mild and severe underweight can be shown using the examples in Figure 2. These charts show nonparametric kernel estimates of the probability density functions (PDFs) for children's weight-for-height z scores in three countries, from successive DHS surveys in our dataset. The case of Guinea (Figure 2a) shows a rightward shift in the distribution from 1999 to 2005, Togo (Figure 2b) shows a leftward shift from 1988 to 1998, and Morocco (Figure 2c) 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, as indicated by the Kolmogorov-Smirnov (KS) and Mann-Whitney-Wilcoxon (MWW) statistics for differences between the distributions shown in Figure 2.

The FGT measures count all observations to the left of z = -2 (for severe underweight), between -2 and 0 (for mild underweight), and to the left of 0 (for all levels of underweight). The distinction turns out to be important, because the conventional focus on severe underweight would miss almost all of the change in Guinea, and would also miss much of the increased frequency of underweight children in Morocco from 1992 to 2003. These shifts occur only in the frequency of mild malnutrition, and so can be captured only by a measure that counts z scores in that range.

Rankings by underweight prevalence

The frequency with which FGT measures for mild and severe underweight give different rankings across our sample is illustrated in Figure 3, as detailed in Table 3. Here we show only the ordinal rank of each population, from 1 (the least underweight) to 130 (the most underweight), using the headcount ratios for both severe and all underweight ($FGT^{0,severe}$ and $FGT^{0,all}$). Table 3 lists the rankings, in order of $FGT^{0,all}$. Figure 3 arrays the rankings in a scatter plot, with the conventional measure ($FGT^{0,severe}$) on the horizontal axis and our new measure of all underweight ($FGT^{0,all}$) on the vertical axis. A 45-degree line through the origin represents equality between the two measures.

The scatter plot in Figure 3 has two noteworthy features. First, there is no clear relationship between the two rankings. Our new measure of all underweight does not systematically give lower rankings at lower levels of underweight, for example. Second, the rankings differ substantially. The scatter plot follows the 45 degree line, but not very closely. To describe these differences, we have labeled the points for six specific countries of general interest. From left to right, these are Colombia (CO), Egypt (EG), Tanzania (TZ), Rwanda (RW), Ghana (GH) and Bangladesh (BD).

The labeled points reveal, for example, that Colombia (CO) has a consistently higher (more desirable) ranking in terms of severe underweight than has using all underweight. In Egypt (EG) the opposite is generally true. Changes within a country sometimes cause even more extreme change in rankings. From 1991 to 1999, Tanzania (TZ) saw an improvement in its ranking by severe underweight, but its ranking in terms of all underweight worsened. From 1992 to 2000, Rwanda (RW) experienced the opposite 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 (DB), almost all the change has been in rankings by severe underweight, with little change in the ranking by total underweight.

Correlation with child mortality

Results for equation (3) are presented in Tables 4a-4c. The dependent variable for all three tables is child mortality, which we regress on successive measures of child underweight, without and with country fixed effects and real income per capita. All variables are in logs. Table 4a shows results for the headcount prevalence of underweight (FGT^0), Table 4b uses the depth of underweight (FGT^1) and Table 4c uses its severity (FGT^2). In each table, the first set of columns use the conventional definition of severe undernutrition (below z = -2), the second use our new definition of all underweight (below the median), and the third have just the mild cases ($-2 < z < 0$).

Table 4a reveals that the estimated coefficients on our new measures ($FGT^{0,all}$, $FGT^{0,mild}$) in columns 4-9 are much larger at high confidence levels than the corresponding coefficients on conventionally-defined underweight ($FGT^{0,severe}$) in columns 1-3. The estimated elasticities on our new measures are above 1.0 when we include cross-sectional variation in columns 4 and 7. When we control for country fixed effects in columns 5 and 8, these elasticities are above 0.5 and they are about 0.4 when we also control for changing national income over time in columns 6 and 9, remaining significantly different from zero at the 95 percent confidence level. In contrast, the estimated elasticity of child mortality with respect to conventionally-defined severe child underweight is relatively small in column 1, and is not significantly different from zero when we control for country fixed effects in columns 2 and 3.

