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Abstract

Malnutrition is manifested in various degrees of both underweight and overweight, with large differences and rapid changes in their prevalence and severity. This paper introduces a new approach to characterizing the distribution of a population's nutritional status, to help analyze changes in that distribution over time and across countries. Our method draws on the poverty literature to construct Foster-Greer-Thorbecke measures for the incidence and severity of under- and overweight, based on deviations in either direction from the median of a healthy population. We apply this median-based measure to the nutritional status of over 400,000 preschool children, as measured in 130 DHS surveys covering 53 countries over a period from 1986 to 2006. Unlike conventional threshold-based methods, the new approach counts changes in every child's bodyweight. We find that this offers a more sensitive measure of differences across countries and changes over time, showing in particular that children's bodyweights are closely linked to local agricultural output and gender equality as well as real GDP per capita.

Keywords: Underweight, Overweight, Malnutrition, Poverty

JEL: I12, Q18

The Distribution of Child Nutritional Status across Countries and over Time

Nutritional status is an important element of human welfare and economic development, differing widely across countries and over time. Starting with the influential work of Malthus (1798), economists have recognized food intake to be a key cause and also an important consequence of activity levels and economic productivity. In the modern era, Fogel (1994) focused economists' attention on changing nutritional status in the history of now-industrialized countries, while Strauss (1986) and others demonstrated its importance in today's low-income countries. Indeed, Deaton (1997) argues that nutritional status variables are among the most important and practical measures of human welfare, as compared to real incomes or expenditures as proxies for money metric utility.

To compare peoples' nutritional status, nutritionists rely on anthropometric measurement of a person's bodyweight relative to their height, age and sex. Variation in bodyweight is only one of many consequences of malnutrition, but it is readily measurable and closely linked to other aspects of nutritional status such as vulnerability to disease. In young children, the greatest concern is with undernutrition, which researchers measure in terms of low weight for height (wasting), height for age (stunting), or weight for age (underweight). Among older children and adults, researchers typically use weight for height squared as a body mass index (BMI), to track whether people are underweight, overweight or obese.

When comparing populations, researchers typically consider the fraction of people whose measurements exceed a conventional threshold. This treats wasting, stunting, underweight, overweight and obesity as yes/no questions, but nutritional status -- especially when captured with such a crude measure as bodyweight -- is clearly a continuous variable rather than a discrete condition. Moreover, the extent of deviation from a person's "healthy weight" is itself of interest, because the degree of under- or overweight may be correlated with a range of health risks. As a result, simple headcount measures of the fraction of people exceeding a threshold are incomplete measures of a population's nutritional status.

In the economics literature, Sahn and Stifel (2002) introduced the use of continuous measures for bodyweight to monitor and compare nutritional status across countries and time, applying techniques borrowed from the poverty-measurement literature (Foster, Greer and Thorbecke 1984) to capture the severity as well as the extent of underweight among children in very low-income countries. This was followed by Jolliffe (2004), Madden (2006) and Sahn (2007), who apply similar techniques to measure the extent and severity of overweight among adults in higher-income settings. These studies move beyond "headcount" measures by considering severity beyond the threshold, but by definition they do not capture differences in nutritional status at sub-threshold levels of under- or overweight.

This study builds on Sahn and Stifel's finding that the level of threshold used to define "underweight" is even more important in determining country comparisons than are differences in the degree of malnutrition beyond the thresholds. Our innovation is to devise an FGT-type measure that looks over all thresholds and considers the full distribution of bodyweights, by counting nutritional status as a deviation from the median of a healthy population rather than from an arbitrary cut-off point. Following standard practice, we measure each child's bodyweight as the z score of their weight for height (WHZ), relative to a reference population of well-nourished children (WHO 2006). We then summarize the distribution of these z scores in each country and year, first using conventional threshold-based FGT measures and then using our new median-based measure. We compare the two kinds of results, and regress them on a range of possible determinants to test their sensitivity to varying socioeconomic conditions across the sample.

In this paper we apply our approach to the population most dramatically affected by the nutrition transition in developing countries, namely preschool children aged 3 to 35 months. Body weights of children in this age range are especially sensitive to socioeconomic conditions as shown by Shrimpton et al. (2001), and deprivation at these ages has been linked to lifelong impairment in studies such as those described by Martorell (1995). Changes in bodyweights for older children and adults are important as well, and can be addressed using our approach using other data. Here we rely on the detailed coverage of preschool children in developing countries from the USAID-funded Demographic and Health Surveys (Macro International, 2008). Our results include all available DHS data, from 130 surveys in 53 countries between 1986 and 2005, for a total sample size of 428,753 children.

Background and literature review

The World Health Organization (WHO 2002) estimates that being underweight accounts for more disability and loss of life than any other health risk factor, and is the underlying cause of more than half of all child deaths in the world. It is estimated to kill nearly 6 million children each year – a figure roughly equivalent to the entire preschool population of Japan (FAO 2005). At the same time, a rapidly rising number of people around the world are overweight or obese. In many settings the two forms of malnutrition coexist (Popkin 1994), sometimes even within the same household (Doak et al. 2000).

The economic determinants of human nutrition have been studied widely. Some studies focus on consumption of specific foods and nutrients (e.g. Behrman and Deolalikar 1987, Sahn 1988), while others use measured bodyweights to capture the balance between consumption and an individual's nutritional needs, focusing on the prevalence of underweight (e.g. Smith and Haddad 2002), overweight (e.g. Sahn 2007), or both (e.g. Mendez, Monteiro and Popkin, 2005).

Underweight prevalence and severity has been linked to a variety of factors beyond per-capita income, including infectious diseases, education (Pritchett and Summers, 1996); women's educational and social status, economic inequality, access to health services, ethnicity (Larrea and Kawachi, 2004; 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).

