THE DUAL BURDEN OF MALNUTRITION IN CHILDREN IN LOW- AND MIDDLE-INCOME COUNTRIES

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A dissertation submitted to the faculty at the University of North Carolina at Chapel Hill in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the Department of Nutrition.

Chapel Hill
2016

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ABSTRACT

Emma Tzioumis: The dual burden of malnutrition in children in low- and middle-income countries
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High levels of childhood undernutrition persist in many low- and middle-income countries (LMIC). Rapid shifts in dietary and physical activity patterns brought about by the nutrition transition have led to increased childhood obesity in these same countries, leading to the co-existence of under- and overnutrition, known as the dual burden of malnutrition. The dual burden occurs at the population, household, and individual level. We used two different data sources to address the different levels of the dual burden in children: 1) Demographic and Health Surveys (DHS) from over 35 countries to assess contemporary global anthropometric trends in children <5y and to explore the role of socioeconomic status, and 2) the Cebu Longitudinal Health and Nutrition Survey (CLHNS) to assess determinants of discordant nutritional status among mother-daughter dyads during a period of rapid economic change in the Philippines.

Global malnutrition prevalence in children <5y decreased, driven by stunting decreases. Overweight increased in over a third of countries. Children <2 years experienced worse stunting and overweight trends compared to children 2-5y. Countries with nearly equal prevalence of stunting and overweight increased over time. We did not detect a pronounced shift in anthropometry with respect to wealth status as has been noted in adults, however we document a widening wealth gap between the poorest and richest households in a majority of countries. Considerable between-country heterogeneity was noted, which may make drawing global

conclusions difficult. We observed a U-shaped relationship between the mother-daughter dyad's height difference and daughter's adult central adiposity, with the tallest and shortest daughters experiencing increased central adiposity.

This is the first assessment of dual burden trends in children on a global scale. Governments and policy makers must be aware of the changing dynamics and adapt nutrition programs and policies accordingly.

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BMI	Body mass index
CI	Confidence interval
CLHNS	Cebu Longitudinal Health and Nutrition Survey
DHS	Demographic and Health Surveys
DOHaD	Developmental Origins of Health and Disease
HAZ	Height-for-age z-score
IC	Index child
IWI	International Wealth Index
LAZ	Length-for-age z-score
LMIC	Low- and middle-income country
OEP	Opposite effects proportion
PEI	Population effect interval
PI	Prediction interval
SD	Standard deviation
SES	Socioeconomic status
WC	Waist circumference
WHO	World Health Organization
WHZ	Weight-for-height z-score

CHAPTER I: INTRODUCTION

A. Overview

High levels of childhood undernutrition persist in many low and middle income countries (LMIC). Rapid shifts in dietary and activity patterns have led to increased childhood obesity in these same countries, leading to the co-existence of under- and overnutrition, known as the "dual burden" of malnutrition. This is a novel and complex problem for governments and health organizations, as they must tackle opposite ends of the malnutrition spectrum. Three distinct, but interrelated, manifestations of the dual burden have been identified: community (e.g.: high prevalence of under- and overweight in the same population), household (e.g.: both under- and overweight individuals living together), and individual (e.g.: overweight coupled with stunting).

Research has not systematically examined the dual burden levels jointly. Existing studies that assess the dual burden on each level are largely cross-sectional and focus on adults. We address this gap with a combination of global and longitudinal surveys to explore the following three research questions regarding the dual burden in children: 1) what is the contemporary global prevalence and time trends with respect to both under- and overnutrition in children, 2) how does socioeconomic status (SES) affect population-level dual burden, and 3) are there adverse health outcomes associated with intergenerational improvements in linear growth? Together, this provides information that will better inform public health interventions in addressing the needs of those at-risk at both ends of the malnutrition spectrum.

B. Research Aims

To address our research aims, we take advantage of two separate data sources: the Demographic and Health Surveys (DHS) and the Cebu Longitudinal Health and Nutrition Survey (CLHNS). DHS are nationally representative, household based surveys of women of reproductive age and their young children (0-5y). They have been conducted in over 90 countries since 1984 and provide data on population health, maternal and child health, and nutrition that are comparable across time and countries. This study employs surveys from approximately 40 countries with at least two surveys, contributing over 600,000 children <5y. This allows for the analysis of contemporary trends across multiple countries over time. CLHNS is a community-based, prospective cohort study that enrolled pregnant women who gave birth to index children in 1983-1984 in the Metro Cebu area of the Philippines (n=3080). The dataset contains community, household, and individual level data, including detailed anthropometry, SES, and diet data collected for the mothers and index children from 1983 to 2005.

Aim 1. To describe trends in country- and individual-level dual burden of malnutrition in children <5 years, and age-stratified (<2 years, ≥2 years) country-level trends, in thirty-six low- and middle-income countries (LMIC).

Aim 2. To assess if the burden of malnutrition in children <5y in LMIC is shifting between wealth sub-groups, by summarizing the association of each of three anthropometric indicators (stunting, wasting, overweight) with household wealth within countries over time and exploring the extent to which country-level wealth affects our summary estimates.

Aim 3. Assess the relationship between mother-daughter dyad height differences and daughter's adult central adiposity status, and explore the role of socioeconomic status, body image and weight management behaviors, and the timing of pubertal development.

CHAPTER II: LITERATURE REVIEW

A. Overview

Childhood nutritional diseases are a significant global problem, but the distribution of under- and overnutrition is changing, especially in low- and middle-income countries (LMIC). The various forms of undernutrition (e.g.: stunting, wasting, micronutrient deficiencies) in children under five continue to pose a substantial public health concern (1,2). Stunting, or being short for one's age, is one of the major manifestations of undernutrition, with an estimated 171 million children under five stunted worldwide in 2010 (3). As the nutrition transition progresses, childhood overnutrition becomes a concern. In 2010, 43 million children under five were overweight or obese, with an additional 93 million children at risk of overweight (4). Despite economic development, substantial economic disparities remain and nutritional insufficiencies continue to affect many children in LMICs. These under- and overnutrition trends are increasingly documented to co-exist within the same context, producing a phenomena known as the "dual burden" of malnutrition (5–7). This dual burden manifests on three levels (community, household, and individual) and presents a unique and complex public health challenge (8).

Childhood is often an ignored life-stage in the field of dual burden research. Childhood undernutrition is a drain on human capital and a society's potential for growth; stunted children generally grow up to be adults of small stature with low lean body mass, reduced productivity and wages in occupations involving manual labor (9). Undernutrition contributes to cognitive impairment, resulting in delayed school entry, poor school performance, and decreased graduation rates (9–11). Overnutrition also affects the child's potential contributions to society; childhood obesity is associated with increased risk of adult chronic diseases and reduced earnings (12). There is a strong economic rationale for targeting undernutrition, with every dollar spent on reducing stunting generating approximately $18 in economic returns (13). However, interventions that target only undernutrition often result in overnutrition as an unintended consequence. This has been documented in a supplementary feeding program in Chile that led to increased childhood overweight, and the *Oportunidades* conditional cash transfer in Mexico which increased adult overweight, obesity, and blood pressure (14,15). The consequences of ignoring the changing nutrition needs and burden of disease in children are dire.

B. Community level dual burden

Comparisons of population-level trends in under- and over-nutrition in children are scarce, outdated, and imprecise. The most recent comprehensive assessment was in 2000; global prevalence of wasting was higher than overweight but there was great variability on the country level (16). Furthermore, this was cross-sectional and did not include multiple surveys within a country, which would have provided a better sense of the direction of the patterns. Results indicated that although the prevalence of wasting was generally higher than overweight, a majority of the countries had a higher prevalence of overweight than stunting. These countries with greater overweight were typically wealthier, indicating a shift in disease burden as countries progress through the stages of the nutrition transition. However, the data for this study came from WHO Country Surveys which vary in quality and representativeness, calling into question the accuracy of between-country comparisons. Since 2000, few direct comparisons of under- and over-nutrition in children have been executed, and those that do either are single cross sections in time and/or ignore the role of SES as an explanatory factor. The relationship between SES and obesity in developing countries was first documented as existing almost exclusively in high socioeconomic groups (17). However, around the new millennium, a new dynamic emerged where obesity shifted to low socioeconomic groups in these same countries (18,19). It has been shown in adult women that as a country's gross national product (GNP) increases, the burden of obesity shifts to lower socioeconomic groups (20), although some question this (21). People of lower SES may be more at the mercy of an obesogenic environment; they do not have the economic means to avoid the nutrient-poor, yet often ubiquitous, food choices (22). Many in the lower socioeconomic groups of LMIC continue to struggle with undernutrition, even as obesity and overnutrition increase. Others have found high prevalence of overweight across all SES groups (23). Although there is a growing body of evidence in adults, there is no work examining the shifting obesity burden in young children.

Social class is a complex and multidimensional factor. It is believed to confer health advantages, either because of education, money, or occupation/status. Occupation, education, income, and wealth have been used to stand in for the underlying social construct, and are often used interchangeably in epidemiological analyses. However, their effects are actually outcome dependent, and should not be used as indicators of the same latent social construct. They are correlated, but act via different causal mechanisms (24). Even within the economic component of social class, income and wealth are not interchangeable (25). Income (i.e.: money) and wealth (i.e.: assets) are thought to operate via distinct causal pathways. Income affects more proximal factors that influence health, like behaviors, and represents the resources available at a certain point in time, altering an individual's ability to control their circumstances. Wealth represents an accumulation of economic resources, and is thought to be a better predictor of health than income alone. Both income and wealth are thought to indirectly affect health, through conversion of money or assets to provide health enhancing environments and consume health improving commodities and services (26).

Measurement of wealth and income is challenging. In many developing countries or in informal work sector, people may not know what their income is, or only know it in broad ranges. In these settings, remittances are also common, and may be overlooked when reporting income. In agricultural settings, a person's income may fluctuate greatly with the season (e.g.: after harvest). This makes it hard to produce a reliable estimate of income (27). Income is also subject to reverse causality. In contrast, wealth is more stable, as material possessions are less likely to vary, and is considered a good indicator of long-term economic status. For example, a person may not be making much money during in the months before a harvest, or might even spend money they do not have; however, their bed does not disappear during these seasonal fluctuations. These longer term measures of SES are thought to be more predictive of health outcomes.

An index of wealth or assets is one way of assessing the long term stability of wealth. It measures wealth at the household level and can be used to assess relative wealth within the population. One of the first uses was to assess the relationship between household wealth and educational attainment in India (28). The International Wealth Index (IWI), which was created using data from 165 surveys from 97 LMIC to generate a wealth index that is comparable across countries and time (29). Household assets (durable goods, basic services, and housing characteristics) reported by the child's mother were subjected to a principal components analysis to generate a wealth score for each household. The IWI is a continuous variable, with values ranging from 0-100 (29). Some have used country-level indicators such as gross domestic product, but since we are interested in the relationship within a country, this is not appropriate. Therefore, the choice to use the IWI is both theoretical and practical.

Researchers have taken a variety of methodological approaches to investigating the relationship between SES and obesity across multiple countries. They generally fall into two broad methodological categories: 1) pooled analyses and 2) multilevel modeling. Pooled analysis treat all countries the same and estimates a single estimate. This is usually accomplished by pooling the country data within year and then adjusting for a country fixed effect (30,31). These analyses have been limited to two survey years per country to allow for consistent pooling across time. Multilevel modeling models the estimate within each country independently. Individuals and individual level variables (e.g. anthropometrics, SES) are nested within countries and country-level variables (e.g.: gross domestic product) (32). Individuals may additionally be nested within households or primary sampling units (21).This approach allows for a weighted estimate for country-specific estimates. Meta-regression is one application of multilevel modeling. Using this method allows us to examine the relationship of the different anthropometric indicators with varying degrees of SES within each country, and then across countries.

C. Household level dual burden

Intergenerational aspects of the dual burden are under-studied and may provide key insight into the household-level dual burden. Household-based surveys find undernourished and overnourished persons living in a shared household environment with common macro-level social, environmental, and economic factors. Differences in nutritional status among them likely reflect individual differences in age and secular trend-related exposure history, as well as current individual behaviors (e.g., physical activity and work patterns), physiology, and nutrient needs (per kilogram nutrient needs are substantially higher in growing children than in adults). Differences may also reflect differential susceptibility or response to environmental factors according to age or developmental stage. Finally, there may be household level differences in the allocation of resources.

The dual-burden household is defined as a household in which at least one member is undernourished and at least one member is overweight. Distinct household typologies exist, including stunted child/overweight mother (SCOWT) (33) and overweight child/ underweight adult households (34). Mother–child dyads are often the unit of analysis when assessing weight discordance; it is assumed they share more resources, are in closer contact than other household members, and should be less likely to differ in weight status.

A short mother (i.e.: one who was herself stunted) propagates an intergenerational cycle of short stature; short, poorly nourished mothers may give birth to low birthweight babies who also experience stunting in early infancy, but who may be exposed to improving socioeconomic circumstances and therefore have altered adult outcomes. We are interested in the daughters who surpass their short mothers, as this is inconsistent with their early life exposures. Little is known regarding the consequences of these intergenerational improvements in linear growth, specifically if these children more likely to have higher central adiposity, and if so, how do changes in their SES from infancy to early adulthood influence this relationship.

We examine the undernourished mother and overweight child, an understudied but important household typology (34), to better understand. if improving upon the previous generation's adult height is associated with unintended consequences (adult central adiposity in the daughters). We then explore potential predictors of this phenomenon, including socioeconomic status and timing of pubertal maturation. Studying the undernourished mother and overweight child will shed light on how exposures during critical periods of growth may result in differences in nutritional status for the mother and child.

D. Individual level

Metabolic susceptibility to central adipose accumulation may be different for stunted versus non-stunted children. Dual burden on the individual level is a particularly troubling manifestation; if the individual is getting excessive energy to be able to store it as fat, their diet should theoretically provide enough nutrients needed for optimal linear growth and normal metabolic processes. However, this is not always true and fetal and childhood origins of adult obesity may play a role. A constrained fetal environment and childhood stunting have been linked to adult obesity and chronic disease. Poor early nutrition (i.e.: stunting, underweight) may also alter physiology to preferentially accumulate fat mass versus lean mass (35). Poor early nutrition fosters a "thrifty phenotype" with increased efficiency of fat storage (36). Poor nutrition in utero results in small abdominal viscera and low muscle mass but high levels of adiposity (37,38). Similarly, stunted children have a greater accumulation of fat mass and a lower lean mass gain when compared to their non-stunted counterparts, and are more likely to deposit fat centrally when entering puberty (35,39). These results may be explained by lower rates of fat oxidation in the stunted children versus non-stunted children, or alterations in cortisol metabolism, which may occur in utero or early childhood (40). Stunted children have also exhibited abnormal appetite control and increased energy intake per unit body weight (35,41) Deficits in muscle mass relative to fat persist into adulthood, resulting an increased risk of nutrition-related chronic disease at lower BMI for Asians than for other race/ethnicities (42,43).

CHAPTER III: PREVALENCE AND TRENDS IN THE CHILDHOOD DUAL BURDEN OF MALNUTRITION IN LOW- AND MIDDLE-INCOME COUNTRIES, 1990–2012

A. Introduction

Childhood nutritional diseases are a significant global problem, but the distribution of under- and overnutrition is changing, especially in low- and middle-income countries (LMIC). The various forms of undernutrition (e.g.: stunting, wasting, micronutrient deficiencies) in children under five continue to pose a substantial public health concern (1,2), with an estimated 171 million children under five stunted worldwide in 2010 (3). As the nutrition transition progresses, diets become simultaneously more energy-dense yet nutrient-poor, while lifestyles become more sedentary, leading to overnutrition (44). In 2010, globally, 43 million children under five were overweight or obese, with an additional 93 million children at risk of overweight (4). Despite sustained economic development in many countries, substantial economic disparities remain within LMIC and nutritional insufficiencies continue even while obesity prevalence is increasing, resulting in a "dual burden" of malnutrition on the population-level (5,7,45). The dual burden presents a unique and complex public health challenge.