In Tables 4b and 4c we obtain similar results. Using the underweight gap (FGT^1) in Table 4b and the sum of squared gaps (FGT^2) in Table 4c, our new measure of mild underweight is a statistically significant correlate of child mortality in all cases, even with country fixed effects and controlling for per-capita income, whereas the conventional measure of severe underweight becomes insignificant with those controls. These higher-order FGT measures make results using *all* underweight (in columns 4-6) similar to those that count only severe underweight (in columns 1-3), as the exponents weight extremes more heavily. Clearly, it is the variance in mild underweight that serves as the better predictor of child mortality at the population level. Mild underweight poses less of a mortality risk in a clinical sense, but its variance across countries and over time is more informative than the variance in severe underweight.

Correlation with determinants of child underweight

Results for equation (4) are presented in Tables 5a and 5b. The dependent variables in these two tables are each successive FGT measure of underweight, 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. Table 5a uses the headcount index, while Table 5b uses higher-order FGT measures. In Table 5a, columns 1 and 2 use conventionally-defined severe underweight ($FGT^{0,severe}$), columns 2 and 3 use our new measure of all underweight ($FGT^{0,all}$), and columns 4 and 5 use only mild underweight ($FGT^{0,mild}$). Each pair of columns presents results without and with country fixed effects. In contrast, for Table 5b, country fixed effects are omitted as explained below. Columns 1, 2 and 3 show results using the depth of underweight below each threshold ($FGT^{1,severe}$, $FGT^{1,all}$ and $FGT^{1,mild}$), while columns 4, 5 and 6 show results using its severity as the sum of squared gaps below each threshold ($FGT^{2,severe}$, $FGT^{2,all}$ and $FGT^{2,mild}$). Results for both tables were obtained without the Gini coefficient as a regressor; that variable is available for only a subset of our data (N=88), and when included it is not significantly different from zero in any of our specifications.

In Table 5a, estimated coefficients on the four variables (real income, gender equality and its square, and agricultural output) are almost all significant in every case when using the cross sectional variation (columns 1, 3 and 5), but not when controlling for country fixed effects (columns 2, 4 and 6). What changes is that our new measure of all underweight correlates to these determinants with larger estimated elasticities than severe underweight, and local agricultural output becomes a significant correlate even when controlling for country fixed effects. This significance holds for all underweight (in column 4) and for mild underweight only (column 6). When using only mild underweight (columns 5 and 6), we find generally lower elasticities but continued high significance levels.

Table 5b results are broadly similar to those of Table 5a, in that estimated coefficients are generally larger and more significant when using our new measure of all underweight than when only severe underweight is counted. The agricultural output index is consistently significant only for mild underweight. Otherwise all variables are significantly different from zero, and show larger estimated elasticities with respect to all underweight than with respect to only severe underweight. In the case of mild underweight only, with an FGT of order 2 the estimated elasticities turn smaller for all variables except agricultural output per rural person, which has a slightly larger and a more significant elasticity than in the regressions with all malnutrition. All of these higher-order results hold over the whole panel. With country fixed effects, none of the time-varying variables are significantly different from zero, so those results are suppressed from the table.

Taken together, these results reveal the prevalence of *all* underweight provides different country rankings than conventionally-defined *severe* malnutrition, and provides closer correlations with child mortality and with the various determinants of child malnutrition. The difference involves cases of mild underweight. The value of counting all underweight below the reference median, instead of focusing only on cases of severe malnutrition below an extreme threshold, could arise because of greater measurement errors at the extremes than around the median, or because mild underweight is a symptom of otherwise unobserved risk factors such as chronic disease.

Conclusions

The literature using anthropometric measures to track causes and consequences of malnutrition focuses primarily on the extent of severe under- or over-weight. Counting only extreme values is entirely appropriate in a clinical setting, since mild cases pose low risks that may not justify intervention. But for population-level studies, where the entire distribution of measured bodyweights is available, focusing on the extremes misses information that might be provided by variation in the extent of mild malnutrition.