Overweight prevalence and severity has been linked to a somewhat different set of factors, including particularly dietary composition and physical inactivity (Martorell, Hughes and Grummer-Strawn, 1998; Kain, Vio and Albala, 2003); urbanization and mother's education (Martorell et al., 2000); the entry of women into the workforce (Anderson, Butcher and Levine, 2003); the supply of convenience food and cigarette smoking (Chou, Grossman and Saffer, 2001).

Clearly, economic development helps people gain weight but the increase does not necessarily stop at healthy weight levels, and there is a wide range of experience within any one country. Developing accurate indicators of these changes is the first step in tackling the problem of malnutrition, associated health risks and their economic consequences.

To measure changes and differences in distributions we use Foster-Greer-Thorbecke (FGT) measures. In FGT terminology, a measure of order zero (FGT0) captures the traditional "headcount" ratio or percentage of people who are beyond a threshold, while a measure of order one (FGT1) captures the cumulative "gap" by which those people fall above or below the threshold, and a measure of order two (FGT2) captures the "severity" of the problem by adding up the square of each person's distance from the threshold.

FGT measures were developed to measure income distribution relative to a poverty line; corresponding thresholds in the nutrition context are whether a child is one or two standard deviations below or above the median healthy child of their age and sex, or whether an adult has a BMI below 18.5 kg/m^2 (underweight) or above 25 kg/m^2 (overweight). Sahn and Stifel (2002) find that the most important determinant of measured undernutrition prevalence was the choice of threshold, because some countries have relatively large numbers of children at near-threshold levels of bodyweight.

Our innovation is to use FGT measures to capture changes over time or differences across countries at every level of bodyweight, including sub-threshold values. This whole-distribution approach is needed in part because of heterogeneity and uncertainty about what the healthiest bodyweights might be for any given person, and in part because the underlying risk of disease is itself a continuous function of bodyweight even within the "normal" range.

The continuous relationship between bodyweight and health risks has been emphasized by Fogel (1994), drawing attention to the work of Waaler (1984) whose results on BMI and mortality risk among Norwegian adults is shown in Figure 1. Waaler's finding of a U-shaped relationship between bodyweight and mortality suggests a fairly narrow region of minimum risk, and an asymmetric relationship between risk and a person's degree of under- or overweight. Several other studies suggest that mortality and morbidity vary continuously with body weight and it is difficult to assign a specific threshold at which health risks begin, from either overweight (Pi-Sunyer 1993, Willet et al. 1995) or underweight (Fawzi et al. 1997, Pelletier 1994).

In this study we treat bodyweight as a continuous variable, and look separately at both sides of the distribution to allow for asymmetries such as those illustrated in Figure 1. Working with child data, the natural origin for our measure is a z-score of zero, so that each child is compared to the median healthy child in the WHO reference population, and the bodyweight of every child is counted in our FGT measures. Fawzi et al. (1997, page 1064) draws a mortality-risk curve similar to Figure 1 for using weight for height z scores of a sample of over 28,000 children in Sudan, finding roughly linear increases in child mortality as underweight falls below the median. Pelletier (1994) summarizes analogous evidence from 28 epidemiological studies in 12 countries, drawing somewhat similar risk curves of varying shapes and slopes. In light of these studies, when using these median-based FGT measures, two important caveats should be kept in mind.

A first concern is that the median of the reference population is likely to be a relatively desirable level of bodyweight, but it may not be the absolutely lowest health risk for any particular population. We have no firm estimate for the lowest-risk level of bodyweight, perhaps in part because as shown by Pelletier et al. (1995) the risks posed by malnutrition depend in part on the other risk factors to which a person is exposed. We might expect, for example, that higher bodyweights would minimize risks for children who are heavily exposed to parasitic diseases and infection, whereas lower bodyweights might be helpful for those more likely to suffer later in life from diabetes or cardiovascular disease. With better information on the minimum-risk bodyweight, we could readily adjust our measure to define “underweight” as below that, and “overweight” as above it. In the meantime, however, the median of the WHO’s reference population offers a convenient dividing line along which to divide the sample in two.

A second caveat is that the functional form by which deviations from the median is associated with increased risk is unknown, and is likely to vary by risk factor. Using our FGT measures captures three simple alternatives: FGT0 implies a stepwise loss function, FGT1 implies that health risks rise linearly with the degree of malnutrition, and FGT2 implies a cost burden that rises with its square. Again, with better information from epidemiological studies we could construct an FGT-type measure that exactly matches any estimated functional form by which health risks or other costs might be affected by a child’s bodyweight. In the meantime, we offer these three alternatives and test their implications.

Methodology: measurement of nutritional status

To construct our FGT measures of a population's nutritional status, we must first construct comparable measures for each child's condition. In this paper we use weight for height, which is a relatively sensitive measure of whether a child has recently absorbed an appropriate level of nutrition needed to maintain normal bodyweight given their particular growth and activity. The measure is particularly important for children aged 3-35 months, whose normal growth requires rapidly increasing quantities of high-quality foods. Children of this age may also be at risk of overweight, although weight gain is cumulative so its prevalence and severity is higher among older children and adults.

To measure the status of a particular child relative to healthy children, we use z-scores to compare their weight-for-height to the values observed in the World Health Organization's Multicentre Growth Reference Study (WHO, 2006). Unlike other 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.

A z-score is defined as the difference between the observed value and the median of the reference population, in terms of standard deviations for that variable in the reference population. This can be written as:

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

where z_i is the z-score of the ith person, y_{50} and σ_y are the median and the standard deviation of the reference population, and y_i is the observed value for the ith person.

Once we have computed each child's z-score, we summarize the distribution of z-scores over all children in each country and year using the Foster-Greer-Thorbecke (FGT) measures, whose formula can be written as:

$$FGT^{\alpha} = \frac{1}{N}\sum_{i=1}^{N} \max\left[0, \frac{|z_i| - |t|}{|t|}\right]^{\alpha} \tag{2}$$

where the definition of the FGT measure depends on α, a parameter which we will vary between 0, 1 and 2. This "order" parameter determines the weight given to the gap between the absolute values of each child's z-score (z_i) and some threshold (t) measured in standard deviation units. The traditional thresholds for child malnutrition are -2 s.d. for underweight, and +1 s.d. for overweight. When the order parameter is α=0, all positive gaps where the child's z-score lies outside the threshold have an equal weighting of 1, so the FGT measure is the headcount fraction of the N children in the survey. With an order parameter of α=1, the FGT measure sums the gaps, and when α=2 the gaps are squared.