Tracking of population-level anthropometric trends has focused primarily on children <5y old. WHO and UNICEF commonly report anthropometric indicators for this age group, and children <5y are targeted in the Millennium Development Goals (MDGs) (46,47). However, the first two years of life have emerged as a critical developmental period, as recognized by the creation of the 1000 Days initiative (48). A child's linear growth potential is largely determined by this age, thus much of the developmental origins of adult health and human capital work uses linear growth status at 2 years to predict future growth and health (1,9,11,49). Studies in high-income countries have also documented the role of early development of overweight and obesity in the first two years of life, since early weight status predicts later weight status and chronic disease risk (50). Recent evidence from a collaboration of five birth cohorts in LMIC also suggests that faster relative weight gain before 2y is associated with increased risk of overweight in young adults (51). However, the extent of the dual burden in this younger age group has not been estimated. The transition from exclusive breastfeeding to family foods is typically complete around 2y, and appropriate nutrition interventions will differ for children <2y and ≥2y. Therefore, age-specific information is critical when targeting children for nutritional interventions to reduce stunting and at the same time, prevent overweight and obesity.

Direct comparisons of population-level trends in under- and over-nutrition in children are scarce, outdated, and imprecise. The most recent comprehensive assessment was in 2000, which compared overweight and wasting in children <5y (16). However, more than half of the countries only had one survey, precluding the authors from establishing time trends, and the data came from WHO Country Surveys which vary in quality and representativeness. Since 2000, few explicit comparisons of global trends in child nutrition status have been published. Studies using similar data sources have been published on global trends in stunting (3) and overweight (4), separately. The 2013 Maternal and Child Nutrition *Lancet* series included a section on childhood anthropometrics (2). However, time trends were aggregated by region, and the country-level data were from a combination of sources and often more than 10 years old. Others have reported on the dual burden in various countries in Latin America, Africa, Middle East, and Asia, but these studies do not use nationally representative data, which limits generalizability and prevents direct comparisons with other countries (52–59). To our knowledge, there are no comparisons of population-level studies of the dual burden in children (<5y) or that distinguish between children <2y and ≥2y.

This paper documents contemporary trends in the population-level prevalence of stunting, wasting, and overweight in children <5y in LMIC, and separately reports these trends for children <2y and ≥2y. We also provide estimates of country-level and individual-level (concurrent stunting and overweight in the same child) dual burden in children <5y. Demographic and Health Surveys (DHS), which are rigorously collected and standardized, provide the necessary data to directly calculate and compare trends across countries and time.

B. Subjects and methods

Data source and study population

We use publicly available DHS (available from http://www.measuredhs.com) data for infants and young children (0-59 months). DHS data derive from nationally representative, household-based surveys of women of reproductive age and their young children (0-5y). Conducted in more than 90 countries since 1984, they provide data on population health, maternal and child health, and nutrition. DHS respondents are selected with a two-stage sampling process, described elsewhere in detail (60,61). Participant response rates are often over 90% (60). Interviewers are rigorously trained to ensure reliability, and questionnaires have been standardized and pre-tested to ensure comparability across time and countries (60).

We identified 63 LMIC with at least one survey with child anthropometry between 1988 and 2012. To be included in the present analysis, each country had to have at least two surveys with child anthropometry, and at least one survey had to occur in 2005 or later to capture recent trends. Thirty-six countries met these criteria, with survey years from 1990 to 2012, 2-8 surveys each, and sample sizes from 1 270 to 44 827. Intermediate surveys conducted between the first and final surveys were included when more than two surveys were available. The study population includes all singleton children ages 0-59 months identified in the 36 LMIC with a survey since 2005 (n = 839 507).

Measures

Our main variables are height (or length if age <2y), weight, age, and sex. All measurements were collected by trained field staff. Standing height (>2y) or recumbent length (<2y) were measured to the nearest 0.1 cm. Weight was measured with a pediatric scale or beam balance scale to the nearest 0.1 kg. Stunting and wasting are defined using the conventionally used Z-scores of height/length-for-age (HAZ) <-2SD and weight-for-height/length (WHZ) <-2SD, respectively, based on the 2006 WHO Growth Standards (46,62). For comparability, we define overweight using the opposite end of the WHZ distribution: WHZ >2SD. This definition of overweight encompasses obesity (WHZ>3SD). However, we hereafter refer to overweight/obesity as overweight. Although some define overweight based on BMI-for-age Z-scores, the WHZ definition is also used and provides similar estimates of overweight prevalence (4,16).

Countries are classified as low- or middle-income according to the gross national income per capita (Atlas method) from the World Bank (63).

Statistical analysis

We calculated country-level prevalence of stunting and wasting to represent undernutrition, and country-level prevalence of overweight to represent overnutrition. Sample weights were used to estimate nationally representative prevalence and 95% confidence intervals (95%CI) for each indicator among all children <5y, and separately for age groups <2y and ≥2y (64). We excluded children with missing anthropometry (n=33 372) or implausible measurements (HAZ < -6 or >+6 (n=19 911), or WHZ <-5 or >+5 (n=16 290)). The 1999 Nigeria survey is excluded from our analyses as there are documented measurement issues with the childhood anthropometry data (65). Our final analytic sample size was 773 547.

To compare the overall trends across countries and to account for differences in inter-survey intervals, we calculated the mean annualized change in prevalence between the first and final available surveys for each country ($\frac{final\ prevalence - first\ prevalence}{no.\ years\ between\ the\ two\ surveys}$). Next, we examined annualized change in prevalence in the decades before and after 2000. This choice was both theoretical and practical; the Millennium Development Goals were set forth in 2000 at the Millennium Summit (66), and the majority of countries had a survey in the early 1990s which allowed us to compare trends in two decades (1990-2000 and 2000-2010). To estimate trends in these two decades, we selected three surveys per country: 1) the survey conducted soonest after the year 1990, 2) the survey conducted closest to 2000 (either immediately prior to 2000, or after 2000) and 3) the most recent survey year (final year). We estimated the annualized prevalence changes between surveys 1) and 2), and between surveys 2) and 3). Trends are defined as increasing (≥0·1%/y), decreasing (≤-0·1%/y), or stable (between -0·1% and 0·1%/y) (4,16). Eight countries did not have a survey before 2000 (Armenia, Cambodia, Congo Brazza, Ethiopia, Gabon, Guinea, Honduras, Lesotho); therefore we estimated trends before 2000 for 28 countries and trends after 2000 for all 36 countries. Sensitivity analyses showed that trends did not differ when different numbers of countries were included, so we report estimates for 28 countries in the first decade but 36 in the second.

We estimate individual level burden using two metrics: 1) the percent of all children who are concurrently stunted and overweight ($\frac{stunted\ and\ overweight\ children\ 0-59\ mo.}{all\ children\ 0-59\ mo.}$), and 2) the percent of stunted children who are also overweight ($\frac{overweight\ children\ 0-59\ mo.}{stunted\ children\ 0-59\ mo.}$).

Management and descriptive analysis of data as described above were performed in Stata (Version 12, 2012, StataCorp, College Station, TX) using the svy command to account for survey design.

C. Results

Selected survey characteristics and country-level prevalence estimates and 95%CI for stunting, wasting, and overweight in all 36 countries at each survey year are shown in **supplementary table 3.1**. Prevalence of stunting, wasting, and overweight vary between countries and over time. Globally, the combined prevalence of the three distinct forms of childhood malnutrition decreased over time (**figure 3.1**), driven predominantly by declines in stunting (from 39·3% to 32·2%). Small reductions in wasting occurred (from 9·9% to 7·3%), while overweight increased (from 4·8% to 6·0%).

Annualized changes in prevalence

Table 3.1 shows the absolute and annualized changes in country-level prevalence of stunting, wasting, and overweight for all children <5y, grouped according to World Bank income group (low versus middle income). Overall, the majority of countries decreased stunting prevalence, with annual changes in prevalence ranging from -0·13%/y (Mozambique, Cote D'Ivoire) to -1·29%/y (Bangladesh). Stunting increased in six countries, five of which were in Africa. Wasting declined in just over half the countries. The magnitude of annual wasting changes were similar to those of stunting (-0·10%/y (Rwanda and Uganda) to -1·03%/y (Mali). Wasting was stable in 11 countries. Overweight increased in 36% of countries, with annual increases in these countries ranging from 0·12%/y (Niger) to 0·74%/y (Benin). Overweight did not change appreciably in 19 countries. On average, stunting decreased more in middle income countries, while wasting decreased more in low income countries. Absolute overweight prevalence increased more in middle income countries (low income: 0.66%, middle income: 0.98%), but overweight increased slightly more quickly in low income countries (low income: 0.07%/y, middle income: 0.04%/y).

Time trends before and after the millennium

Figure 3.2 displays the annualized changes in country-level prevalence of stunting and overweight for all children <5y, before and after 2000 (listed in descending order of stunting change before 2000 to visually characterize trends in countries of different stunting rates). Inconsistent country-level trends were observed before and after the millennium. Most countries experienced decreases in stunting during both time intervals, and only in Benin did stunting increase both before and after 2000. In four countries (Senegal, Egypt, Namibia, Niger), stunting was decreasing before 2000 but had subsequent increases after 2000. Most countries experienced increases in overweight after 2000, even if they experienced simultaneous increases in stunting (*e.g.:* Benin, Niger, Egypt, Namibia, and Guinea).

To determine whether an increase in overweight prevalence occurred simultaneously with declines in stunting prevalence, we cross-tabulated the stunting and overweight trends (*i.e.:* increase, no change, or decrease in prevalence of each indicator. Data not shown). Before 2000, 36% of countries experienced a decrease in stunting with concurrent overweight increases. This was the most frequent combination of trends before 2000. After 2000, this pattern occurred in fewer countries (22%). Instead, a decline in stunting with no change in overweight was the most common combination (33% of countries).

Age-specific annualized changes in prevalence

To determine if trends differed by age and sex, we compared country-level prevalence of stunting, wasting, and overweight at each country-year in males <2y, males ≥2y, females <2y, and females ≥2y. Trends did not differ by sex, but they did differ by age (sex-stratified results not shown). We found statistically significant age-group differences in stunting prevalence in 88% of surveys, in wasting in 90% of surveys, and in overweight in 63% of surveys, and therefore present age-stratified trends.

Age-specific absolute and annualized changes in country-level prevalence of stunting, wasting, and overweight across the full time period for which data are available are shown in **table 3.2**, grouped according to World Bank income group. Across both age groups, declines in stunting and wasting were observed in more countries than were increases. Increases in stunting occurred much less often in children ≥2y (10% of countries), compared to <2y (36% of countries). Less than one-tenth of countries experienced wasting increases in children <2y, whereas a third of countries saw wasting increases in children ≥2y. Overweight increased in more countries than it decreased in both age groups. Overweight increased in children <2y in two-thirds of countries, but only increased in children ≥2y in approximately half of countries. With respect to income group, stunting in children <2y decreased more in middle income countries, whereas it decreased more in low income countries for children ≥2y. Wasting decreased more in low than middle income countries for both age groups. Greater increases in overweight were observed in low income countries for children <2y, but not for children ≥2y, where overweight increased in middle income countries, but decreased in low income countries.

Age-specific time trends before and after the millennium

Figures 3.3 A and B show the annualized changes for country-level stunting and overweight before and after 2000 for children <2y and ≥2y. Countries are listed in descending order by annual changes in stunting before 2000. Both before and after 2000, stunting rates decreased for children ≥2y in more countries than for children <2y (before 2000: stunting rates decreased in 61% and 86% of countries in children <2y and in children ≥2y respectively; after 2000: stunting rates decreased in 75% of countries and 83% of countries in children <2y and ≥2y, respectively). Both before and after 2000, overweight rates increased in children <2y in more countries than for children ≥2y (before 2000: overweight rates increased in children <2y in 64% of countries and in children ≥2y in 46% of countries; after 2000: overweight rates increased in 64% of countries and 53% of countries in children <2y and ≥2y, respectively.

Dual burden

Figure 3.4 shows countries ranked by their ratio of country-level stunting to overweight prevalence at the millennium and at the most recent survey. No countries had a ratio less than one, which would indicate higher overweight than stunting prevalence. Three countries

(Armenia, Egypt, and the Dominican Republic) had a ratio of close to one in 2000, indicating nearly equal prevalence of stunting and overweight. Those same three countries, plus Jordan, had ratios close to one in the final year. The maximum ratio in 2000 was 99·02 (Nepal), but was much lower in the final year (27·46, Nepal).

We examined individual-level dual burden for each country at each year by cross-tabulating stunting and overweight status within children, grouped according to World Bank income group (**table 3.3**). The percent of children <5y within a country who were stunted and overweight ranged from 0·31% (Nepal, 2006) to 10·87% (Egypt, 2008). Ten percent of country-years had >5% of children affected by both stunting and overweight. The percent of stunted children within a country who were also overweight ranged from 0·61% (Nepal, 2006) to 37·82% (Egypt, 2008). Sixty two percent of country-years had >5% of stunted children also affected by overweight. Compared to low income countries, middle income countries had higher proportions of children who were stunted and overweight, as well as stunted children who were overweight.

D. Discussion

This study is the first to directly compare prevalence of stunting, wasting, and overweight in children <5y, to estimate the dual burden of malnutrition in children <5y, and to examine differences between children <2y and ≥2y for multiple LMIC. Our findings suggest that overall malnutrition is decreasing in children <5y, but trends varied for the three individual forms of malnutrition. Stunting has been the focus of many international efforts and programs and as a result has declined but remains high, especially in sub-Saharan Africa and Southeast Asia. Unfortunately, declines in stunting are occurring alongside increases in overweight among young children in many settings. Consequently, the dual burden is becoming reality in an increasing number of countries, particularly middle income countries.

Globally, stunting decreased by similar magnitude before 2000 and after 2000 in children <5y. Average annual change in stunting prevalence before 2000 was -0·37%/y, and annual change after the millennium was slightly more pronounced (-0·41%/y). Reductions in wasting occurred before 2000 (average annual change of -0·39%/y), but plateaued after the millennium (-0·06%/y). Overweight increased similarly before and after 2000, with average annual changes of 0·10%/y and 0·08%/y, respectively. The stunting trends indicate steady, but not accelerating progress, whereas wasting flat lined after 2000. The trends reported here are similar to findings from country-specific analyses in LMIC (67–69) and in recent global assessments of preschool children (3,4,70). Variability across countries may reflect differences in breastfeeding practices, the time of introduction to and quality of complementary foods, urban vs. rural environment, and family wealth (67,71–73). Given the widespread focus on MDGs and global investment in reducing childhood undernutrition, this is disappointing. The combination of increases in overweight with a decelerating reduction in stunting and wasting, paint an even more worrisome picture, and are slowly gaining attention (74,75) . These opposing individual trends mirror the results of our estimation of the dual burden, with more countries manifesting the dual burden over time.

A key contribution of our work is the exploration of trends before and after age 2, which have not been investigated previously. A child's second birthday has been identified as a critical milestone in physical and cognitive development, therefore gaining awareness of the trends in this age group is important (76). In our study, we showed differences between children <2y and ≥2y, with children <2y in a worse situation regarding both under- and overnutrition. Stunting decreased more in children ≥2y than in children <2y both before and after 2000. Stunting continued to increase in children <2y in one-third of countries after 2000, whereas few increases were seen after 2000 in children ≥2y. Overweight rates increased in both age groups, but the rates increased in more countries for children <2y than ≥2y before and after 2000. Additionally, the magnitude of changes are more extreme in children <2y compared to those ≥2y.