In this paper we construct population-level measures that count both severe and mild underweight among children between the ages of three months and three years, relative to the median value of weight-for-height in 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 the much larger number of children whose weight-for-height ratio falls anywhere below the median and thereby considers the entire distribution of child underweight. These distributions are summarized by FGT measures for prevalence, depth and severity, which apply exponents of 0, 1 or 2 as increasingly large weights on the gap between observed and reference values.

Comparing our FGT measures across 130 DHS surveys, we find that the new median-based approach sometimes affects a country's ranking relative to others, across countries or over time. This is illustrated by the six countries whose values are labeled in Figure 3 (Colombia, Egypt, Tanzania, Rwanda, Ghana and Bangladesh), all of whom at one point experienced an improvement over time in the conventional ranking even as the new one worsened, or vice-versa. Many other countries ranked higher than another in severe underweight, while ranking lower in terms of all underweight.

Counting all underweight instead only severe cases can be particularly important if its variance is more closely correlated to health outcomes. Here we show higher estimated elasticities and more significant relationships when all instead of only severe underweight is used as a regressor for the child mortality rate, and when all instead of severe underweight is regressed on standard determinants of nutrition such as national income, income inequality, gender equality and local agricultural output. Despite small sample sizes, the agricultural output measure remains a significant correlate of all underweight even when controlling for country fixed effects, allowing only variance over time. And variance in all underweight provides a stronger correlate of child mortality. Most notably, severe underweight becomes insignificantly different from zero when controlling for country fixed effects, with or without controls for per-capita income, whereas variance in all underweight remains statistically significant with an estimated elasticity around 0.4-0.5.

In summary, a clinician's focus on severe cases may not be appropriate for nutrition monitoring and economic analysis, where the full distribution of anthropometric status is available to the researcher. We find that counting mild cases of child underweight makes population-level measures more closely correlated with child mortality rates than when only severe underweight is considered. These new measures are also more closely correlated with various possible influences on nutritional status such as local agricultural production. In this paper we 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 severe malnutrition to inform health policy and improve health outcomes.

References

Atkinson, A.B. and A. Brandolini. 2009. "On Data: A Case Study of the Evolution of Income Inequality Across Time and Across Countries." *Cambridge Journal of Economics* 33(3):381-404.

De Onis, M., E.A. Frongillo, and M. Blössner. 2000. “Is Malnutrition Declining? An Analysis of Changes in Levels of Child Malnutrition since 1980.” *Bulletin of the World Health Organization* 78(10):1222-1233.

Deaton, A. 1997. *The Analysis of Household Surveys: A Microeconometric Approach to Development Policy.* John Hopkins University Press, Baltimore.

FAO. 2009. *FAOStat database.* Online at http://faostat.fao.org.

Fawzi, W.W., M.G. Herrera, D.L. Spiegelman, A.E. Amin, P. Nestel, and K.A. Mohamed. 1997. “A Prospective Study of Malnutrition in Relation to Child Mortality in the Sudan.” *The American Journal of Clinical Nutrition* 65(4):1062-9.

Fogel, R. 1994. “Economic Growth, Population Theory and Physiology: The Bearing of Long-Term Processes on the Making of Economic Policy.” *American Economic Review* 84(3): 369-95.

Foster, J., J. Greer, and E. Thorbecke. 1984. “A Class of Decomposable Poverty Measures.” *Econometrica* 52:761-766

Frongillo, E.A., M. de Onis, and K.M.P. Hanson. 1997. “Socioeconomic and Demographic Factors Are Associated with Worldwide Patterns of Stunting and Wasting of Children.” *Journal of Nutrition* 127(12):2302-2309.

Hong, R. 2007. “Effect of Economic Inequality on Chronic Childhood Undernutrition in Ghana.” *Public Health Nutrition* 10:371-378.