Our approach modifies standard FGT measures by replacing the threshold with the median of the distribution (a z-score of 0), and then considering deviations from that midpoint in both directions. The result captures changes in the bodyweight of every person in the entire sample, which we call a "median-based" approach. To allow for asymmetry between under- and overweight we will separate the left and right halves of the distribution.

The difference between traditional threshold-based and our median-based measures can perhaps best be seen graphically using actual data. Figure 2 presents smoothed frequency distributions of children's weight-for-height z scores in three countries, from successive DHS surveys. The case of Guinea (Figure 2a) shows a rightward shift in the distribution from 1999 to 2005, Namibia (Figure 2c) shows a leftward shift from 1992 to 2000, and Morocco (Figure 2b) shows a rightward shift from 1987 to 1992 followed by an expansion in both underweight and overweight.

Using a conventional threshold-based measure to compare the distributions in Figure 2 would count only changes below or above the z-scores shown by vertical lines at -2 and +1.   This would miss almost all of the change in Guinea and Namibia, which occurs at sub-threshold levels of bodyweight, and would also miss much of the increased frequency of underweight children in Morocco from 1992 to 2003, which occurs at z-scores just to the right of -2.

Our median-based approach captures changes throughout the distribution, comparing every observation in a given survey to the midpoint of the reference population. We will present the results separately for underweight and overweight. With FGT0, by definition the two measures sum to 100% of the surveyed population. With FGT1, the two measures can be summed into a measure of the total “nutrition gap” by which that population’s bodyweights deviate from the median healthy child, and with FGT2 they measure the sum of squared gaps to reflect exponentially increasing health risks of z-scores that are further from the median.

Methodology: comparison across populations

The potential value of our approach is to offer a more sensitive measure of a population’s nutritional status, for use in population-level studies of the causes and consequences of malnutrition. To judge the usefulness of this method we compare these median-based measures with conventional threshold-based results, and then test their performance in a standard model of socioeconomic correlates of the nutrition transition.

Smith and Haddad (2000) provide a comprehensive review of such cross country studies. We build on this literature to test our measure using reduced-form equations of the type:

$$FGT_{j,t}^{\alpha,a,d} = \alpha^{\alpha,a,d} + \beta^{\alpha,a,d} X_{j,t} + \varepsilon_{j,t}^{\alpha,a,d} \qquad (3)$$

where each equation has superscripts that capture the type of FGT measure. The order parameter (α) takes a value of 0 for prevalence rates, 1 for the nutrition gap, and 2 for the sum of squared gaps; the approach (a) takes a value of t for threshold-based measures and m for our new median-based measures, and the direction (d) takes a value of u for underweight or o for overweight. So there are 12 equations, each of which regresses the malnutrition measure for country j in year t on a set of potential correlates X.

Our central hypothesis is that for some variables the estimated β coefficients will be systematically larger when using our median-based measures than with the threshold-based measures, indicating that we have successfully captured a larger fraction of that variable's link to variation in all children's bodyweights. By including variation in children whose bodyweights are between the reference median and the threshold, we may obtain a more sensitive measure of how nutritional status varies with socioeconomic conditions. The factors we consider here are a country's real income per capita, its local agricultural output per capita, its degree of gender equality between men and women, and its degree of income equality across households.

The first link we consider is between nutritional status and income. We expect underweight to decline as income rises, but at a decreasing rate since Engel's law observes that the income elasticity of demand for food is positive but less than one. Conversely, we expect overweight to rise slowly with increases in average income in the lowest-income societies where there are few people at risk of overweight, and to rise faster in middle- and upper-income countries. In both cases, a quadratic functional form may be appropriate.

A second variable of potential importance is local food production, as suggested by Smith and Haddad (2002) among others. For comparability, we use the FAO estimates of net national agricultural output per capita, measured at international prices. All else equal, more local production per person would allow more consumption, through lower local prices of nontraded foods and some traded foods (thanks to different transportation patterns), or through higher income for farmers. Again, to focus on proportional changes we use the log of the value of net agricultural output, in thousands of international dollars.

Another factor we consider is gender equality, which has been addressed by several studies (Osmani and Sen, 2003). The status of women could be crucial from a purely physiological perspective, as maternal health has a direct bearing on infants' weight and height, and they may allocate more resources to older children as well (Schultz, 2002). The broadest measure of gender equality we could find is the gap between male and female life expectancy, which captures the effect of many kinds of discrimination at every stage of life. To focus on proportional changes the variable we use is the log of the life expectancy difference, in years.

Finally, we consider the impact of income inequality, whose link to nutrition has been studied widely (Larrea and Kawachi, 2004; Hong 2007, Pei and Rodriguez, 2006). Due to Engel's law, income that is concentrated at the upper end of the income distribution can be expected to have less correlation with underweight prevalence than the income of the poor. Income inequality may also have indirect effects via access to land for own farm production, or access to health services and education.