Given how critical the window from birth to age 2y is for future growth and development, it is concerning that children in this age group have poorer indicators than older children. The limited recovery from stunting after 2y has led to prioritization of efforts to reduce stunting in children <2y (77,78). Overweight/obesity in this age-group also deserves attention, because although overweight tends to persist and becomes more prevalent towards adolescence and adulthood, rapid growth and weight gain in infancy have been identified as risk factors for subsequent overweight in childhood (79–83) and adult body composition (49,84–86). Since this is a cumulative problem, it is important to identify at risk children as early as possible to avoid initializing the chain of events. Additionally, interventions that target only undernutrition, especially those that promote "catch-up" growth, may unintentionally contribute to overweight/obesity (87). This has been documented in a supplementary feeding program in Chile that led to increased childhood overweight, and the *Oportunidades* conditional cash transfer in Mexico which increased adult overweight, obesity, and blood pressure (14,15). Targeting children <2y in both stunting and overweight interventions provides an opportunity for renewed progress to be made in improving childhood nutrition in a climate where improvements have plateaued.

The country-level dual burden ratios for children <5y presented here indicate that although stunting prevalence is still higher than overweight in many countries, the difference between the two forms of malnutrition is getting smaller, as demonstrated by the maximum ratio in 2000 (99·85) and in the most recent year (46·31). Not only is the decreasing maximum indicative of a move towards the dual burden over time, but the entire range of ratios is shifted closer to 1, indicating that this is happening across the distribution of countries. These ratios must be interpreted in the context of the overall prevalence. Given a normal distribution of Z-scores in a population, we expect 2·5% of children to have Z-scores of -2 and 2·5% to have Z-scores of +2, producing a ratio of 1. However, the stunting prevalence is much greater than 2·5% for all countries in our study, and therefore higher than what would be expected for a normally distributed population. For example, the countries with ratios closest to 1 have stunting prevalence in 2000 >10% and overweight prevalence >5%. Armenia and Egypt have high rates of both stunting and overweight in both years, whereas Jordan and the Dominican Republic have more moderate rates. Therefore, in these countries we feel confident in our interpretation of the ratio as an indicator of the dual burden, and not as an artifact of the normal distribution.

We show that the dual burden of under- and overnutrition also occurs on the individual-level. Substantial proportions of children in a country were concurrently stunted and overweight and stunted children were also overweight, more so in middle- than low-income countries. This occurred alongside the already large numbers of the population who are either stunted or overweight. These instances of individual-level dual burden are particularly troublesome, and similar results have recently been reported in a number of LMIC in young children (88–90). One explanation is that poor early nutrition (i.e.: stunting) may alter physiology to preferentially accumulate fat mass versus lean mass (35,91). Poor early nutrition fosters a “thrifty phenotype” with increased efficiency of fat storage (36), and in utero results in small abdominal viscera and low muscle mass but high levels of adiposity (37,38). Stunted children have a greater accumulation of fat mass and a lower lean mass gain when compared to their non-stunted counterparts, and are more likely to deposit fat centrally when entering puberty (35,39). These results may be explained by lower rates of fat oxidation in the stunted children versus non-stunted children, or alterations in cortisol metabolism, which may occur in utero or early childhood (40). Stunted children have also exhibited abnormal appetite control and increased energy intake per unit body weight (35,41). Therefore, stunted children lack sufficient nutrients for optimal linear growth, but if they over-consume energy relative to their needs, they may preferentially store it as fat. The interventions and approaches needed to identify and optimize the health and nutrition for these distinct segments of the population may be very different.

This study is not without limitations. First, the selected countries are not globally representative, since certain regions are over-represented (Africa) while others are under-represented (Asia). This limits the generalizability of our findings but was a trade-off with our inclusion criteria which ensured we were able to assess trends over time. Our data represent almost three-quarters of a million children from many of the world's regions. Second, in a few countries, the age range differed slightly, depending on how each country carried out their DHS (*i.e.:* only children <3y were measured in 12 of 131 country-years, only children <4y were measured in 2 of 131 country-years). This could give the impression of lower rates in these country-years, as anthropometric deficits tend to accumulate over time. Third, this is cross-sectional data so we cannot make statements about age-specific trends within the same children. Despite these limitations, we believe our results are a valid attempt at quantifying trends in childhood malnutrition and estimating the dual burden. Our results provide a baseline for continued surveillance of global trends.

Recent studies in adults document global shifts in anthropometrics, with many reporting that overweight now exceeds underweight (32,92,93). Although we show that overweight continues to increase and previous reductions in stunting and wasting have slowed, levels of overweight have not yet surpassed those of stunting or wasting in children <5y. This offers a glimmer of hope that the shift observed in adults is not as severe in young children. We must not be complacent, however, as the dual burden ratio indicates that there are countries with equivalent levels of stunting and overweight and the number is increasing. These ratios are likely driven by decreases in stunting, but, even in the countries where stunting is still high (*e.g.:* sub-Saharan Africa), we note increases in overweight. We need to be careful of unintentionally increasing overweight when interventions only target undernutrition (14,15).

Childhood undernutrition is decreasing, largely reflecting reductions in stunting. However, these reductions are not consistent across the globe, and they are slowing down. Improvements in wasting have stalled, as well. Conversely, overweight continues to increase, which is of great concern. In concert, these individual indicator trends produce a dual burden of malnutrition, both within a population and within the child. Children <2y should be identified as a high-risk demographic and be screened for early intervention. The global nutrition community must continue to engage governments and international agencies to increase efforts to reduce stunting, while simultaneously avoiding overweight.

Figure 3.1. Cumulative country-level prevalence of stunting, wasting, overweight at three time points (year closest to 1990, year closest to 2000, and final year)

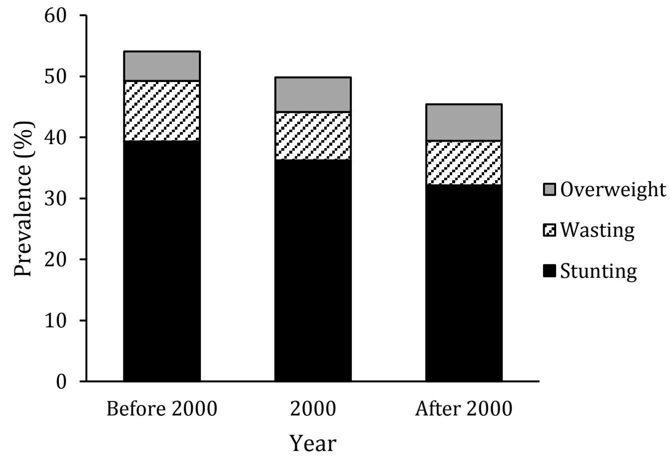

Table 3.1. Overall absolute and annualized change in stunting, wasting, and overweight from first survey to final survey for each country, grouped by World Bank income status

		Stunting		Wasting		Overweight	
Country	**Time range**	**Abs. change (%)**	**Ann. change (%/y)**	**Abs. change (%)**	**Ann. change (%/y)**	**Abs. change (%)**	**Ann. change (%/y)**
Low income countries							
Bangladesh	1996 – 2011	-19.4	-1.29	-5.2	-0.35	-0.1	-0.01
Benin	1996 – 2006	8.4	0.84	-8.6	-0.86	7.4	0.74
Burkina Faso	1992 – 2010	-5.4	-0.30	0.8	0.04	-0.2	-0.01
Cambodia	2000 – 2010	-10.3	-1.03	-5.3	-0.53	-1.8	-0.18
Ethiopia	2000 – 2011	-12.8	-1.17	-2.7	-0.25	0.0	0.00
Guinea	1999 – 2005	4.5	0.76	1.3	0.22	1.0	0.17
Haiti	1994 – 2012	-16	-0.89	-4.0	-0.22	-0.3	-0.01
Kenya	1993 – 2008	-4.8	-0.32	-0.2	-0.01	-0.9	-0.06
Malawi	1992 – 2010	-8.5	-0.47	-2.5	-0.14	-1.1	-0.06
Mali	1995 – 2006	1.5	0.14	-11.4	-1.03	2.6	0.24
Mozambique	1997 – 2011	-1.8	-0.13	-6.1	-0.43	2.0	0.14
Nepal	1996 – 2011	-16.6	-1.10	-4.0	-0.27	0.5	0.03
Niger	1992 – 2006	6.7	0.48	-5.7	-0.40	1.6	0.12
Rwanda	1992 – 2010	-12.0	-0.66	-1.7	-0.10	3.4	0.19
Tanzania	1991 – 2010	-8.0	-0.42	-2.7	-0.14	-0.3	-0.01
Uganda	1995 – 2011	-12.5	-0.78	-1.6	-0.10	-1.0	-0.06
Zimbabwe	1994 – 2010	3.6	0.22	-3.2	-0.20	-1.5	-0.10
Average		*-6.1*	*-0.36*	*-3.7*	*-0.28*	*0.7*	*0.07*
Middle income countries							
Armenia	2000 – 2010	1.8	0.18	1.7	0.17	-0.1	-0.01
Bolivia	1994 – 2008	-6.9	-0.49	-4.0	-0.29	0.5	0.04
Cameroon	1991 – 2011	-4.3	-0.22	1.7	0.08	1.5	0.07
Colombia	1995 – 2010	-7.3	-0.49	-0.8	-0.05	0.3	0.02
Congo Brazza	2005 – 2011	-7.1	-1.18	-2.0	-0.34	-4.9	-0.81
Cote D'Ivoire	1994 – 2011	-2.2	-0.13	-2.9	-0.17	0.5	0.03
Dom. Republic	1991 – 2007	-10.4	-0.65	0.1	0.01	4.1	0.26
Egypt	1992 – 2008	-0.8	-0.05	3.7	0.23	5.9	0.37
Gabon	2000 – 2012	-9.5	-0.79	-0.7	-0.06	2.5	0.21
Ghana	1993 – 2008	-4.7	-0.32	-5.4	-0.36	2.7	0.18
Honduras	2005 – 2011	-7.2	-1.20	0.0	0.00	-0.5	-0.08
India	1992 – 2005	-9.6	-0.73	-1.2	-0.09	-1.0	-0.08
Jordan	1990 – 2009	-11.4	-0.60	-2.5	-0.13	-1.9	-0.10
Lesotho	2004 – 2009	-5.0	-1.01	-1.1	-0.22	0.9	0.17
Namibia	1992 – 2006	-5.0	-0.36	-1.9	-0.13	0.7	0.05
Nigeria	1990 – 2008	-9.4	-0.52	2.6	0.14	6.3	0.35
Peru	1992 – 2012	-19.2	-0.96	-1.1	-0.06	-1.9	-0.09

Senegal	1992 – 2010	-4.9	-0.27	0.6	0.03	-1.0	-0.06
Zambia	1992 – 2007	-0.8	-0.05	-0.7	-0.05	4.1	0.27
Average		*-6.5*	*-0.52*	*-0.7*	*-0.07*	*1.0*	*0.04*

Figure 3.2. Annualized change in prevalence for stunting and overweight for children <5y, before and after 2000

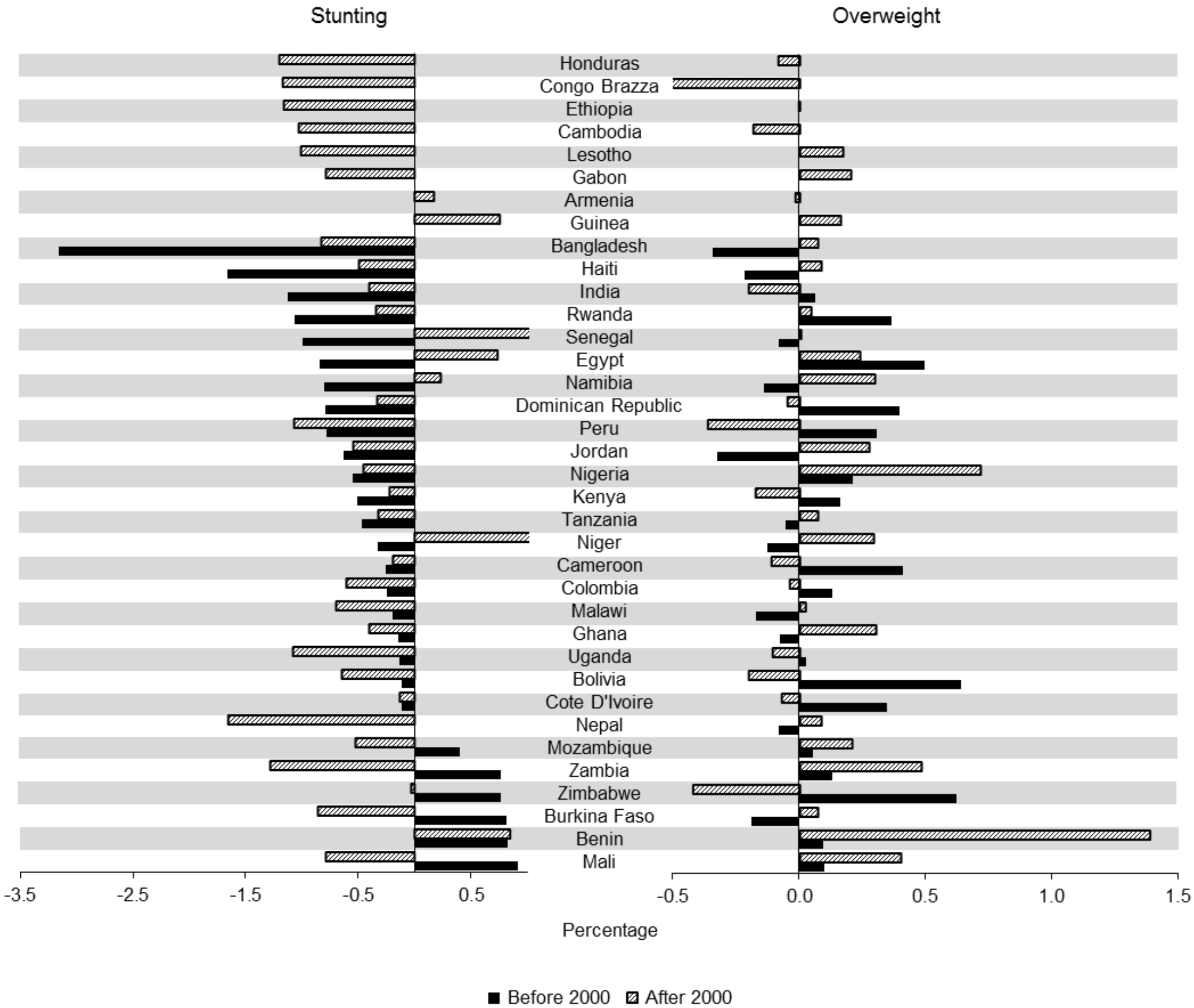

Table 3.2 Age-specific absolute and annualized changes in stunting, wasting, and overweight from first survey to final survey for each country for children <2y and children ≥2y, grouped by World Bank income group