Klasen, S. and C. Wink. 2002. “A Turning Point in Gender Bias in Mortality? An Update on the Number of Missing Women.” *Population and Development Review* 28(2):285-312.

Larrea C., and I. Kawachi. 2005. “Does Economic Inequality affect Child Malnutrition? The case of Ecuador.” *Social Science and Medicine* 60(1):165-178.

Macro International. 2008. Demographic and Health Surveys. Online at www.measuredhs.com.

Moradi, A. and J. Baten, 2005. "Inequality in Sub-Saharan Africa: New Data and New Insights from Anthropometric Estimates." *World Development* 33(8):1233-1265.

Pelletier, D.L. 1994.“The Relationship Between Child Anthropometry and Mortality in Developing Countries: Implications for Policy, Programs and Future Research.” *Journal of Nutrition* 124(10, Supplement): 2047S-2081S.

Pelletier, D.L., E.A. Frongillo, D.G. Schroeder, J.P. Habicht. 1995. “The Effects of Malnutrition on Child Mortality.” *Bulletin of the World Health Organization* 73(4):443-448.

Pritchett, L., and L.H. Summers. 1996. “Wealthier is Healthier.” *Journal of Human Resources* 31(4):841-868.

Sahn, D., and D.C. Stifel. 2002. “Robust Comparisons of Malnutrition in Developing Countries.” *American Journal of Agricultural Economics*. 84:716-735.

Shrimpton R., V.G. Cesar, M, deOnis, R.C. Lima, M. Blössner, and G.Clugston. 2001. **“**Worldwide Timing of Growth Faltering: Implications for Nutritional Interventions.” *Pediatrics* 107(5 May):75

Smith, L.C. and L. Haddad. 2002. “How Potent Is Economic Growth in Reducing Undernutrition? What Are the Pathways of Impact? New Cross-Country Evidence.” *Economic Development and Cultural Change* 51:55–76.

UNICEF. 2008. UNICEF Child Mortality Estimates: Under-five mortality rates. Online at: www.childinfo.org. Accessed on July 23, 2009.

UNU/WIDER. 2008. World Income Inequality Database, Version 2.0c, May 2008

Waldman, R.J. 1992 “Income Distribution and Infant Mortality” *Quarterly Journal of Economics* 107(4), 1283-1302.

World Health Organization. 2002. *World Health Report 2002.* Online at www.who.int/whr.

WHO Child Growth Standards. 2006. Length/height-for-age, weight-for-age, weight-for-length, weight-for-height and body mass index-for-age. Geneva: WHO; 2006 Online at www.who.int/childgrowth/standards.

World Health Organization. 2008. Program files and supporting documentation for igrowup. Online at www.who.int/childgrowth/software/en.

Table 1: List of Demographic and Health Surveys used to construct FGT 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, 2007), 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)

Table 2: Descriptive statistics for all variables ($N = 130$) [1]

Variable	Mean	Std	Min	Max	Definition	Source
$FGT^{0,severe}$	9.43	6.57	0.62	29.00	Prevalence (headcount) for z < -2	Author's calculation using DHS data
$FGT^{1,severe}$	0.27	0.19	0.02	0.93	Depth (cumulative gap) for z < -2	Author's calculation using DHS data
$FGT^{2,severe}$	0.82	0.59	0.05	3.09	Severity (sum of sq. gaps) for z < -2	Author's calculation using DHS data
$FGT^{0,all}$	52.24	16.57	20.84	82.55	Prevalence (headcount) for z < -2	Author's calculation using DHS data
$FGT^{1, all}$	0.62	0.30	0.14	1.36	Depth (cumulative gap) for z < -2	Author's calculation using DHS data
$FGT^{2, all}$	1.24	0.73	0.17	3.66	Severity (sum of sq. gaps) for z < -2	Author's calculation using DHS data
$FGT^{0,mild}$	42.80	11.54	18.74	69.05	Prevalence (headcount) for z < -2	Author's calculation using DHS data
$FGT^{1,mild}$	0.35	0.13	0.12	0.68	Depth (cumulative gap) for z < -2	Author's calculation using DHS data
$FGT^{2,mild}$	0.42	0.18	0.12	0.87	Severity (sum of sq. gaps) for z < -2	Author's calculation using DHS data
realgdp	0.26	0.20	0.05	1.04	Real GDP per capita in PPP terms	World Bank (2008)
geneq	0.06	0.04	-0.05	0.18	Gender equity in life expectancy	World Bank (2008)
gini	46.51	9.89	28.70	73.90	Gini coefficient in income	UNU-WIDER (2008)
agout	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 1,000	UNICEF (2008)