To test the sensitivity of our measures with respect to these socioeconomic correlates, we use OLS controlling only for heteroskedasticity with standard errors clustered on countries. For each of these regressions, suppressing superscripts, equation (3) becomes:

$$FGT_{j,t} = a + \beta_1 realgdp_{j,t} + \beta_2 realgdp2_{j,t} + \beta_3 lnagout_{j,t} + \beta_4 lngeneq_{j,t} + \beta_4 gini_{j,t} + \varepsilon_{j,t} \qquad (3')$$

Data and results

To compute our FGT measures we use weight and height data for children aged 3 through 35 months from the Demographic and Health Survey (Macro International, 2008). We use all rounds of surveys from DHS I (1984–1989), DHS II (1988–1993), DHS III (1992–1997) and DHS+ (1997–2006), conducted between 1986 and 2005 in 53 countries. The surveys' sample size ranges from 323 (for Kazakhstan in 1999) to 25,092 (for India in 1998), for a total number of underlying observations of 428,753. The net result is a total of 130 distributions of weight-for-height z-scores, from which we calculate each of the six FGT measures using Stata software. Our procedure was to calculate each child's z-score relative to WHO (2006) standards with the igrowup command (WHO, 2008), smooth the distribution using an Epanechnikov kernel density regression at a bandwidth of 0.15, and then sum the results over the range indicated by equation (2) above.

The explanatory variables are drawn from public sources. Our income variable (*realgdp*) is 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. The variable for agricultural output (*agout*) is the value of net production, also measured in constant 2000 international dollars, from FAO file data used to compute their index of output per capita. Gender equality (*geneq*) is the difference between female and male life expectancy at birth, in years, from the UN Population Projections as reported in the WDI. And our income-inequality measure (*gini*) is the Gini coefficient of income as compiled by UNU WIDER. In most cases we were able to match observations of these variables to the countries and years of the DHS surveys; in a few cases values were imputed from adjacent years, and where adjacent years are not available the data are left missing.

Table 1 provides summary statistics for all variables, while Table 2 lists the country and year coverage of the dataset, by region. To compare the performance of our new median-based measure against conventional threshold-based measures, we begin with a set of scatter plots and then present a more formal test using our regression model.

Figure 3 shows each type of FGT measure as a scatterplot, with the conventional result on the horizontal axis and our new median-based result on the vertical axis. A 45-degree line through the origin represents equality between the two measures. By construction the new median-based FGT measures are always larger in magnitude than the threshold-based ones, and so all points lie above the 45-degree line. But if the two are measuring the same phenomenon, and the points form a line that is steeper than 45 degrees, then we can say that the median-based measure is a more sensitive measure than the traditional one. The observations turn out to form a line steeper than 45 degrees mainly for the FGT0 measure at low prevalence rates. (The charts for FGT0 under- and overweight are identical, by construction. Both are shown here only for clarity.) The FGT1 measure clusters along a somewhat steeper slope, and the FGT2 measure even less so. For all cases the slope of the scatter plot is steepest at low levels of the FGT measure, as our measure captures differences in below-the-threshold malnutrition that are missed by the traditional approach. When many people are already beyond the threshold, or in the higher order FGT measures, the slope of the scatter plot falls towards 45 degrees because the two measures handle above-the-threshold malnutrition similarly.

Figure 4 provides another informal but instructive way to compare the two measures, plotting each of them on the vertical axis against that population's real income per capita. Here, a steeper line implies greater sensitivity to whatever is the underlying relationship between income and nutrition, and again the median-based measure appears to be more sensitive to income-driven changes in nutrition – especially at lower levels of income. An alternative view of these same data is provided in Figure 5, through a quadratic prediction plot of FGT scores against income and income squared, with both the predicted value and the 95 percent confidence interval being shown.

For a more formal approach, Table 3 presents results from OLS estimation of equation (3'), regressing each FGT measure of malnutrition on that population's per-capita income, income squared, log of agricultural output, log of gender equality and income inequality. Coefficient estimates are of the expected signs, and their magnitudes are indeed much larger for the median-based measures than for the threshold-based measures, especially with the lower-order FGT measures. (The estimated coefficients on the measure of order 0 for under- and overweight are identical, by construction, and both are shown only for clarity.)

For instance, the estimated coefficient on income is three times larger for headcount prevalence when it is median-based as opposed to threshold-based (-99.21 as opposed to -28.76), twice as large for the "underweight gap" (-1.63 as opposed to -0.85), and slightly larger for the sum of squared gaps (-3.67 as opposed to -2.64). In other words, in the poorest countries a given unit of income growth raises roughly three times as many children past the median than it does past the threshold, reduces the total undernutrition gap by roughly twice as many z-score units below the median than it does below the threshold, and reduces the squared gap slightly more when the bodyweights of above–threshold children are included.

The results of Table 3 confirm that a substantial amount of the link between nutrition and per-capita income occurs through changes in sub-threshold levels of bodyweight, which are captured in our measure but not in the conventional approach. A similar result can be seen with respect to the link between underweight prevalence and local agricultural output, which is large and strongly significant in our data. The link between underweight and gender equality has a somewhat different pattern, however, in that it has relatively larger coefficients for the higher-order FGT measures, and a smaller difference in results between the median-based and threshold-based variables.

The regressions shown in Table 3 have a sample size of only 68, because of missing regressors for many of the countries and years for which we have nutrition data. Table 4 shows results without the Gini coefficient, which raises the sample size to 83. In this larger sample, the link between nutrition and per-capita income is much weaker, while the agricultural output and gender equality effects remain about the same. In particular, we have the same greater sensitivity to these variables in the median-based than in the threshold-based regressions, indicating that these variables are associated with changing the bodyweights of many children at mild to moderate levels of underweight.

The policy implications of these results can perhaps most clearly be seen by returning to Figure 2, which shows the entire distribution of children's bodyweights in three countries. Shifts in each distribution associated with changing socioeconomic conditions affect different numbers of children at different points in the distribution. Using a median based measure captures changes for a larger number of children and hence could be more useful in many settings.

Conclusions

In this paper we introduce a new approach to measuring how a population's nutritional status varies over time and across countries, using observed values throughout the distribution to avoid loss of information associated with traditional thresholds. We include every observation by computing FGT measures relative to the median of a healthy population, and apply the technique to the weight-for-height z scores of children aged 3-35 months using the entire set of 130 DHS surveys covering more than 400,000 children in the developing world.