		Stunting				**Wasting**				**Overweight**			
		Under 2y		**Over 2y**		**Under 2y**		**Over 2y**		**Under 2y**		**Over 2y**	
Country	**Time range**	**Abs. Δ (%)**	**Ann Δ (%/y)**	**Abs. Δ (%)**	**Ann. Δ (%/y)**	**Abs. Δ (%)**	**Ann. Δ (%/y)**	**Abs. Δ (%)**	**Ann. Δ (%/y)**	**Abs. Δ (%)**	**Ann. Δ (%/y)**	**Abs. Δ (%)**	**Ann. Δ (%/y)**
Low income countries													
Bangladesh	1996 – 2011	-13.4	-0.89	-23.9	-1.59	-13.8	-0.92	0.6	0.04	0.3	0.02	-0.3	-0.02
Benin	1996 – 2006	10.9	1.09	-9.0	-0.90	-8.6	-0.86	-4.3	-0.43	10.1	1.01	5.0	0.50
Burkina Faso	1992 – 2010	-1.0	-0.06	-9.6	-0.54	0.6	0.03	1.7	0.1.0	0.0	0.00	-0.5	-0.03
Cambodia	2000 – 2010	-5.1	-0.51	-12.9	-1.29	-5.9	-0.59	-5.0	-0.50	-2.9	-0.29	-1.1	-0.11
Ethiopia	2000 – 2011	-14.8	-1.35	-12.1	-1.10	-4.4	-0.40	-1.4	-0.13	-0.6	-0.06	0.4	0.03
Guinea	1999 – 2005	2.0	0.33	7.9	1.31	0.0	0.00	1.7	0.28	1.5	0.26	0.5	0.08
Haiti	1994 – 2012	-10.6	-0.59	-19.7	-1.09	-5.4	-0.30	-3.1	-0.17	-1.7	-0.09	0.8	0.04
Kenya	1993 – 2008	0.0	0.00	-8.0	-0.53	-1.4	-0.09	0.6	0.04	0.8	0.05	-2.1	-0.14
Malawi	1992 – 2010	1.9	0.11	-19.2	-1.07	-3.7	-0.20	-0.9	-0.05	2.3	0.13	-3.6	-0.20
Mali	1995 – 2006	2.7	0.24	-14.5	-1.32	-8.0	-0.73	-8.0	-0.72	3.6	0.33	1.6	0.15
Mozambique	1997 – 2011	2.1	0.15	-19.5	-1.39	-5.2	-0.37	-3.1	-0.22	4.9	0.35	-1.6	-0.12
Nepal	1996 – 2011	-21.9	-1.46	-26.8	-1.79	-1.6	-0.11	-1.3	-0.09	1.3	0.08	-0.1	0.00
Niger	1992 – 2006	7.3	0.52	5.0	0.36	-8.1	-0.58	-3.1	-0.22	2.3	0.16	1.1	0.08
Rwanda	1992 – 2010	-9.6	-0.54	-14.8	-0.82	-3.6	-0.20	-0.2	-0.01	4.6	0.26	2.7	0.15
Tanzania	1991 – 2010	-5.0	-0.27	-11.3	-0.59	-2.0	-0.10	-3.0	-0.16	1.8	0.09	-1.8	-0.09
Uganda	1995 – 2011	-10.9	-0.68	-18.8	-1.18	-0.9	-0.06	-0.8	-0.05	0.0	0.00	-2.2	-0.14
Zimbabwe	1994 – 2010	3.3	0.21	-5.2	-0.32	-2.5	-0.16	-2.4	-0.15	-0.2	-0.01	-1.6	-0.10
Average		*-3.7*	*-0.22*	*-12.5*	*-0.81*	*-4.4*	*-0.33*	*-1.9*	*-0.14*	*1.7*	*0.13*	*-0.2*	*0.00*
Middle income countries													
Armenia	2000 – 2010	3.4	0.34	1.1	0.11	0.2	0.02	2.4	0.24	-3.7	-0.37	2.2	0.22
Bolivia	1994 – 2008	-7.9	-0.56	-14.1	-1.01	-3.3	-0.24	-3.6	-0.26	0.8	0.05	1.0	0.07
Cameroon	1991 – 2011	-1.5	-0.08	-6.4	-0.32	2.2	0.11	1.1	0.06	2.0	0.10	1.0	0.05
Colombia	1995 – 2010	-1.8	-0.11	-11.7	-0.69	-1.0	-0.06	-1.2	-0.07	0.9	0.05	0.1	0.01

Congo Brazza	2005 - 2011	-4.1	-0.28	-9.5	-0.64	-0.7	-0.05	-0.8	-0.05	0.7	0.04	0.0	0.00
Cote D'Ivoire	1994 - 2011	-4.2	-0.70	-9.2	-1.53	-2.5	-0.42	-1.7	-0.29	-5.3	-0.89	-4.5	-0.76
Dom. Republic	1991 - 2007	-11.3	-0.70	-9.6	-0.60	-0.2	-0.01	0.4	0.03	4.5	0.28	4.0	0.25
Egypt	1992 - 2008	-1.4	-0.09	0.0	0.00	2.9	0.18	4.1	0.25	7.6	0.47	4.9	0.31
Gabon	2000 - 2012	-7.2	-0.60	-11.3	-0.94	-2.1	-0.18	0.5	0.04	3.4	0.28	1.6	0.14
Ghana	1993 - 2008	-4.8	-0.32	-16.6	-1.11	-1.9	-0.13	-3.4	-0.23	2.4	0.16	3.4	0.23
Honduras	2005 - 2011	-5.8	-0.96	-7.0	-1.17	-0.1	-0.01	-0.1	-0.01	-0.8	-0.13	-0.5	-0.08
India	1992 - 2005	-6.5	-0.50	-17.2	-1.33	-1.1	-0.08	1.7	0.13	-0.4	-0.03	-1.3	-0.10
Jordan	1990 - 2009	-10.2	-0.53	-12.2	-0.64	-3.3	-0.17	-1.9	-0.10	-3.4	-0.18	-0.9	-0.05
Lesotho	2004 - 2009	-6.3	-1.26	-3.6	-0.72	-2.1	-0.41	-0.4	-0.08	2.0	0.40	-0.3	-0.06
Namibia	1992 - 2006	-6.9	-0.50	-3.4	-0.24	-0.6	-0.04	-3.0	-0.21	0.9	0.06	0.7	0.05
Nigeria	1990 - 2008	0.7	0.04	-17.8	-0.99	2.7	0.15	2.7	0.15	7.8	0.43	5.4	0.30
Peru	1992 - 2012	-7.8	-0.39	-26.6	-1.33	-1.7	-0.08	-0.8	-0.04	-1.5	-0.07	-2.1	-0.11
Senegal	1992 - 2010	1.0	0.06	-9.4	-0.52	-1.5	-0.08	2.2	0.12	-1.4	-0.08	-0.6	-0.03
Zambia	1992 - 2007	1.5	0.10	-3.8	-0.25	-0.9	-0.06	-0.3	-0.02	6.1	0.40	2.6	0.17
Average		*-4.3*	*-0.37*	*-9.9*	*-0.73*	*-0.8*	*-0.08*	*-0.1*	*-0.02*	*1.2*	*0.05*	*0.9*	*0.03*

Figure 3.3A and B. Age-specific annualized change in prevalence for stunting and overweight for children <2y (A) and children ≥2y (B), before and after 2000

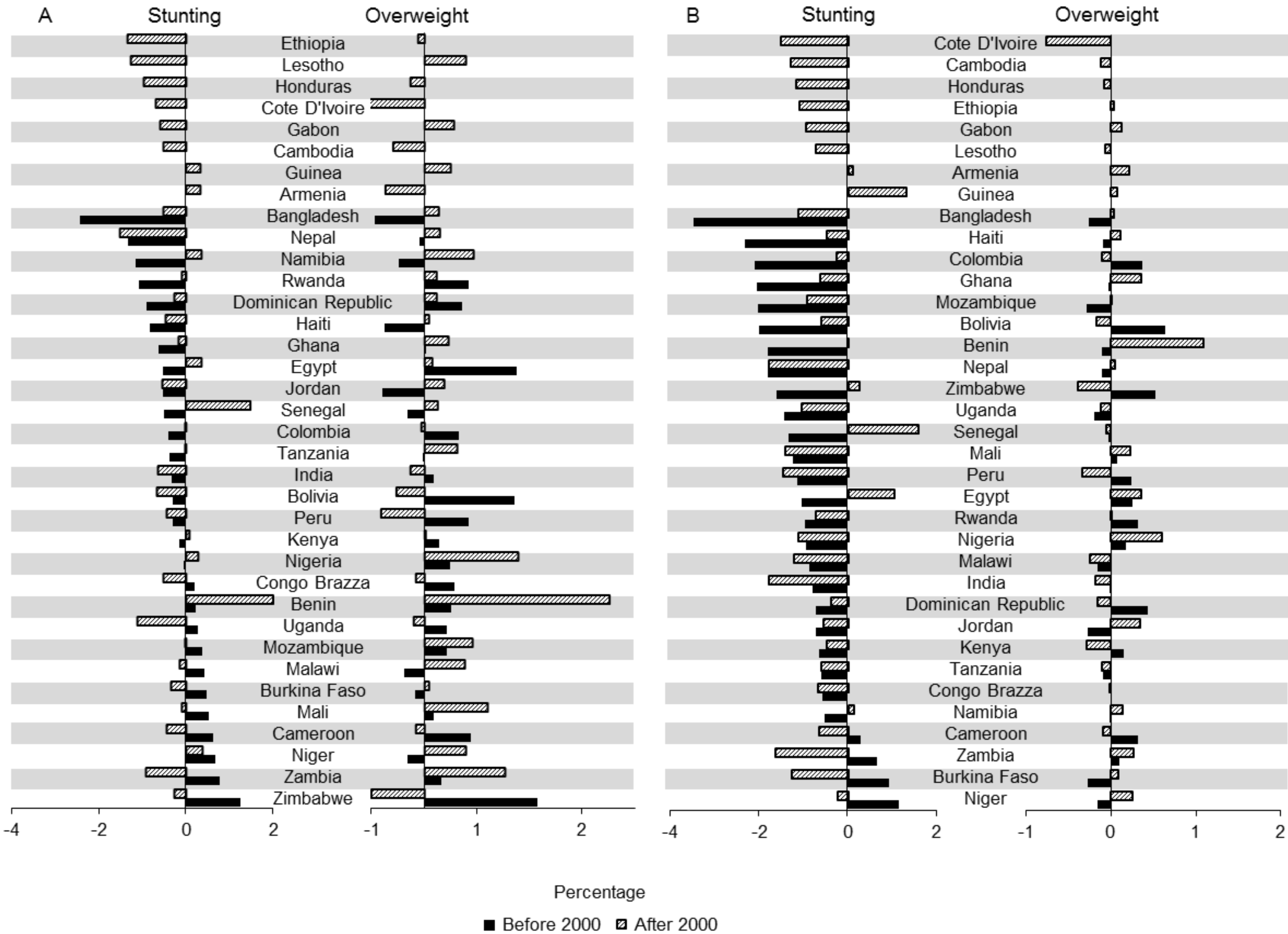

Figure 3.4. Comparison of an estimation of the country-level dual burden (ratio of stunting prevalence to overweight prevalence) for children <5y in the year closest to 2000 and the most recent year. Countries are ranked according to the dual burden ratio in the year closest to 2000

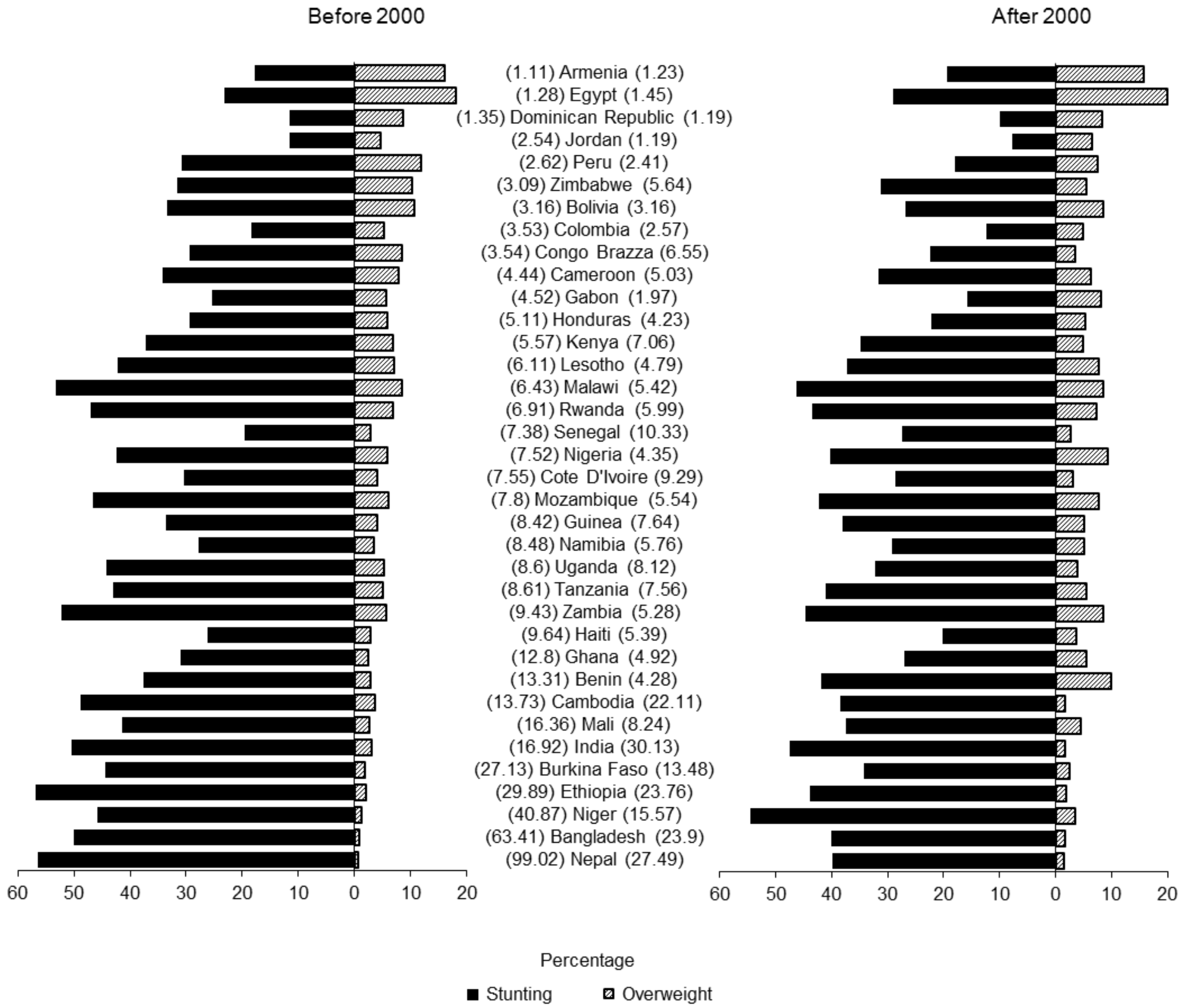

Table 3.3. Number and proportion of children <5y experiencing individual-level dual burden in each country-year, grouped by World Bank income group