[1] Number of observations=89 for the Gini variable and 114 for agout.

Table 3: Rankings based on prevalence of severe (z=-2) and all (z=0) underweight

Country	Year	Rank Z=0	Rank 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 Republ	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 Re	2002	25	15
Colombia	1995	26	9
Dominican Re	1996	27	19
Colombia	1986	28	4
Nicaragua	2001	29	22
Dominican Re	1991	30	16
Kazakhstan	1995	31	36
Dominican Re	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 & To	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

Table 4a: Results for child mortality regressed on conventional and new measures of underweight prevalence (FGT0)

Regressors:	***Severe underweight only***			***All underweight***			***Mild underweight only***		
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**
$FGT^{0,severe}$	0.512***	0.056	0.035						
	(0.047)	(0.104)	(0.090)						
$FGT^{0,all}$				1.158***	0.538*	0.389*			
				(0.120)	(0.228)	(0.184)			
$FGT^{0,mild}$							1.253***	0.544*	0.419*
							(0.152)	(0.244)	(0.185)
Real GDP per capita			-0.916***			-0.872***			-0.871***
			(0.165)			(0.166)			(0.161)
Constant	3.636***	5.154***	3.597***	0.131	2.194*	2.341**	-0.007	2.280*	2.300**
	(0.105)	(0.320)	(0.277)	(0.474)	(1.005)	(0.745)	(0.573)	(1.024)	(0.716)
Country fixed effects	NO	YES	YES	NO	YES	YES	NO	YES	YES
R-squared	0.507	0.841	0.891	0.461	0.853	0.898	0.379	0.855	0.900
N	117	117	117	117	117	117	117	117	117

The dependent variable for all regressions is under-five child mortality rate per thousand live births.

All variables are in natural logarithms.

The Huber White sandwich estimator of variance is used for standard errors (in parentheses).

Significance levels shown are * $p<0.05$, ** $p<0.01$, *** $p<0.001$.

Table 4b: Results for child mortality regressed on conventional and new measures of underweight depth (FGT1)

Regressors:	*Severe underweight only*			*All underweight*			*Mild underweight only*		
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**
$FGT^{1,severe}$	0.52*** (0.049)	0.03 (0.098)	0.02 (0.084)						
$FGT^{1,all}$				0.80*** (0.077)	0.18* (0.157)	0.13 (0.137)			
$FGT^{1,mild}$							0.98*** (0.111)	0.44* (0.184)	0.35* (0.141)
Real GDP per capita			-0.92*** (0.163)			-0.91*** (0.166)			-0.88*** (0.160)
Constant	5.47*** (0.080)	4.04*** (0.359)	3.67*** (0.343)	5.12 (0.055)	5.30* (0.023)	3.80** (0.323)	5.74*** (0.127)	4.26*** (0.398)	4.23*** (0.182)
Country fixed effects	NO	YES	YES	NO	YES	YES	NO	YES	YES
R-squared	0.489	0.841	0.891	0.495	0.844	0.893	0.433	0.854	0.899
N	117	117	117	117	117	117	117	117	117

The dependent variable for all regressions is under-five child mortality rate per thousand live births.

All variables are in natural logarithms.

The Huber White sandwich estimator of variance is used for standard errors (in parentheses).

Significance levels shown are * $p<0.05$, ** $p<0.01$, *** $p<0.001$.