Using our new median-based measures as opposed to traditional thresholds provides a more sensitive measure of how a population's bodyweights vary with socioeconomic conditions. We use scatterplots to describe the difference between the two kinds of measure, and then test their usefulness in cross-country regressions of malnutrition on real GDP per capita, local agricultural output per capita, gender equality (as measured by the female-male gap in life expectancy), and income inequality (as measured by the Gini coefficient). As expected, these conditions are much more robustly linked to underweight than to overweight in this age range, when children are especially at risk of receiving insufficient nutrition relative to their needs. Our preferred regression shows every measure of underweight to be strongly correlated with a country's real income, agricultural output and gender equality. Income inequality has little additional significance when controlling for those other factors.

The new approach reveals that real income and agricultural output have particularly large correlations with mild and moderate levels of underweight, which is captured by our measures but would be neglected using traditional thresholds. Gender equality also has a greater correlation with the new measures than the traditional ones. Observers are naturally more concerned with extreme malnutrition, which our new measures capture as well, but the much larger absolute numbers of people affected by mild to moderate underweight should also be of concern to policymakers.

The health risks and welfare changes associated with changes in bodyweight throughout its distribution have been emphasized by Fogel (1994) and documented by Pelletier (1994) among others. Our approach allows the entire distribution to be summarized and compared across countries and over time, with no additional data requirements beyond the survey data that underlie traditional methods. We find clear differences in results for preschool children, among whom underweight is the principal health risk. Future work can apply this same approach to older children and adults, for whom overweight and obesity imposes a greater burden. In both cases, capturing change in the entire distribution offers a promising approach with which to summarize household surveys and test for the determinants of nutritional status at the population level.

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Table 1: Descriptive statistics for all variables

Variable	Description	Obs	Mean	Std. Dev.	Min	Max	Source
FGT measures of prevalence and severity, computed using weight-for-height z scores (WHZ)							
WHZ0tu	FGT of order 0, threshold-based, for underweight	130	9.29	6.33	0.67	29.74	Author’s calculations
WHZ1tu	FGT of order 1, threshold-based for underweight	130	0.27	0.19	0.02	0.93	Author’s calculations
WHZ2tu	FGT of order 2, threshold-based, for underweight	130	0.82	0.59	0.05	3.09	Author’s calculations
WHZ0mu	FGT of order 0, median-based, for underweight	130	52.16	16.09	21.92	83.02	Author’s calculations
WHZ1mu	FGT of order 1, median-based, for underweight	130	0.62	0.30	0.14	1.36	Author’s calculations
WHZ2mu	FGT of order 2, median-based, for underweight	130	1.24	0.73	0.17	3.66	Author’s calculations
WHZ0to	FGT of order 0, threshold-based, for overweight	130	20.05	10.21	3.23	45.77	Author’s calculations
WHZ1to	FGT of order 1, threshold-based, for overweight	130	0.36	0.20	0.05	1.10	Author’s calculations
WHZ2to	FGT of order 2, threshold-based, for overweight	130	0.78	0.50	0.08	3.25	Author’s calculations
WHZ0mo	FGT of order 0, median-based, for overweight	130	47.84	16.09	16.98	78.08	Author’s calculations
WHZ1mo	FGT of order 1, median-based, for overweight	130	0.49	0.23	0.10	1.19	Author’s calculations
WHZ2mo	FGT of order 2, median-based, for overweight	130	0.86	0.51	0.10	3.30	Author’s calculations
Socioeconomic conditions used as explanatory variables							
realgdp	GDP per capita, PPP (constant 2000 international $)	128	2408.75	1809.19	491.03	7378.53	World Bank WDI
agout	Agricultural output per capita (‘000s of 2000 int’l. $)	87	0.17	0.16	0.06	1.12	FAOStat file data
geneq	Difference in female and male life expectancy (years)	129	3.29	2.29	-1.74	10.70	World Bank WDI
gini	Gini coefficient for income inequality	100	49.16	11.02	28.70	77.00	UNU WIDER

Table 2: Country and years included in the dataset

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 3: Regression results for alternative FGT measures on real income, agricultural output, gender equality and income inequality

	(1) WHZ0mu	(2) WHZ0tu	(3) WHZ1mu	(4) WHZ1tu	(5) WHZ2mu	(6) WHZ2tu	(7) WHZ0mo	(8) WHZ0to	(9) WHZ1mo	(10) WHZ1to	(11) WHZ2mo	(12) WHZ2to
realgdp	-99.21**	-28.76**	-1.63**	-0.85**	-3.67**	-2.64**	99.21**	58.98*	1.29*	1.05	2.31	2.14
	(35.89)	(9.79)	(0.52)	(0.29)	(1.18)	(0.91)	(35.89)	(27.76)	(0.61)	(0.56)	(1.38)	(1.35)
realgdp2	98.08*	27.94*	1.58*	0.82*	3.57*	2.57*	-98.08*	-61.67	-1.39	-1.16	-2.73	-2.57
	(46.64)	(12.35)	(0.67)	(0.36)	(1.47)	(1.12)	(46.64)	(35.80)	(0.79)	(0.72)	(1.76)	(1.71)
lnagout	-7.43***	-2.18**	-0.12***	-0.06*	-0.26**	-0.17*	7.43***	4.28*	0.09*	0.07	0.13	0.12
	(2.06)	(0.75)	(0.03)	(0.02)	(0.08)	(0.07)	(2.06)	(1.82)	(0.04)	(0.04)	(0.08)	(0.08)
lngeneq	-5.86**	-3.45***	-0.14***	-0.10***	-0.36***	-0.30***	5.86**	2.88*	0.07*	0.05*	0.12*	0.11*
	(1.76)	(0.68)	(0.03)	(0.02)	(0.07)	(0.06)	(1.76)	(1.09)	(0.02)	(0.02)	(0.05)	(0.05)
Gini	-0.22	-0.10*	-0.00	-0.00*	-0.01*	-0.01*	0.22	0.07	0.00	0.00	-0.00	-0.00
	(0.17)	(0.05)	(0.00)	(0.00)	(0.01)	(0.00)	(0.17)	(0.13)	(0.00)	(0.00)	(0.01)	(0.01)
constant	68.20***	16.76***	0.97***	0.49***	2.13***	1.51***	31.80**	13.43	0.34	0.26	0.67	0.62
	(9.31)	(2.82)	(0.14)	(0.08)	(0.32)	(0.27)	(9.31)	(7.80)	(0.17)	(0.16)	(0.40)	(0.40)
N	68	68	68	68	68	68	68	68	68	68	68	68
R^2	0.5870	0.6829	0.6804	0.6715	0.6858	0.6524	0.5870	0.4446	0.4279	0.3582	0.2812	0.2547