Country	Year	No. total	No. stunted	No. stunted and overweight	% stunted and overweight	% of stunted who are overweight
Bangladesh	1996	4674	2,783	62	1.3	2.2
	1999	5294	2605	26	0.5	1.0
	2004	5871	2870	28	0.5	1.0
	2007	5250	2247	19	0.4	0.8
	2011	7549	3003	52	0.7	1.7
Benin	1996	2443	835	38	1.6	4.6
	2001	4241	1617	58	1.4	3.6
	2006	11878	4994	854	7.2	17.1
Burkina Faso	1992	4309	1559	57	1.3	3.7
	1998	4485	1937	38	0.8	2.0
	2003	7954	3405	238	3.0	7.0
	2010	6352	2147	97	1.5	4.5
Cambodia	2000	3486	1753	95	2.7	5.4
	2005	3538	1557	30	0.8	1.9
	2010	3660	1449	45	1.2	3.1
Ethiopia	2000	8659	4602	98	1.1	2.1
	2005	3815	1786	95	2.5	5.3
	2011	9398	3958	85	0.9	2.1
Guinea	1999	4232	1413	88	2.1	6.2
	2005	2528	966	69	2.7	7.1
Haiti	1994	2708	972	48	1.8	4.9
	2000	5410	1502	41	0.8	2.7
	2005	2500	712	46	1.8	6.5
	2012	3894	846	45	1.2	5.3
Kenya	1993	4814	1875	107	2.2	5.7
	1998	4478	1691	140	3.1	8.3
	2003	4608	1558	105	2.3	6.7
	2008	4981	1680	135	2.7	8.0
Malawi	1992	3109	1607	185	6.0	11.5
	2000	8924	4554	484	5.4	10.6
	2004	7931	4087	536	6.8	13.1
	2010	4457	2028	230	5.2	11.3
Mali	1995	4614	1668	48	1.0	2.9
	2001	9170	3821	136	1.5	3.6
	2006	10684	4015	277	2.6	6.9
Mozambique	1997	3346	1474	113	3.4	7.7
	2003	7827	3538	209	2.7	5.9

	2011	9071	3517	412	4.5	11.7
Nepal	1996	3706	2090	21	0.6	1.0
	2001	6144	3465	24	0.4	0.7
	2006	5190	2604	16	0.3	0.6
	2011	2130	965	15	0.7	1.6
Niger	1992	4591	1996	49	1.1	2.5
	1998	3816	1693	19	0.5	1.1
	2006	3595	1776	79	2.2	4.4
Rwanda	1992	4261	2305	91	2.1	3.9
	2000	5958	2714	243	4.1	9.0
	2005	3584	1767	137	3.8	7.8
	2010	3984	1723	150	3.8	8.7
Tanzania	1991	6274	3129	222	3.5	7.1
	1996	5176	2542	117	2.3	4.6
	2004	6940	2904	164	2.4	5.6
	2010	6646	2605	183	2.8	7.0
Uganda	1995	4466	1845	104	2.3	5.6
	2000	5038	2178	141	2.8	6.5
	2006	2322	890	44	1.9	4.9
	2011	2025	636	35	1.7	5.5
Zimbabwe	1994	2048	581	47	2.3	8.1
	1999	2590	808	129	5.0	16.0
	2005	3833	1249	170	4.4	13.6
	2010	4226	1341	104	2.5	7.8
Average					*2.3*	*5.7*
Middle income countries						
Armenia	2000	1495	263	63	4.2	24.0
	2005	1202	170	37	3.1	21.8
	2010	1318	282	104	7.9	36.9
Bolivia	1994	2882	972	93	3.2	9.6
	1998	6147	2214	286	4.7	12.9
	2003	9053	3014	348	3.8	11.5
	2008	7636	2011	186	2.4	9.2
Cameroon	1991	2556	824	35	1.4	4.2
	1998	1756	572	49	2.8	8.6
	2004	3090	1072	122	3.9	11.4
	2011	4845	1516	121	2.5	8.0
Colombia	1995	4466	871	41	0.9	4.7
	2000	4120	760	34	0.8	4.5
	2005	12239	1919	49	0.4	2.6
	2010	15773	2259	82	0.5	3.6
Congo Brazza	2005	3809	1059	192	5.0	18.1
	2011	4323	1129	65	1.5	5.8

Cote D'Ivoire	1994	3333	1008	32	1.0	3.2
	1998	1506	416	33	2.2	7.9
	2011	3086	900	42	1.4	4.7
Dom. Republic	1991	3133	758	37	1.2	4.9
	1996	3647	567	22	0.6	3.9
	2002	9117	1136	107	1.2	9.4
	2007	9093	1019	107	1.2	10.5
Egypt	1992	7241	2004	313	4.3	15.6
	1995	10165	3477	679	6.7	19.5
	2000	10078	2279	717	7.1	31.5
	2003	5911	1147	222	3.8	19.4
	2005	12038	3167	1092	9.1	34.5
	2008	9275	2665	1008	10.9	37.8
Gabon	2000	3386	978	60	1.8	6.1
	2012	3222	744	82	2.5	11.0
Ghana	1993	1825	578	16	0.9	2.8
	1998	2664	873	28	1.1	3.2
	2003	2987	1077	67	2.2	6.2
	2008	2293	625	58	2.5	9.3
Honduras	2005	9092	3196	99	1.1	3.1
	2011	9841	2519	73	0.7	2.9
India	1992	26786	14411	536	2.0	3.7
	1998	24892	12033	607	2.4	5.0
	2005	40963	17748	534	1.3	3.0
Jordan	1990	6519	1327	186	2.9	14.0
	1997	5490	652	60	1.1	9.2
	2002	4745	635	49	1.0	7.7
	2007	4312	662	190	4.4	28.7
	2009	4236	428	53	1.3	12.4
Lesotho	2004	1351	591	49	3.6	8.3
	2009	1580	618	53	3.4	8.6
Namibia	1992	2511	870	50	2.0	5.7
	2000	2875	776	47	1.6	6.1
	2006	3603	1059	63	1.7	5.9
Nigeria	1990	5705	2655	85	1.5	3.2
	2003	4275	1763	151	3.5	8.6
	2008	18660	7811	1160	6.2	14.9
Peru	1992	7607	2939	242	3.2	8.2
	1996	14708	5192	415	2.8	8.0
	2000	11475	3966	412	3.6	10.4
	2005	2269	734	47	2.1	6.4
	2007	2346	774	49	2.1	6.3
	2008	5646	1567	104	1.8	6.6

	2011	8625	2034	56	0.6	2.8
	2012	9071	1864	46	0.5	2.5
Senegal	1992	4419	1431	62	1.4	4.3
	2005	2808	584	19	0.7	3.3
	2010	3606	1079	58	1.6	5.4
Zambia	1992	4811	2236	101	2.1	4.5
	1996	5373	2657	193	3.6	7.3
	2001	5324	2816	188	3.5	6.7
	2007	4947	2150	271	5.5	12.6
Average					*2.7*	*9.9*

Supplementary Table 3.1. Survey year, sample size, and prevalence and 95%CI of stunting (HAZ < -2SD), wasting (WHZ < -2SD), and overweight (WHZ > 2SD) in children <5y

Country	Survey year	Sample size	Stunting		Wasting		Overweight	
			%	95% CI	%	95% CI	%	95% CI
Armenia	2000	1517	17.7	15.0, 20.4	2.4	1.4, 3.5	15.9	13.7, 18.2
	2005	1270	16.8	12.5, 21.0	4.8	2.9, 6.7	11.5	9.2, 13.8
	2010	1429	19.5	16.8, 22.1	4.1	2.7, 5.5	15.8	13.5, 18.1
Bangladesh	1996	5223	59.6	57.8, 61.3	20.8	19.3, 22.3	1.8	1.4, 2.2
	1999	5898	50.1	48.4, 51.8	12.3	11.3, 13.4	0.8	0.5, 1.0
	2004	6107	49.6	47.6, 51.6	14.6	13.5, 15.7	0.9	0.7, 1.2
	2007	5682	43.9	41.9, 45.9	17.4	16.0, 18.8	0.9	0.6, 1.2
	2011	8160	40.2	38.5, 41.9	15.6	14.5, 16.6	1.7	1.3, 2.0
Benin	1996*	2561	33.5	31.2, 35.8	16.8	14.8, 18.8	2.4	1.6, 3.1
	2001	4336	37.7	35.8, 39.6	9.2	8.3, 10.0	2.8	2.3, 3.4
	2006	12854	41.9	40.5, 43.3	8.2	7.5, 9.0	9.8	8.9, 10.7
Bolivia	1994*	2985	33.8	31.2, 36.3	5.5	4.5, 6.4	8.0	6.8, 9.2
	1998	6384	33.3	31.5, 35.1	1.6	1.3, 1.9	10.5	9.5, 11.6
	2003	9274	32.2	30.6, 33.8	1.6	1.3, 2.0	9.2	8.3, 10.1
	2008	8010	26.9	25.3, 28.5	1.4	1.1, 1.8	8.5	7.7, 9.3
Burkina Faso	1992	4618	39.6	38.1, 41.1	15.0	13.7, 16.2	2.8	2.1, 3.5
	1998	4711	44.5	42.6, 46.4	14.9	13.6, 16.2	1.6	1.1, 2.2
	2003	8630	42.8	40.7, 44.9	21.3	19.9, 22.6	4.6	3.6, 5.6
	2010	6620	34.2	32.6, 35.9	15.8	14.4, 17.2	2.5	2.0, 3.1
Cambodia	2000	3729	48.7	46.5, 51.0	16.7	15.0, 18.4	3.5	2.8, 4.3
	2005	3737	41.6	39.3, 43.8	8.6	7.4, 9.8	1.5	1.0, 2.0
	2010	3836	38.5	36.2, 40.8	11.5	10.1, 12.9	1.7	1.2, 2.3
Cameroon	1991	2596	36.0	32.5, 39.5	4.3	3.2, 5.5	4.8	3.4, 6.3
	1998*	1868	34.3	31.3, 37.2	8.3	6.4, 10.2	7.7	6.1, 9.3
	2004	3219	34.7	32.4, 37.0	6.4	5.3, 7.4	7.9	6.6, 9.3
	2011	5051	31.7	30.0, 33.4	6.0	5.2, 6.8	6.3	5.4, 9.3
Colombia	1995	4528	19.6	18.2, 21.1	1.7	1.3, 2.1	4.5	3.9, 5.2
	2000	4165	18.4	16.9, 19.9	1.0	0.7, 1.3	5.2	4.4, 6.0
	2005	12339	15.3	14.3, 16.3	1.6	1.3, 1.8	4.2	3.6, 4.8
	2010	16705	12.3	11.6, 13.1	0.9	0.7, 1.1	4.8	4.4, 5.3
Congo Brazza	2005	4068	29.4	27.5, 31.3	7.6	6.3, 8.9	8.3	7.1, 9.5
	2011	4452	22.4	20.4, 24.3	5.6	4.5, 6.7	3.4	2.4, 4.4
Cote D'Ivoire	1994*	3410	30.8	29.0, 32.6	10.7	9.6, 11.8	2.6	2.0, 3.3
	1998	1559	30.4	26.8, 33.9	6.9	5.5, 8.3	4.0	2.9, 5.1
	2011	3346	28.6	26.4, 30.8	7.8	6.5, 9.1	3.1	2.3, 3.8
Dominican Republic	1991	3265	20.3	17.9, 22.7	2.1	1.4, 2.7	4.2	3.2, 5.2
	1996	3783	13.2	11.7, 14.7	2.0	1.4, 2.5	6.7	5.4, 8.0
	2002	9384	11.6	10.3, 12.8	1.9	1.5, 2.3	8.6	7.6, 9.5

	2007	9823	9.9	8.9, 10.9	2.2	1.7, 2.7	8.3	7.4, 9.3
Egypt	1992	7577	29.8	27.8, 31.8	3.9	3.3, 4.4	14.1	12.7, 15.5
	1995	10632	34.1	32.4, 35.7	5.7	5.0, 6.3	14.3	13.1, 15.5
	2000	10418	23.1	21.7, 24.6	2.9	2.5, 3.4	18.1	16.8, 19.4
	2003	6051	19.5	18.1, 20.8	5.2	4.4, 6.0	8.9	7.8, 10.0
	2005	12713	22.7	21.3, 24.1	4.9	4.3, 5.6	13.8	12.6, 14.9
	2008	10155	29.0	24.0, 34.1	7.5	4.9, 10.2	20.0	15.1, 24.9
Ethiopia	2000	9038	56.8	55.0, 58.6	12.5	11.4, 13.7	1.9	1.5, 2.3
	2005	4392	49.9	47.3, 52.4	12.1	10.7, 13.6	4.4	3.6, 5.3
	2011	10235	43.9	42.1, 45.7	9.8	8.8, 10.8	1.8	1.5, 2.2
Gabon	2000	3952	25.3	23.4, 27.2	4.1	3.2, 4.9	5.6	4.6, 6.6
	2012	3460	15.9	13.5, 18.2	3.4	2.6, 4.2	8.1	6.4, 9.7
Ghana	1993*	1914	31.7	29.3, 34.1	14.2	12.4, 16.1	2.8	2.0, 3.6
	1998	2774	31.0	28.8, 33.1	9.6	8.4, 10.8	2.4	1.8, 3.1
	2003	3169	35.2	32.9, 37.4	8.3	7.2, 9.4	4.3	3.5, 5.1
	2008	2579	26.9	24.6, 29.3	8.9	7.6, 10.1	5.5	4.2, 6.7
Guinea	1999	4551	33.6	31.8, 35.3	9.5	8.5, 10.5	4.0	3.4, 4.6
	2005	2633	38.1	35.7, 40.6	10.9	9.2, 12.5	5.0	3.9, 6.1
Haiti	1994	2834	36.2	33.5, 38.9	9.1	7.8, 10.3	4.0	2.9, 5.1
	2000	5486	26.2	23.3, 29.1	5.3	4.5, 6.1	2.7	2.1, 3.4
	2005	2552	27.6	24.8, 30.3	10.4	8.1, 12.7	4.1	3.1, 5.0
	2012	3983	20.3	18.3, 22.3	5.1	4.2, 5.9	3.8	3.0, 4.5
Honduras	2005	10091	29.5	27.9, 31.0	1.4	1.1, 1.6	5.8	5.1, 6.4
	2011	10113	22.3	21.0, 23.5	1.4	1.1, 1.6	5.3	4.7, 5.9
India	1992†	44827	57.2	56.2, 58.1	21.1	20.3, 22	2.6	2.3, 2.9
	1998*	27241	50.4	49.5, 51.3	19.8	19.2, 20.5	3.0	2.7, 3.3
	2005	43407	47.6	47.0, 48.2	20.0	19.5, 20.5	1.6	1.4, 1.7
Jordan	1990	6770	19.1	17.7, 20.6	3.9	3.3, 4.5	8.4	7.6, 9.3
	1997	5650	10.7	9.6, 11.8	2.3	1.9, 2.7	4.3	3.7, 4.8
	2002	4883	11.6	10.5, 12.7	2.3	1.6, 3.0	4.6	3.8, 5.4
	2007	5003	14.5	12.7, 16.3	7.3	5.9, 8.7	12.2	10.3, 14.1
	2009	4558	7.8	6.4, 9.1	1.5	0.9, 2.1	6.5	5.1, 8.0
Kenya	1993	5070	39.7	37.6, 41.7	6.8	6.0, 7.7	5.8	5.0, 6.7
	1998	4745	37.1	35.3, 39.0	7.0	6.2, 7.9	6.7	5.8, 7.5
	2003	4815	35.3	33.4, 37.1	5.9	4.8, 6.9	5.7	4.9, 6.5
	2008	5346	34.9	32.7, 37.1	6.7	5.7, 7.7	4.9	4.2, 5.7
Lesotho	2004	1449	42.2	39.0, 45.5	5.3	3.9, 6.7	6.9	5.3, 8.6
	2009	1686	37.2	34.4, 40.0	4.2	3.2, 5.3	7.8	6.2, 9.3
Malawi	1992	3320	54.8	52.6, 57.0	6.5	5.4, 7.7	9.6	8.0, 11.3
	2000	9545	53.2	51.6, 54.9	6.7	6.0, 7.4	8.3	7.3, 9.2
	2004	8723	51.2	49.7, 52.8	6.2	5.5, 7.0	9.5	8.7, 10.3
	2010	4798	46.2	44.2, 48.3	4.1	3.3, 4.9	8.5	7.6, 9.5
Mali	1995*	4921	35.9	34.2, 37.6	26.9	25.2, 28.6	1.9	1.4, 2.5