Table 4c: Results for child mortality regressed on conventional and new measures of underweight severity (FGT2)

Regressors:	*Severe underweight only*			*All underweight*			*Mild underweight only*		
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**
$FGT^{2,severe}$	0.508***	0.018	0.007						
	(0.048)	(0.092)	(0.079)						
$FGT^{2,all}$				0.638***	0.059	0.036			
				(0.061)	(0.122)	(0.105)			
$FGT^{2,mild}$							0.846***	0.341*	0.266*
							(0.093)	(0.152)	(0.123)
Real GDP per capita			-0.920***			-0.917***			-0.888***
			(0.163)			(0.164)			(0.162)
Constant	4.878***	5.312***	3.641***	4.625***	4.012***	3.660***	5.478***	4.027***	4.054***
	(0.041)	(0.067)	(0.288)	(0.039)	(0.279)	(0.281)	(0.097)	(0.328)	(0.327)
Country fixed effects	NO	YES	YES	NO	YES	YES	NO	YES	YES
R-squared	0.479	0.840	0.891	0.493	0.841	0.891	0.450	0.851	0.897
N	117	117	117	117	117	117	117	117	117

The dependent variable for all regressions is under-five child mortality rate per thousand live births.

All variables are in natural logarithms.

The Huber White sandwich estimator of variance is used for standard errors (in parentheses).

Significance levels shown are * $p<0.05$, ** $p<0.01$, *** $p<0.001$.

Table 5a: Results for conventional and new measures of child underweight prevalence (FGT0), regressed on standard influences

Dependent variable:	***Severe underweight*** **($FGT^{0,severe}$)**		***All underweight*** **($FGT^{0,all}$)**		***Mild underweight*** **($FGT^{0,mild}$)**	
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Real GDP per capita	-3.182**	-3.691	-9.098***	-1.126	-0.142**	0.077
	(1.054)	(2.462)	(2.608)	(4.398)	(0.046)	(0.104)
Gender equality	-111.173***	4.392	-220.098***	5.486	-2.444**	-0.369
	(28.550)	(34.763)	(59.211)	(67.476)	(0.918)	(1.167)
Gender	502.869***	3.768	1111.869***	356.610	16.190**	11.126
equal. sq.	(142.833)	(251.248)	(302.635)	(377.364)	(5.081)	(6.871)
Ag. output index	-2.122*	1.331	-7.120*	-8.807*	-0.155**	-0.285*
	(0.992)	(2.102)	(2.789)	(4.325)	(0.056)	(0.112)
Constant	5.526**	0.553	34.509***	31.047***	3.315***	3.456***
	(1.943)	(2.375)	(4.516)	(4.617)	(0.084)	(0.097)
Country fixed effects	NO	YES	NO	YES	NO	YES
R-squared	0.414	0.830	0.498	0.915	0.436	0.803
N	114	114	114	114	114	114

All variables are in natural logarithms except for gender equality and the Gini coefficient.

The Huber White sandwich estimator of variance is used for standard error (in parentheses).

Significance levels shown are * $p<0.05$, ** $p<0.01$, *** $p<0.001$

Table 5b: Results for conventional and new measures of child underweight depth and severity (FGT1 and FGT2), regressed on standard influences

	FGT1 Measures			FGT2 Measures		
Dependent variable:	**Severe ($FGT^{1,severe}$)**	**All ($FGT^{1,all}$)**	**Mild ($FGT^{1,mild}$)**	**Severe ($FGT^{2,severe}$)**	**All ($FGT^{2,all}$)**	**Mild ($FGT^{2,mild}$)**
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Real GDP per capita	-0.095** (0.031)	-0.166*** (0.048)	-0.211*** (0.062)	-0.301** (0.101)	-0.397** (0.121)	-0.252*** (0.071)
Gender equality	-2.826*** (0.727)	-4.456*** (1.120)	-4.089** (1.315)	-8.414*** (2.193)	-10.876*** (2.707)	-5.199** (1.553)
Gender eq. squared	12.584*** (3.612)	20.358*** (5.601)	22.473** (6.947)	37.420*** (10.886)	49.097*** (13.537)	28.399*** (8.309)
Ag. output index	-0.050 (0.029)	-0.101* (0.046)	-0.205** (0.072)	-0.144 (0.093)	-0.212 (0.113)	-0.245** (0.082)
Constant	0.152** (0.053)	0.373*** (0.081)	-1.636*** (0.109)	0.459** (0.165)	0.706*** (0.202)	-1.590*** (0.126)
Country fixed effects	NO	NO	NO	NO	NO	NO
R-squared	0.378	0.469	0.507	0.350	0.413	0.531
N	114	114	114	114	114	114