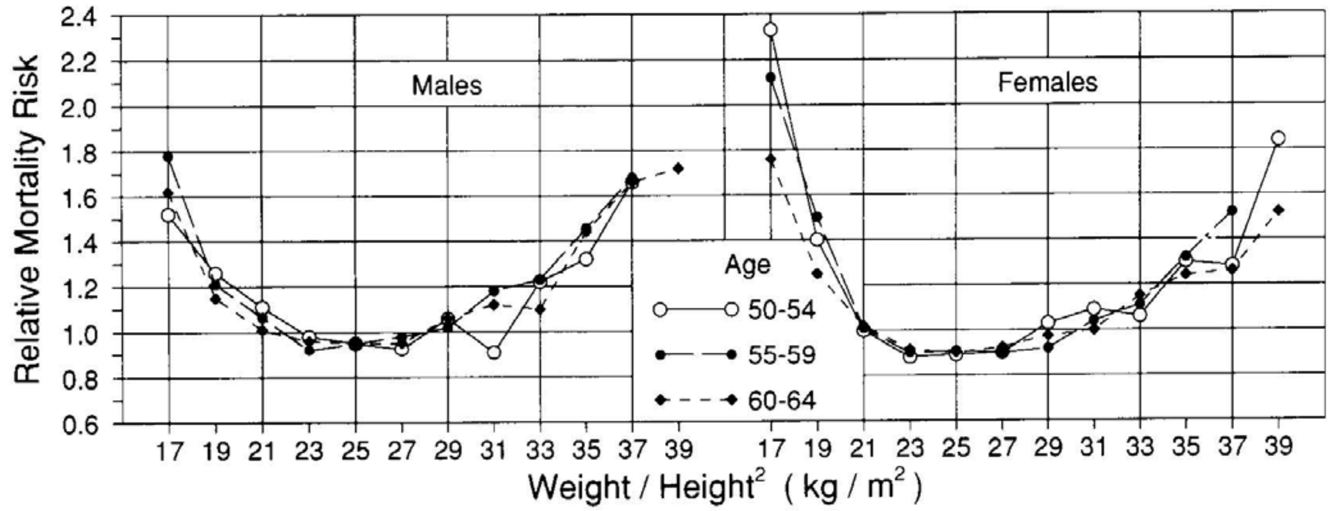
All results shown are OLS with robust standard errors in parentheses, clustered on countries. Significance levels are * $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$.
Coefficients on *realgdp* should be multiplied by 10-4 to be expressed in the same units as the data's descriptive statistics
Coefficients on *realgdp2* should be multiplied by 10-8 to be expressed in the same units as the data's descriptive statistics

Table 4: OLS regression results for alternative FGT measures on real national income, agricultural output and gender equality

	(1) WHZ0mu	(2) WHZ0tu	(3) WHZ1mu	(4) WHZ1mu	(5) WHZ2mu	(6) WHZ2mu	(7) WHZ0mo	(8) WHZ0to	(9) WHZ1mo	(10) WHZ1to	(11) WHZ2mo	(12) WHZ2to
realgdp	-87.10*	-21.80	-1.30	-0.63	-2.77	-1.90	87.10*	56.28	1.28	1.09	2.60	2.46
	(0.03)	(0.09)	(0.05)	(0.10)	(0.07)	(0.11)	(0.03)	(0.05)	(0.05)	(0.06)	(0.07)	(0.08)
realgdp2	83.13	19.54	1.19	0.56	2.50	1.70	-83.13	-57.02	-1.34	-1.17	-2.95	-2.83
	(0.11)	(0.22)	(0.15)	(0.22)	(0.18)	(0.23)	(0.11)	(0.13)	(0.11)	(0.12))	(0.11)	(0.12)
lnagout	-7.34**	-2.07*	-0.12**	-0.06*	-0.25**	-0.16*	7.34**	4.27*	0.09*	0.07*	0.14	0.12
	(0.00)	(0.02)	(0.00)	(0.03)	(0.01)	(0.04)	(0.00)	(0.02)	(0.0165)	(0.04)	(0.06	(0.09)
lngeneq	-6.81***	-3.82***	-0.16***	-0.11***	-0.42***	-0.34***	6.81***	3.04**	0.07**	0.05*	0.10	0.09
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.01)	(0.0098)	(0.03)	(0.05	(0.08)
constant	57.30***	11.59***	0.72***	0.34***	1.50***	1.04***	42.70***	16.71***	0.40***	0.28**	0.62**	0.54**
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.0001)	(0.00)	(0.00)	(0.01)
N	83	83	83	83	83	83	83	83	83	83	83	83
R^2	0.5339	0.5872	0.5962	0.5805	0.5978	0.5670	0.5339	0.4257	0.4112	0.3539	0.2852	0.2615

All results shown are OLS with robust standard errors in parentheses, clustered on countries. Significance levels are * $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$.
Coefficients on *realgdp* should be multiplied by 10-4 to be expressed in the same units as the data's descriptive statistics
Coefficients on *realgdp2* should be multiplied by 10-8 to be expressed in the same units as the data's descriptive statistics

Figure 1: The asymmetric U-shaped relationship between BMI and mortality among Norwegian adults at risk of mortality between 1963 and 1979



Source: Fogel (1994), using data from Waaler (1984).