	2001	9846	41.4	39.4, 43.3	12.6	11.4, 13.9	2.5	2.0, 3.1
	2006	11729	37.4	35.8, 39.1	15.6	14.6, 16.5	4.5	3.8, 5.3
Mozambique	1997*	3543	44.1	40.8, 47.5	12.1	10.2, 14.1	5.7	4.2, 7.1
	2003	8084	46.6	44.5, 48.6	5.1	4.3, 6.0	6.0	5.2, 6.8
	2011	9493	42.3	40.7, 44.0	6.1	5.4, 6.8	7.6	6.9, 8.4
Namibia	1992	2747	34.2	31.3, 37.0	9.4	7.9, 10.9	4.4	3.5, 5.2
	2000	2990	27.7	24.9, 30.5	9.5	8.1, 10.9	3.3	2.4, 4.1
	2006	3769	29.1	27.0, 31.3	7.5	6.5, 8.5	5.1	4.0, 6.1
Nepal	1996*	3963	56.4	54.1, 58.7	14.8	13.4, 16.2	1.0	0.6, 1.3
	2001	6242	56.4	54.2, 58.6	11.4	9.9, 12.9	0.6	0.4, 0.8
	2006	5270	49.2	46.6, 51.9	12.5	11.2, 13.8	0.6	0.3, 0.9
	2011	2365	39.9	37.1, 42.6	10.8	9.1, 12.4	1.4	0.8, 2.1
Nigeria	1990	5998	49.6	47.2, 52.0	11.7	9.6, 13.8	2.9	2.1, 3.7
	1999*‡	2889	50.1	46.9, 53.4	14.1	12.3, 15.8	23.3	20.8, 25.9
	2003	4668	42.5	39.5, 45.4	11.1	9.8, 12.5	5.6	4.7, 6.6
	2008	23683	40.2	39.1, 41.3	14.3	13.4, 15.2	9.2	8.6, 9.8
Niger	1992	4907	47.8	45.8, 49.7	18.6	17.3, 19.9	1.9	1.4, 2.3
	1998*	3974	45.8	43.6, 47.9	25.1	23.3, 26.9	1.1	0.8, 1.5
	2006	3909	54.5	52.0, 56.9	12.9	11.4, 14.4	3.5	2.6, 4.4
Peru	1992	7826	37.1	35.1, 39.1	1.8	1.5, 2.1	9.3	8.5, 10.1
	1996	15175	30.9	29.3, 32.4	1.5	1.3, 1.8	9.9	9.1, 10.7
	2000	11765	30.8	29.2, 32.4	1.1	0.9, 1.3	11.8	10.9, 12.6
	2005	2490	29.3	25.4, 33.2	1.1	0.5, 1.6	8.8	7.2, 10.3
	2007	2554	29.4	25.9, 33.0	1.2	0.6, 1.8	9.5	7.7, 11.3
	2008	6203	27.1	24.7, 29.6	0.7	0.3, 1.0	10.1	8.7, 11.6
	2011	8726	19.7	18.1, 21.3	0.4	0.2, 0.5	8.8	7.8, 9.9
	2012	9187	17.9	16.5, 19.3	0.7	0.5, 0.9	7.4	6.5, 8.3
Rwanda	1992	4383	55.5	53.4, 57.6	4.7	3.8, 5.5	3.9	3.2, 4.5
	2000	6283	46.9	45.3, 48.6	8.4	7.5, 9.2	6.8	6.0, 7.5
	2005	3712	50.3	48.4, 52.3	4.5	3.7, 5.3	6.5	5.6, 7.4
	2010	4032	43.5	41.6, 45.5	2.9	2.4, 3.5	7.3	6.4, 8.1
Senegal	1992	4662	32.4	30.4, 34.3	9.2	8.3, 10.2	3.7	3.0, 4.3
	2005	2890	19.5	17.3, 21.7	8.6	7.2, 9.9	2.6	1.7, 3.6
	2010	4164	27.5	25.3, 29.7	9.8	8.8, 10.9	2.7	1.9, 3.4
Tanzania	1991	6588	49.0	46.3, 51.7	7.5	6.5, 8.5	5.7	5.0, 6.4
	1996	5477	48.3	45.9, 50.8	8.4	7.6, 9.3	4.5	3.8, 5.2
	2004	7206	42.9	40.9, 45.0	3.6	3.1, 4.1	5.0	4.3, 5.7
	2010	7001	41.0	39.3, 42.8	4.8	4.2, 5.5	5.4	4.7, 6.1
Uganda	1995†	4654	44.8	42.8, 46.7	6.5	5.6, 7.3	5.0	4.1, 5.8
	2000	5262	44.1	41.9, 46.3	5.0	4.4, 5.7	5.1	4.4, 5.8
	2006	2377	37.4	35.2, 39.5	6.2	5.1, 7.2	5.0	3.9, 6.1
	2011	2160	32.3	29.6, 35.0	4.8	3.7, 5.9	4.0	3.0, 4.9
Zambia	1992	4960	45.4	43.3, 47.6	6.1	5.2, 6.9	4.4	3.8, 5.0

	1996	5555	48.1	46.2, 50.0	5.1	4.4, 5.8	6.0	5.2, 6.8
	2001	5532	52.3	50.4, 54.2	6.0	5.3, 6.8	5.5	4.8, 6.3
	2007	5242	44.6	42.6, 46.6	5.3	4.6, 6.1	8.4	7.4, 9.5
Zimbabwe	1994*	2100	27.7	25.3, 30.0	6.4	5.1, 7.6	7.1	5.9, 8.3
	1999	2999	31.5	29.1, 33.9	7.7	6.3, 9.0	10.2	8.7, 11.7
	2005	4425	32.4	29.8, 34.9	6.5	5.5, 7.5	8.6	7.4, 9.9
	2010	4657	31.2	29.6, 32.8	3.2	2.6, 3.7	5.5	4.8, 6.3

* Survey only included children 0-3y
† Survey only included children 0-4y
‡ Survey excluded from analysis (30)

CHAPTER IV: THE RELATIONSHIP BETWEEN WEALTH AND THE DUAL BURDEN OF MALNUTRITION IN CHILDREN UNDER 5 YEARS IN 40 LOW- AND MIDDLE-INCOME COUNTRIES

A. Introduction

Low- and middle-income countries (LMIC) are experiencing shifts in their burden of nutritional diseases, with overweight and obesity increasingly contributing to hypertension, CVD, and diabetes, which were once thought of as diseases of affluence. The emergence of obesity in LMIC was first documented in adults, and it was thought that children were progressing through the obesity epidemic at a slower rate than adults (94). It is now well-established that children in LMIC are experiencing a similar rise in overweight/obesity (4,16,95). However, while overweight and obesity increase, children continue to experience high levels of undernutrition, producing a dual burden of malnutrition (2,96). Recent estimates report that 171 million children <5y were stunted (short for age) and 52 million children were wasted (low weight for height), while 43 million children were overweight or obese (2–4). Both forms of childhood malnutrition (under- and over-nutrition) have adverse effects on adult health (9,50). Recent evidence in adults suggests that economic development and changes in socioeconomic status (SES) play a role in the transition from undernutrition to overnutrition, but this has not been explored in children <5y.

Evidence from adults regarding the role of SES in the changing anthropometric dynamics is conflicting. Some report that the burden of overweight and obesity is shifting from higher to lower income groups within LMIC over time (22,32,97), while others report that the greatest burden of overweight and obesity remains within the higher SES groups of LMIC (30,98).

Others report that although the burden of overweight and obesity remains higher in higher SES groups, it is growing faster in lower SES groups of LMIC (99,100).

Similar analyses in children are absent from the literature. The few studies examining the effect of SES on malnutrition generally focused within a specific population or country (71,101). In an attempt to provide a global perspective, the recent *Lancet* article on maternal and child nutrition reported that in 79 countries with population based surveys, stunting in children <5y is highest in the poorest quintile of households and overweight is highest in the wealthiest quintile of households (2). Differences in overweight prevalence between the poorest and wealthiest quintiles were small, in part due to overall lower prevalence of overweight than stunting. Although this study demonstrates interest in exploring the socioeconomic factors that influence childhood malnutrition, this analysis only used one survey year per country (which was often very outdated) and therefore could not assess time trends. Previous work showed differences in average prevalence of overweight between low income and middle income countries over time, but did not formally assess the relationship between SES and time (96). To identify and target sub-groups of children most at risk of under- and overnutrition, SES dynamics over time must be further explored among children, as they have been in adults.

This study utilizes nationally representative data from 40 LMIC to determine if the burden of malnutrition in children <5y is shifting between SES sub-groups within countries across time. We document the prevalence of three anthropometric indicators (stunting, wasting, and overweight), determine the relationship of each of the three anthropometric indicators to household SES within a country and over time, and then use meta-regression to produce one global summary estimate to represent trends for each indicator.

B. Methods

Data source and study population

Data come from Demographic and Health Surveys (DHS) of infants and young children (102). DHS are nationally representative, household-based surveys of women of reproductive age and their young children. Conducted in more than 90 countries since 1984, they provide data on population health, maternal and child health, and nutrition. DHS respondents are selected with a two-stage sampling process, which is described elsewhere in detail (60,61).

We identified 41 countries with available child anthropometry and wealth data, and at least two surveys, with the latter completed after 2008. These 41 countries contributed a total of 135 surveys from 1990-2014 (median number of surveys per country = 3, range = 2-6). The study population consists of all singleton children ages 0-59m in these 41 countries (n=764,359). We excluded the entire Nigeria 1999 (n=2,889) and Benin 2012 (n=11,574) surveys, as the anthropometry data are unreliable due to measurement issues (65,103). Excluding the Benin 2012 survey caused us to drop Benin completely from the analysis, as the next most recent year was 2006, which was before our 2008 cut-off (n=19,751). We also excluded children with missing anthropometry (n=18,788), missing wealth (n=3,165), or implausible anthropometric indicator values (n=31,467). Our final sample size was 692,656 for the analysis of stunting, and 688,304 for wasting and overweight.

Measures

Height (or length if age <2y), weight, age, and sex were used to calculate the three anthropometric indicators: stunting, wasting, and overweight. All measurements were collected by trained field staff. Standing height (>2y) or recumbent length (<2y) were measured to the nearest 0.1 cm. Weight was measured with a pediatric scale or beam balance scale to the nearest 0.1 kg. Stunting, wasting and overweight were defined using Z-scores based on the 2006 WHO Growth Standards as height/length-for-age (HAZ) <-2SD, weight-for-height/length (WHZ) <-2SD, and WHZ >2SD respectively (46,62).

Household SES is represented by the International Wealth Index (IWI), which was created using data from 165 surveys from 97 LMIC to generate a wealth index that is comparable across countries and time (29). Household assets (durable goods, basic services, and housing characteristics) reported by the child's mother were subjected to a principal components analysis to generate a wealth score for each household. The IWI is a continuous variable, with values ranging from 0-100 (29). We defined categorical variables representing thirds of the distribution of the IWI within countries for each survey year.

Countries were also classified by income level according to the gross national income (GNI) per capita (Altas method), obtained from the World Bank Development Indicators Database (104). Country-level income category (low income, middle income) was used in the meta-regression analysis.

Statistical analysis

We first estimated the mean and standard error (SE) for household SES, and calculated the prevalence and 95% confidence interval (CI) of each anthropometric indicator (stunting, wasting, and overweight) at each survey year for all countries.

Within each survey year, we calculated the prevalence of each anthropometric indicator according to tertile of household SES, and the respective prevalence difference between the poorest tertile and richest tertile. A positive prevalence difference reflects a higher prevalence in children from the wealthiest households, while a negative prevalence difference indicates children from the poorest households have the higher prevalence.

To determine if there were changes in wealth disparities between the poor and rich, we examined mean IWI in the poorest and richest tertiles in the initial and final survey years $[(mean\ IWI_{richest\ tertile,final\ year} - mean\ IWI_{\ poorest\ tertile,final\ year}) - (mean\ IWI_{richest\ tertile,initial\ year} - mean\ IWI_{\ poorest\ tertile,initial\ year})\ ]$. A positive value reflects a widening difference in mean household wealth between the richest and poorest children (more wealth disparity), while a negative value represents a narrowing difference in mean household wealth (less wealth disparity).

To estimate the association between household wealth and anthropometric indicators over time, we fit the following logistic regression model for each country [eq. 1]. We fit this model separately for each outcome (stunting, wasting, and overweight) and for each of the three tertiles of household wealth:

$$logit[pr(Y_i = 1)] = \beta_0 + \beta_1 time + \varepsilon_i \qquad [eq. 1]$$

We used meta-regression to determine to what extent the heterogeneity observed across countries in changing anthropometric status over time is related to wealth, producing an estimate of the average global effect of wealth on anthropometry over time (μ_R). We abstracted the time beta coefficients (β_1) from *eq.1* from each country and ran a random effects meta-regression model, using the *metareg* command. We estimated the between-country variance, τ^2, by restricted maximum likelihood (105). To describe the observed heterogeneity among the countries and express the spread of each random effects distribution, we calculated a 95%CI, a 95% prediction interval (PI; 95% of whose limits would cover the true β_1 that would be estimated in the next study in hypothetical repetitions of the entire literature-generating process)

(106,107), and opposites effect proportion (OEP; the estimated proportion of populations whose β_1 is on the opposite side of the null from our mean effect estimate, μ_R) (108). Wider intervals and a large OEP reflect greater heterogeneity.

Finally, we included country-level income in a univariable meta-regression model to explore whether income group explained additional between-country heterogeneity of our estimates. We calculated the proportion of variance explained when country-level income was included ($\frac{\tau^2_{crude} - \tau^2_{univariable}}{\tau^2_{crude}}$); a positive value indicates that country-level income helped to explain the between-country heterogeneity observed in the crude meta-regression model, whereas a negative value indicates that including country-level income did not explain any additional heterogeneity. We also compared the 95% population effects interval (PEI; the interval within which 95% of countries' true $\beta_1 s$ are estimated to lie) (108,109) from the crude and univariable models, with wider intervals representing greater variability.

All analyses were performed in Stata (Version 14, StataCorp, College Station, TX) using procedures to account for survey design and sample weights.

C. Results

Table 4.1 shows the prevalence of stunting, wasting, and overweight, and mean IWI for each country-year. In the earliest survey year available for each country, stunting prevalence ranged from 11.7% (Jordan, 2002) to 56.6% (Ethiopia, 2000), wasting from 1.2% (Peru, 2000) to 27.1% (Mali, 1995), and overweight from 1.0% (Bangladesh, 2004) to 15.9% (Armenia, 2000). In the latest survey year, stunting prevalence ranged from 7.0% (Dominican Republic, 2013) to 46.4% (Malawi, 2010), wasting from 0.4% (Peru, 2011) to 18.4% (Nigeria, 2013), and overweight from 1.6% (Senegal, 2012) to 16.4% (Armenia, 2010). Mean wealth ranged from 4.4

(Ethiopia, 2000) to 87.2 (Jordan, 2002) in the earliest survey year, and from 11.6 (Ethiopia, 2011) to 93.1 (Jordan, 2012) in the latest. Over the respective survey periods, the prevalence of stunting decreased in 37 of 40 countries, wasting decreased in 30 of 40 countries, and overweight increased in 17 of 40 countries. Mean household wealth increased in all 40 countries.