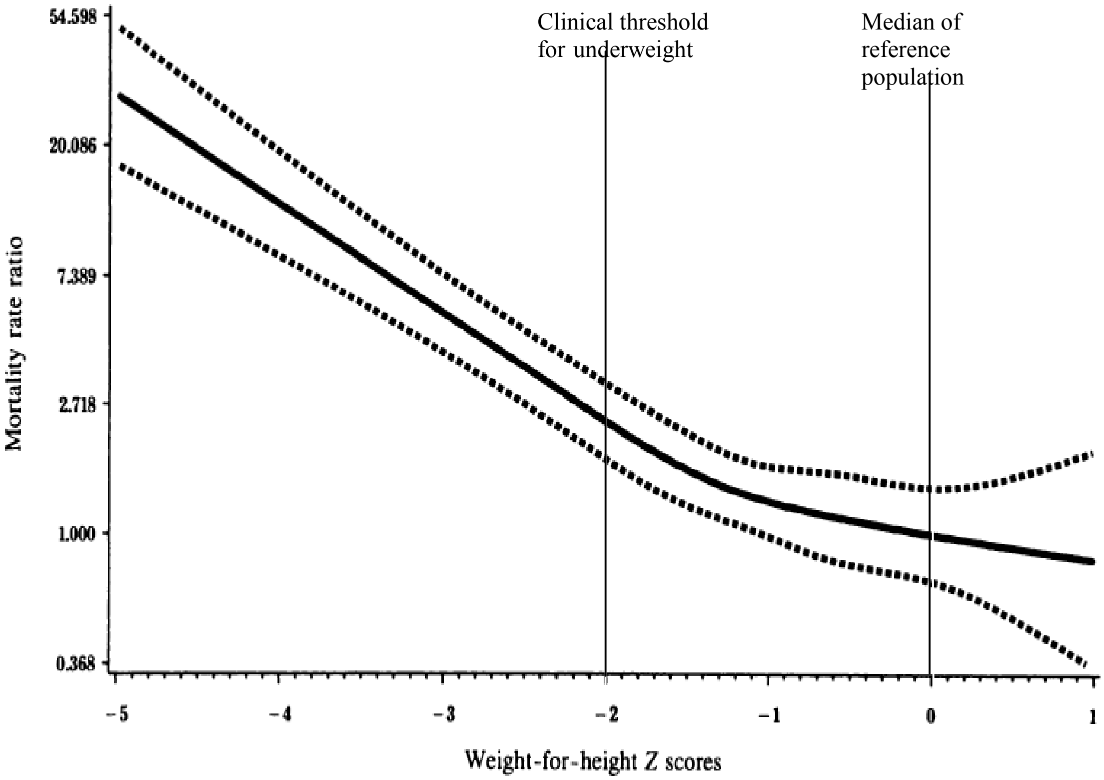
All variables are in natural logarithms except for gender equality and the Gini coefficient.

The Huber White sandwich estimator of variance is used for standard error (in parentheses).

Significance levels shown are * $p<0.05$, ** $p<0.01$, *** $p<0.001$.