Figure 2: Density Estimates of Weight for Height z scores

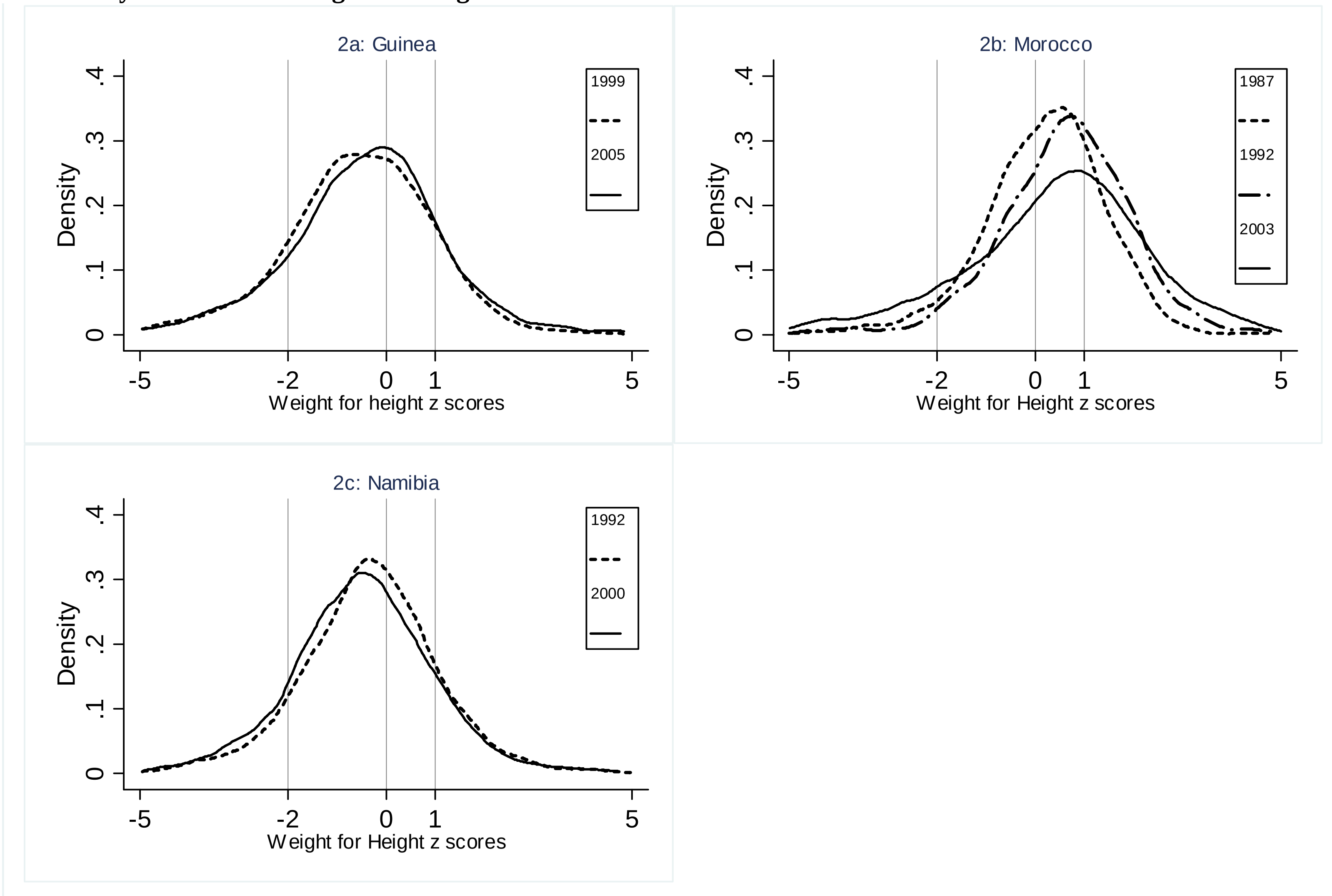


Figure 3: Scatter plots of threshold-based and median-based FGT measures of weight for height z-scores