The prevalence of stunting, wasting, and overweight within wealth tertiles, and the prevalence difference (PD) from lowest to highest tertile are in **Table 4.2**. Stunting PD was negative for all years and countries, reflecting a persistent higher prevalence in the poorest children throughout time and across the globe. Wasting prevalence remained highest in the poorest children in a majority of survey years (112 of 130). Overweight PD was mixed, with 22 of the 40 countries exhibiting a higher overweight prevalence in the poorest compared to the richest children during at least one survey. Of these 22 countries, a clear temporal trend was not observed: seven of these countries experienced the negative PD in the initial survey year, seven in the final survey year, two had a negative PD in all survey years, two had a negative PD at both initial and final years but not middle years, and four exhibited the negative PD during an interim year but not during the initial or final survey year.

Figure 4.1 represents the difference in mean wealth (IWI) between the lowest and highest wealth tertiles from the first to final survey year. This captures changes in wealth inequality within a country over time. Although absolute mean IWI increased within tertiles over time across all countries, a majority of countries (27 of 40 countries) experienced increasing wealth inequality while a decrease in wealth inequality was noted in approximately one-third of countries.

Results of the crude meta-regressions for stunting, wasting, and overweight within household wealth tertiles are presented in **Table 4.3**. Results indicate the odds of all three anthropometric indicators decreased over time, regardless of household wealth status. Stunting odds decreased most in the lowest tertile, odds of wasting showed the smallest decrease in the highest tertile, and the smallest decreases in the odds of overweight occurred in the lowest wealth tertile, while the largest decreases in odds were in the highest wealth tertile. Between-country heterogeneity, as assessed by τ^2, was largest in overweight analyses. This was also reflected in the larger OEPs in the overweight analysis compared to stunting or wasting OEPs.

Univariable meta-regression results for stunting, wasting, and overweight within household wealth tertiles, by country-level income are in **Table 4.4**. Stunting odds over time decreased in both middle and low income countries, with larger decreases observed in middle-income countries compared to low income countries. Wasting odds decreased over time in low-income countries, but increased slightly in middle income countries. However, all of the middle-income country estimates crossed the null value. Odds of overweight in the poorest and middle households in low-income countries increased over time, whereas the odds decreased in the wealthiest households in low-income countries and across all tertiles of household wealth in middle-income countries. Excluding the middle tertile, middle-income country estimate, all estimates were non-significant. Inclusion of country-level income in univariable models did not explain additional variance compared to the crude model in two models: middle wealth households for stunting, or the richest households for overweight. For other models, inclusion of country-level income explained 4-7% of the variance in stunting estimates, 18-32% of the variance in wasting estimates, and 11% of the variance in overweight estimates.

D. Discussion

Our comparison of nationally-representative data on children <5y from 40 LMIC over the past 30 years indicate that stunting prevalence remains high but is decreasing in almost all countries, wasting prevalence decreased in a majority of countries, and overweight prevalence increased in almost half the countries. We document a widening wealth gap between the poorest and richest households in a majority of countries over time. We did not observe a pronounced shift in anthropometry with respect to wealth status as has been noted in adults. However, there was considerable between-country heterogeneity which may make drawing global conclusions difficult.

Over the past decade, many have attempted to determine if countries undergoing a nutrition transition are seeing a shift of overweight and obesity from higher wealth groups to poorer segments of the population as occurs in developed countries (110). These results conducted on adult women of child-bearing age are inconsistent: some find that overweight and obesity remain predominantly within the higher SES groups (98), others find that although overweight remains highest in higher SES groups, the rate of increase in overweight is faster in lower SES groups (97), and still others have documented a country-level income threshold above which lower SES groups did have higher risk of overweight than higher SES groups (22). Recently, some have extended this body of work to explore shifts in under- and overweight with respect to urban/rural residence in adolescents, and find that both under- and overweight are increasing in urban areas in many countries (111).

It has been theorized that overweight trends in children lag behind but are similar to adult trends (94). Analyses of overweight and SES in children from developed countries point to an inverse association, consistent with the adult literature (112). The initiation of adult SES trends in developing countries described above started decades ago in many countries, so one might expect to see a contemporary similar pattern taking shape in children, whereby small (if any) decreases in stunting and wasting occur, and overweight decreases in the wealthiest children while increasing in the poorest children. However, even though overweight prevalence trends are emerging, it is possible that overweight prevalence may not be high enough to observe a shift due to SES, or perhaps not enough time has elapsed to witness the full transition in children. Although children and their parents share a common household environment, households where disparate nutrition states coexist are well documented in the dual burden household (5). As time progresses and more surveys become available, it will be critical to monitor the relationship between wealth and child anthropometry to fully understand who to target for various types of prevention activities.

Our results are consistent with research showing that absolute levels of childhood undernutrition (stunting and wasting) remain higher than overnutrition in most LMIC (2) and that undernutrition continues to be the burden of the poorest children (113). Overweight results in our study were more heterogeneous, with 55% of countries experiencing higher prevalence of overweight in the poorest children, rather than the richest, in at least one survey year. However, this occurrence did not seem to follow a temporal pattern, as has been suggested by the abovementioned adult studies.

These prevalence trends occur within a context of rising wealth inequality, as the gap between the poorest and richest households increased in two-thirds of the countries. Others have shown that global wealth inequality is higher than anticipated, and this could shift the burden of disease (114). Although absolute household wealth increased across all wealth tertiles in all countries, it is important to consider that relative shifts in wealth may have different health implications for different segments of the population. This varied greatly by country. For example, the gap between the poorest and wealthiest groups widened the most in Nepal. Between 1996 and 2011, the mean IWI in the lowest wealth tertile had a small increase (4 to 15) while it increased by a larger amount in the highest wealth tertile (29 to 66). This is in contrast to Egypt, which experienced the greatest narrowing of wealth over a similar time period; from 1995 to 2014, mean IWI remained unchanged in the richest (89 to 92), while it increased dramatically in the poorest (38 to 81). In 2014, since average household wealth in Egypt in the poorest and richest household was roughly the same, children within tertiles were more similar to each other than in previous years. This could level the playing field with respect to access to health care and health-seeking behavior. Indeed, in Egypt in 2014 there is little difference in the prevalence of any of the three anthropometric indicators across wealth tertiles, whereas in Nepal in 2011 stunting and wasting are still greatly concentrated in the poorest children while overweight is highest in the richest children.

Our central hypothesis was that over time, stunting and wasting would remain the burden of the poorest children, while overweight would initially be concentrated in the wealthiest children and then shift down the SES gradient to ultimately produce a dual burden of malnutrition among the most economically disadvantaged children, echoing the SES dynamics observed in adults. However, we did not find evidence of this phenomenon. Odds of stunting, wasting, and overweight decreased over time across all tertiles of wealth. For overweight, the magnitude of this relationship was largest in the highest tertile, perhaps signaling a faster decrease in odds of overweight in richer children than poorer. We used meta-regression as a method to obtain a global summary of the within-country SES dynamics, which may have obscured the considerable between-country heterogeneity, as noted by many confidence intervals which cross the null and large OEPs. For example, for overweight (which has a low absolute prevalence, and inconsistent direction of prevalence difference across countries), the OEP ranges from 36-46% across tertiles, indicating that 36-46% of countries could be expected to have an overweight and time relationship that is in the opposite direction of our reported mean effect estimate. Although we hypothesized a similar shift as reported in adults, it is not entirely surprising that we did not detect it in this study, since not all adult studies have replicated this phenomenon.

Inclusion of country-level income did not appreciably influence the stunting results with respect to magnitude, direction, or precision of estimates. The wasting and overweight estimates did change direction in some cases; both wasting and overweight crude results showed a decreasing time trend, while univariable results suggest an increasing (although non-significant) wasting trend in middle-income countries and increasing overweight (although non-significant) trend in the poorest and middle households in low-income countries. Assessing heterogeneity was not particularly informative; if country-level income did explain some of the between-country variability we believe underlies our crude results, the 95% PEI should narrow upon inclusion of country-level income to the model, and we would expect moderate to high proportion of the variance explained. However, we did not observe this, as the precision of our confidence limit ratios (CLR) and population effects limit ratios (PELR) were basically unchanged from crude to univariate models (CLR: 1.01-1.03; PELR: 1.04-1.17). Additionally, the proportion of variance explained was low in most cases (0.04-0.32) and in fact negative in two cases, implying that adding country-level income to the model was not better than the crude model at predicting the outcome.

This analysis is not without limitations. The selected countries are not truly globally representative, since certain regions are over-represented (Africa) while others are under-represented (Asia). This limits the generalizability of our findings but was a trade-off with our inclusion criteria, which ensured we were able to assess contemporary trends over time. A few country-years do not include children across the entire age range of 0-5y. This was due to how each country carried out their DHS (*i.e.:* only children <3y were measured in 7 of 130 country-years, only children <4y were measured in 1 of 130 country-years). This could give the impression of lower rates in these country-years, as anthropometric deficits tend to accumulate over time. We observed a fair amount of heterogeneity between countries as noted by precision limits which crossed the null and large OEPs, which may be due to the use of individual-level SES. This heterogeneity may partially explain why there is so much controversy regarding whether overweigh/obesity is shifting between SES groups. We attempted to address this by running a meta-regression with a country-level income status indicator, but subsequent approaches should further examine potential macro-level determinants to offer deeper insight into their results. Additional research in children is needed that incorporates other country-level factors to explain some of the country-level variation we have documented here.

This is the first assessment of dual burden SES trends in children under 5y on a global scale. Wealth inequality increased over the past decades in many countries, while stunting and wasting decreased and overweight increased. However, our results do not mirror findings from adults where both under- and overweight increasingly over time appear to be concentrated in the lower wealth groups within a country. Further research should assess the between-country heterogeneity with a more nuanced lens. Governments and policy makers must be aware of these changing dynamics and adapt programs and policies to target children in appropriate social classes for nutrition interventions.

Table 4.1. Anthropometric and household wealth characteristics of children <5y by country and survey year[1]

		Stunting	Wasting	Overweight	IWI
		% (95% CI)	% (95% CI)	% (95% CI)	x (SE)
Country	**Year**	***N***	***n***	***n***	***n***
Armenia	2000	18 (15.3, 20.8)	2.6 (1.5, 3.7)	15.9 (13.6, 18.2)	70.8 (1.1)
		1509	1499	1499	1516
	2005	16.6 (12.5, 20.7)	5.1 (3.1, 7.0)	11.6 (9.3, 14.0)	75.5 (1.0)
		1239	1211	1211	1268
	2010	20.8 (17.8, 23.7)	4 (2.7, 5.4)	16.4 (13.8, 19.0)	83.3 (0.9)
		1360	1335	1335	1427
Bangladesh	2004	49.6 (47.6, 51.6)	14.6 (13.5, 15.8)	1.0 (.7, 1.3)	21.6 (0.8)
		5928	5888	5888	5868
	2007	43.9 (41.9, 45.9)	17.4 (16.0, 18.8)	1.1 (.8, 1.4)	27.3 (0.8)
		5292	5272	5272	5682
	2011	40.1 (38.4, 41.8)	15.6 (14.5, 16.7)	1.9 (1.6, 2.3)	36.6 (0.7)
		7618	7603	7603	8149
Bolivia	1998	33.5 (31.7, 35.3)	1.7 (1.3, 2.0)	10.8 (9.7, 11.8)	46.3 (1.0)
		6232	6181	6181	6353
	2003	32.3 (30.6, 34.1)	1.7 (1.4, 2.0)	9.3 (8.4, 10.2)	42.5 (1.0)
		9140	9090	9090	9272
	2008	27.0 (25.1, 28.8)	1.4 (1.1, 1.8)	8.6 (7.7, 9.4)	52.9 (0.9)
		7694	7652	7652	8005
Burkina Faso	1992	39.5 (37.8, 41.1)	15.1 (13.7, 16.4)	2.9 (2.2, 3.6)	20.5 (0.6)
		4376	4350	4350	4586
	1998	44.5 (42.5, 46.4)	15.0 (13.7, 16.4)	1.9 (1.4, 2.4)	18.4 (0.5)
		4544	4571	4571	4698
	2003	42.6 (40.5, 44.7)	21.2 (19.9, 22.6)	5.5 (4.2, 6.7)	16.9 (0.6)
		8311	8138	8138	8608
	2010	34.3 (32.7, 35.9)	15.7 (14.3, 17.1)	2.8 (2.3, 3.4)	28.2 (0.5)
		6446	6392	6392	6620
Cambodia	2000	47.9 (45.8, 50.1)	16.8 (15.1, 18.5)	4.1 (3.3, 4.9)	21.8 (0.6)
		3623	3548	3548	3726
	2005	41.7 (39.3, 44.0)	8.7 (7.5, 9.9)	1.7 (1.1, 2.2)	30.8 (0.8)
		3567	3561	3561	3737
	2010	38.4 (36.0, 40.8)	11.6 (10.2, 13.0)	1.9 (1.3, 2.4)	39.6 (0.9)
		3697	3692	3692	3836
Cameroon	1998	34.4 (31.5, 37.3)	8.4 (6.6, 10.3)	8.0 (6.3, 9.7)	23 (1.3)
		1777	1769	1769	1865
	2004	34.8 (32.5, 37.2)	6.6 (5.6, 7.6)	8.1 (6.8, 9.4)	24.6 (0.9)
		3126	3124	3124	3217
	2011	31.8 (29.8, 33.8)	6.0 (5.1, 7.0)	6.6 (5.6, 7.5)	37.5 (0.9)
		4885	4890	4890	5051
Colombia	1995	19.6 (18.1, 21.1)	1.7 (1.3, 2.1)	4.6 (3.9, 5.2)	54.9 (0.8)
		4497	4472	4472	4527
	2000	18.4 (16.9, 19.9)	1.0 (0.7, 1.3)	5.3 (4.4, 6.1)	64.6 (0.8)