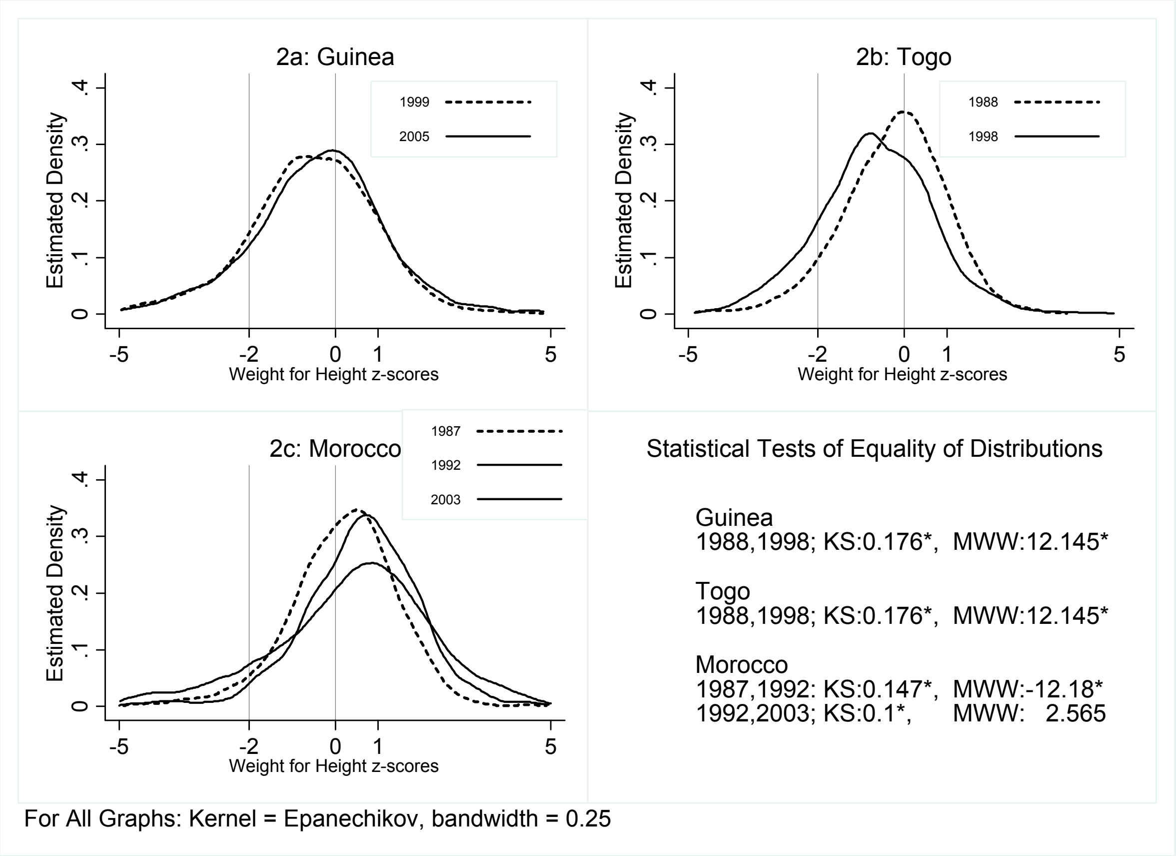
Results with country fixed effects are not shown, as none of the time-varying regressors are significantly different from 0.

Figure 1: Example relationship between child underweight and child mortality



Source: Reprinted from Fawzi, et al. (1997).

Figure 2: Estimated distributions of weight for height z scores for selected countries



Statistical Tests of Equality of Distributions

Guinea
1988,1998; KS:0.176*, MWW:12.145*

Togo
1988,1998; KS:0.176*, MWW:12.145*

Morocco
1987,1992: KS:0.147*, MWW:-12.18*
1992,2003; KS:0.1*, MWW: 2.565

For All Graphs: Kernel = Epanechikov, bandwidth = 0.25

KS and MWW are the results of a Kolmogorov Smirnov and Mann Whitney Wilcoxon test for the equality of the distributions. *p<0.05.

Figure 3: Comparison of prevalence rankings using alternative FGT measures