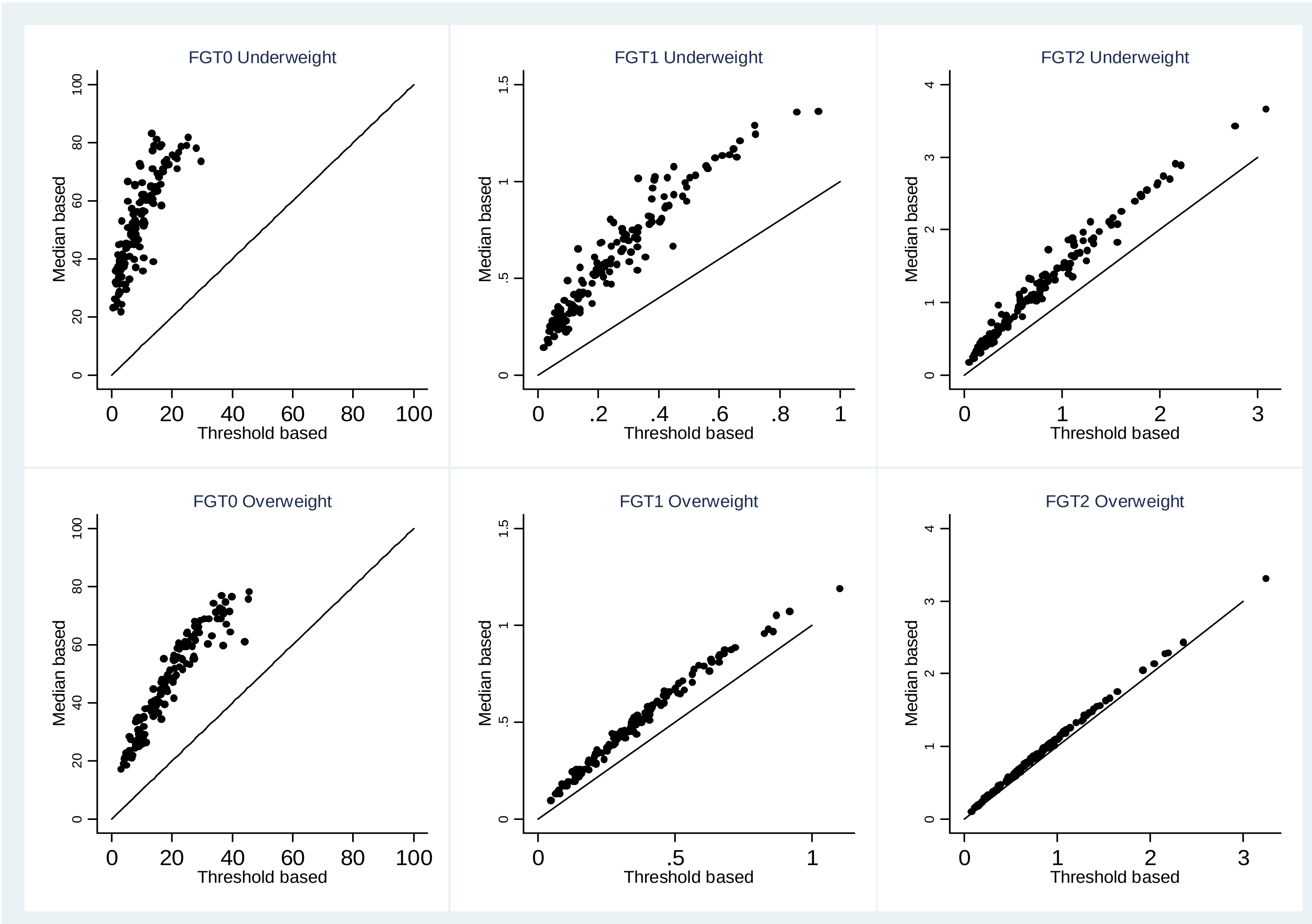


Figure 4: Scatterplots of threshold-based and median-based FGT measures vs. income

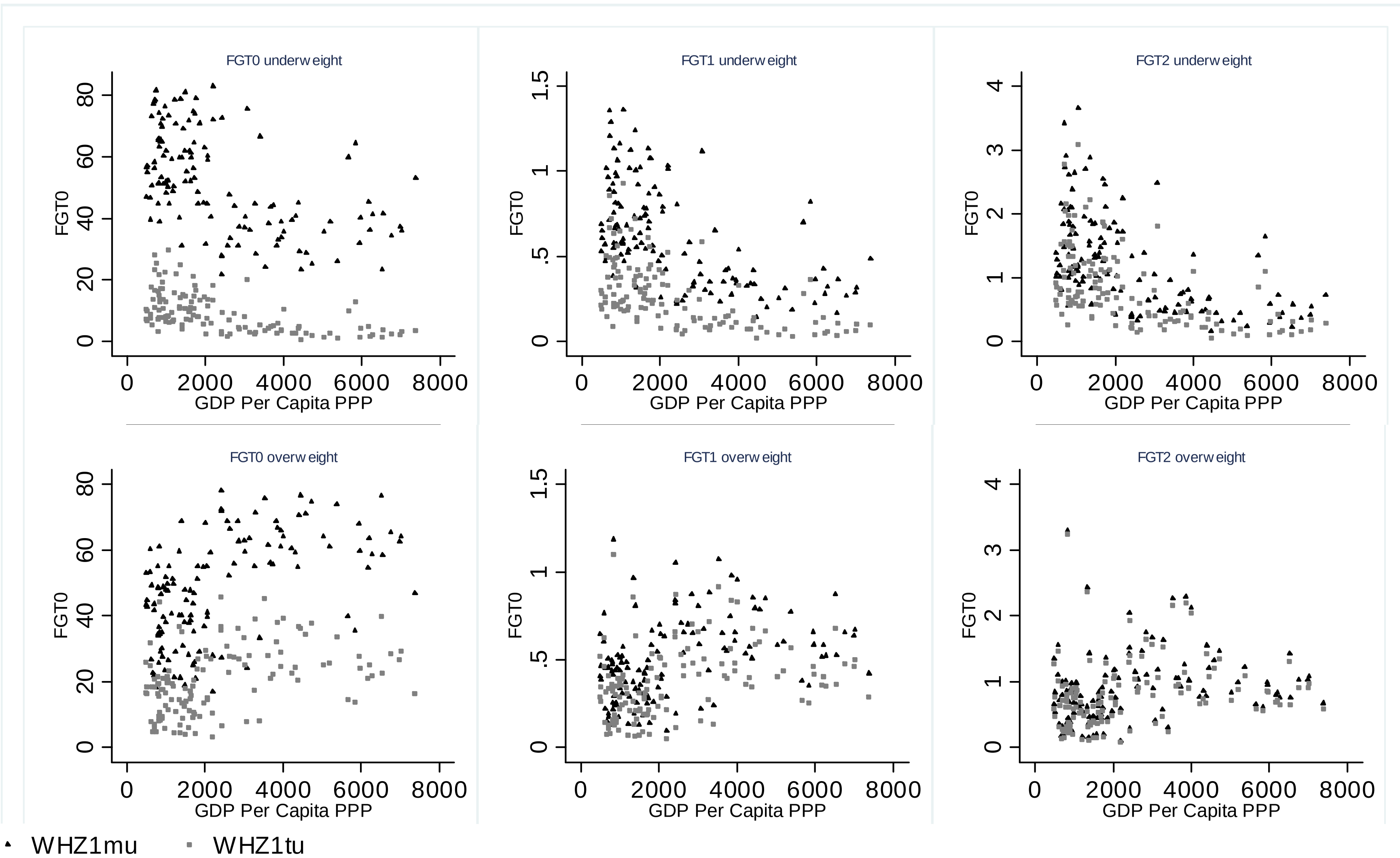


Figure 5: Quadratic prediction plots of threshold-based and median-based FGT measures vs. income