		4137	4125	4125	4153
	2005	15.3 (14.4, 16.3)	1.6 (1.3, 1.9)	4.2 (3.7, 4.8)	68.9 (0.5)
		12278	12246	12246	12339
	2010	12.4 (11.6, 13.1)	0.9 (0.8, 1.1)	4.8 (4.4, 5.3)	73.7 (0.4)
		15806	15781	15781	16705
Comoros	1996	38.2 (34.3, 42.0)	11.2 (9.1, 13.4)	5.7 (4.1, 7.2)	24.7 (1.2)
		948	936	936	974
	2012	29.2 (26.6, 31.8)	11.4 (9.9, 13)	10.4 (8.7, 12.1)	44.3 (1.2)
		2469	2394	2394	2780
Congo Brazzaville	2005	29.8 (27.5, 32.0)	7.8 (6.5, 9.1)	8.5 (7.0, 10.0)	27.9 (1.6)
		3876	3848	3848	4068
	2011	22.4 (20.4, 24.4)	5.6 (4.4, 6.8)	3.6 (2.6, 4.5)	37.3 (1.1)
		4338	4341	4341	4452
Congo Democratic Republic	2007	44.5 (41.5, 47.5)	10.5 (8.5, 12.6)	7.4 (5.9, 8.9)	19.5 (1.1)
		3312	3313	3313	3620
	2013	41.5 (39.5, 43.6)	8.0 (6.9, 9.0)	4.4 (3.6, 5.2)	20.4 (0.9)
		7932	7935	7935	8259
Côte d'Ivoire	1994	30.9 (28.8, 32.9)	10.7 (9.4, 12.1)	2.7 (2.1, 3.4)	35.6 (1.2)
		3363	3354	3354	3395
	1998	30.7 (26.9, 34.5)	6.9 (5.6, 8.3)	4.5 (3.4, 5.7)	31.2 (1.7)
		1523	1519	1519	1559
	2011	28.5 (26.2, 30.9)	7.9 (6.6, 9.2)	3.2 (2.4, 3.9)	42.8 (1.2)
		3112	3127	3127	3341
Dominican Republic	1996	13.2 (11.6, 14.8)	2.0 (1.4, 2.6)	6.8 (5.5, 8.0)	53.0 (1.2)
		3694	3656	3656	3781
	2002	11.7 (10.5, 13.0)	2.1 (1.7, 2.6)	8.6 (7.6, 9.5)	64.7 (0.6)
		9197	9152	9152	9340
	2007	10.1 (9.1, 11.1)	2.3 (1.8, 2.8)	8.3 (7.4, 9.3)	69.8 (0.6)
		9215	9138	9138	9818
	2013	7.0 (5.8, 8.2)	2.2 (1.4, 2.9)	7.7 (6.5, 9.0)	76.5 (0.6)
		3157	3132	3132	3316
Egypt	1995	34.5 (32.7, 36.4)	5.7 (5.0, 6.3)	14.6 (13.3, 15.9)	68.1 (0.8)
		10404	10277	10277	10621
	2000	23.9 (22.3, 25.6)	3.1 (2.7, 3.6)	18.2 (16.8, 19.6)	70.7 (0.7)
		10250	10160	10160	10418
	2003	19.8 (18.4, 21.2)	5.3 (4.5, 6.1)	9.1 (7.9, 10.3)	77 (0.5)
		5981	5964	5964	6051
	2005	23.4 (21.9, 24.9)	5.3 (4.6, 6.0)	14.1 (13.0, 15.3)	80.2 (0.4)
		12325	12268	12268	12710
	2008	30.1 (30.1, 30.1)	8.1 (8.1, 8.1)	20.5 (20.5, 20.5)	82.3 (0.0)
		9656	9488	9488	10155
	2014	22.1 (20.4, 23.7)	9.5 (8.4, 10.6)	15.7 (14.5, 16.9)	85.5 (0.2)
		14056	13674	13674	14775
Ethiopia	2000	56.6 (54.8, 58.5)	12.7 (11.5, 13.9)	2.0 (1.6, 2.4)	4.4 (0.3)
		8770	8768	8768	9037
	2005	49.5 (46.9, 52.1)	12.2 (10.7, 13.7)	5.3 (4.3, 6.2)	8.4 (0.4)

		3914	3936	3936	4390
	2011	43.9 (42.0, 45.8)	9.9 (8.9, 10.9)	1.9 (1.5, 2.3)	11.6 (0.5)
		9490	9493	9493	10235
Gabon	2000	25.4 (23.2, 27.6)	4.1 (3.3, 5.0)	5.6 (4.7, 6.6)	46.1 (1.5)
		3411	3407	3407	3950
	2012	16.3 (13.7, 18.9)	3.7 (2.8, 4.6)	8.1 (6.4, 9.8)	65 (1.2)
		3285	3262	3262	3456
Ghana	1998	31.0 (28.8, 33.2)	9.6 (8.4, 10.9)	2.8 (2.1, 3.5)	23.7 (0.8)
		2693	2686	2686	2773
	2003	35.1 (32.9, 37.3)	8.4 (7.2, 9.5)	4.4 (3.6, 5.3)	27.2 (0.9)
		3048	3012	3012	3165
	2008	27.4 (25.0, 29.8)	9.0 (7.8, 10.3)	5.8 (4.5, 7.1)	39.1 (1.0)
		2346	2327	2327	2579
Guinea	1999	33.5 (31.8, 35.2)	9.8 (8.8, 10.8)	4.3 (3.7, 4.9)	18.1 (0.7)
		4347	4302	4302	4493
	2005	38.0 (35.5, 40.4)	10.9 (9.2, 12.5)	5.5 (4.4, 6.6)	17.7 (1.0)
		2572	2558	2558	2625
	2012	29.9 (27.6, 32.2)	10.4 (9.1, 11.7)	3.7 (2.9, 4.5)	33.8 (1.3)
		3066	3025	3025	3162
Haiti	1994	36.5 (33.8, 39.3)	9.2 (7.9, 10.4)	4.3 (3.0, 5.5)	17.5 (1.4)
		2767	2731	2731	2832
	2000	26.3 (23.3, 29.2)	5.4 (4.6, 6.3)	2.8 (2.1, 3.4)	18.5 (1.6)
		5448	5430	5430	5485
	2005	27.7 (24.8, 30.5)	10.4 (8.1, 12.7)	4.1 (3.1, 5.0)	20.4 (1.2)
		2531	2508	2508	2550
	2012	20.4 (18.3, 22.5)	5.1 (4.3, 6.0)	3.8 (3.1, 4.5)	30.4 (1.0)
		3935	3901	3901	3983
Honduras	2005	29.4 (27.8, 31.0)	1.4 (1.1, 1.7)	5.8 (5.2, 6.5)	48.7 (0.9)
		9155	9120	9120	10088
	2011	22.2 (20.8, 23.6)	1.4 (1.1, 1.6)	5.3 (4.7, 5.9)	60.3 (0.7)
		9866	9847	9847	10110
Jordan	2002	11.7 (10.6, 12.8)	2.3 (1.7, 3.0)	4.6 (3.8, 5.4)	87.2 (0.3)
		4779	4755	4755	4883
	2007	15.9 (14.0, 17.8)	7.6 (6.1, 9.0)	12.4 (10.5, 14.4)	89.2 (0.4)
		4449	4397	4397	5003
	2012	7.9 (6.6, 9.2)	2.4 (1.8, 3.0)	4.8 (3.9, 5.7)	93.1 (0.2)
		6110	6099	6099	6425
Kenya	1993	39.8 (37.7, 41.9)	6.9 (6.1, 7.8)	5.9 (5.1, 6.8)	18.1 (0.8)
		4884	4854	4854	4997
	1998	37.3 (35.4, 39.2)	7.5 (6.6, 8.4)	6.8 (5.9, 7.7)	17.3 (0.8)
		4583	4538	4538	4729
	2003	35.3 (33.5, 37.2)	6.1 (5.0, 7.2)	5.9 (5.1, 6.8)	17.6 (0.8)
		4662	4648	4648	4813
	2008	35.2 (32.9, 37.5)	6.8 (5.7, 7.8)	5.0 (4.3, 5.8)	25.3 (1.1)
		5073	5037	5037	5346
Kyrgyz Republic	1997	32.6 (28.9, 36.2)	3.4 (2.2, 4.5)	9.3 (6.7, 11.9)	50.7 (1.3)

		971	966	966	982
	2012	17.9 (16.0, 19.8)	2.7 (2.1, 3.4)	8.8 (7.7, 10.0)	74.5 (0.6)
		3986	3969	3969	4118
Lesotho	2004	43.1 (39.8, 46.3)	5.4 (4.0, 6.8)	7.3 (5.6, 8.9)	19.1 (0.9)
		1383	1365	1365	1449
	2009	37.3 (34.4, 40.2)	4.2 (3.2, 5.3)	7.9 (6.3, 9.4)	28.7 (1.0)
		1598	1600	1600	1686
Liberia	2007	37.4 (35.3, 39.4)	7.6 (6.5, 8.7)	4.3 (3.5, 5.1)	22.1 (0.9)
		4311	4282	4282	4633
	2013	29.3 (27.0, 31.5)	5.8 (4.6, 7.0)	3.3 (2.4, 4.1)	26.8 (1.1)
		3106	3097	3097	3214
Malawi	1992	54.8 (52.6, 57.0)	6.6 (5.4, 7.7)	9.7 (8.0, 11.4)	13.3 (0.6)
		3200	3146	3146	3305
	2000	53.2 (51.5, 54.9)	6.8 (6.1, 7.5)	8.9 (7.9, 9.9)	12.7 (0.5)
		9110	9071	9071	9474
	2004	51.3 (49.7, 52.8)	6.4 (5.7, 7.2)	10.1 (9.3, 10.9)	13.1 (0.4)
		8119	8089	8089	8723
	2010	46.4 (44.4, 48.4)	4.1 (3.3, 4.9)	9.0 (8.0, 10.1)	20.0 (0.5)
		4560	4512	4512	4796
Mali	1995	36.0 (34.3, 37.7)	27.1 (25.4, 28.8)	2.1 (1.6, 2.7)	20.8 (0.6)
		4800	4670	4670	4903
	2001	41.4 (39.4, 43.4)	12.7 (11.5, 14.0)	3.1 (2.4, 3.7)	16.7 (0.7)
		9468	9386	9386	9806
	2006	37.4 (35.8, 39.1)	15.7 (14.9, 16.6)	4.8 (4.0, 5.5)	18.3 (0.7)
		11078	10874	10874	9870
	2013	37.2 (35.1, 39.4)	13.1 (11.4, 14.8)	2.9 (2.2, 3.6)	33.3 (0.7)
		4322	4324	4324	4725
Mozambique	1997	44.2 (40.9, 47.4)	12.1 (10.1, 14.0)	6.0 (4.5, 7.5)	15.8 (1.3)
		3424	3385	3385	3526
	2003	46.5 (44.4, 48.5)	5.3 (4.4, 6.2)	6.3 (5.4, 7.2)	15.8 (0.6)
		7905	7917	7917	8077
	2011	42.6 (40.8, 44.4)	6.2 (5.5, 7.0)	8.1 (7.3, 8.9)	23.3 (0.5)
		9189	9183	9183	9493
Namibia	1992	35.0 (32.0, 37.9)	9.5 (8.0, 11.0)	4.6 (3.7, 5.5)	32.7 (2.1)
		2666	2528	2528	2742
	2000	28.0 (25.3, 30.8)	9.4 (8.0, 10.9)	3.6 (2.6, 4.5)	29.8 (2.3)
		2929	2891	2891	2982
	2006	29.4 (27.3, 31.5)	7.5 (6.5, 8.5)	5.3 (4.3, 6.4)	41.0 (1.7)
		3663	3647	3647	3769
	2013	20.3 (18.0, 22.7)	8.2 (6.8, 9.6)	4.6 (3.4, 5.7)	46.9 (1.6)
		1789	1760	1760	1892
Nepal	1996	56.4 (54.1, 58.7)	15.0 (13.6, 16.4)	1.0 (0.7, 1.4)	14.5 (0.6)
		3731	3736	3736	3935
	2006	49.3 (46.7, 52.0)	12.6 (11.0, 14.1)	0.6 (0.3, 0.9)	24.5 (1.0)
		5215	5200	5200	5270
	2011	39.8 (37, 42.7)	10.9 (9.2, 12.6)	1.6 (1.0, 2.3)	38.4 (1.3)

		2319	2318	2318	2365
Niger	1998	45.7 (43.5, 47.8)	25.3 (23.5, 27.1)	1.2 (0.8, 1.5)	11.9 (0.6)
		3878	3852	3852	3962
	2006	54.4 (51.9, 56.8)	13.0 (11.5, 14.5)	3.8 (2.9, 4.7)	14.0 (0.7)
		3644	3665	3665	3908
	2012	42.1 (40.1, 44.2)	18.2 (16.7, 19.7)	3.1 (2.4, 3.8)	20.5 (0.7)
		4791	4755	4755	5412
Nigeria	2003	42.6 (39.5, 45.6)	11.2 (9.9, 12.5)	6.3 (5.3, 7.2)	30.3 (1.4)
		4416	4395	4395	4660
	2008	40.2 (38.9, 41.5)	14.5 (13.5, 15.4)	10.5 (9.8, 11.1)	35.9 (0.7)
		20054	19695	19695	23644
	2013	36.2 (34.5, 37.8)	18.4 (17.1, 19.7)	5.0 (4.5, 5.5)	40.5 (0.8)
		24756	24728	24728	26761
Peru	2000	31.0 (29.3, 32.8)	1.2 (0.9, 1.4)	11.9 (11.0, 12.7)	40.7 (0.9)
		11585	11510	11510	11749
	2005	29.2 (25.2, 33.2)	1.1 (0.5, 1.7)	8.8 (7.2, 10.4)	44.6 (2.1)
		2277	2271	2271	2489
	2007	29.5 (25.8, 33.2)	1.2 (0.6, 1.8)	9.5 (7.7, 11.3)	49.8 (2.0)
		2352	2346	2346	2554
	2008	27.3 (24.7, 29.9)	0.7 (0.3, 1.0)	10.2 (8.7, 11.6)	51.5 (1.3)
		5675	5653	5653	6203
	2011	19.7 (18.0, 21.4)	0.4 (0.2, 0.5)	8.8 (7.7, 9.9)	60.4 (0.8)
		8638	8629	8629	8726
Rwanda	1992	55.5 (53.3, 57.6)	4.8 (3.9, 5.7)	4.0 (3.4, 4.6)	8.8 (0.3)
		4303	4300	4300	4377
	2000	46.7 (45.0, 48.4)	8.7 (7.8, 9.7)	7.0 (6.2, 7.8)	7.8 (0.6)
		6106	6033	6033	6214
	2005	50.5 (48.6, 52.5)	4.6 (3.9, 5.4)	6.8 (5.9, 7.8)	8.2 (0.4)
		3625	3621	3621	3693
	2010	43.5 (41.5, 45.5)	2.9 (2.3, 3.5)	7.3 (6.4, 8.2)	19.5 (0.4)
		4003	3993	3993	4032
Senegal	1992	32.6 (30.5, 34.8)	9.3 (8.3, 10.3)	3.9 (3.3, 4.5)	30.9 (1.2)
		4510	4458	4458	4639
	2005	19.7 (17.5, 21.8)	8.6 (7.2, 9.9)	2.8 (1.9, 3.7)	37.4 (1.9)
		2831	2828	2828	2887
	2010	27.6 (25.4, 29.9)	9.9 (8.8, 11.0)	2.9 (2.1, 3.6)	49.2 (1.6)
		3667	3688	3688	4164
	2012	18.2 (16.5, 19.8)	8.9 (7.7, 10.1)	1.6 (1.1, 2.0)	48.1 (1.8)
		5781	5753	5753	5975
Sierra Leone	2008	37.3 (34.5, 40.1)	10.7 (9.2, 12.3)	10 (8.4, 11.6)	20.0 (0.7)
		2114	2046	2046	2345
	2013	36.7 (34.6, 38.8)	9.4 (8.1, 10.8)	8.9 (7.7, 10.1)	23.3 (0.7)
		4164	4132	4132	4788
Tanzania	1991	49.0 (46.2, 51.8)	7.7 (6.7, 8.8)	5.9 (5.2, 6.5)	14.4 (0.7)
		6387	6344	6344	6497
	1996	48.5 (46.0, 50.9)	8.5 (7.6, 9.4)	4.7 (4.0, 5.4)	12.9 (0.6)

		5277	5250	5250	5430
	1999	47.9 (44.1, 51.6)	5.7 (4.3, 7.2)	3.4 (2.5, 4.2)	10.2 (0.8)
		2474	2474	2474	2497
	2004	43.0 (41.0, 45.1)	3.6 (3.1, 4.1)	5.1 (4.4, 5.8)	14.7 (0.5)
		6983	6972	6972	7199
	2010	41.0 (39.2, 42.9)	4.9 (4.3, 5.6)	5.6 (4.9, 6.3)	20.8 (0.7)
		6695	6684	6684	7001
Togo	1998	29.8 (27.8, 31.7)	13.6 (12.2, 15.1)	2.5 (2.0, 3.1)	24.4 (0.7)
		3567	3527	3527	3651
	2013	26.4 (24.3, 28.5)	6.8 (5.8, 7.8)	2.0 (1.5, 2.5)	37.0 (1.0)
		3100	3096	3096	3159
Uganda	1995	44.9 (42.9, 46.9)	6.5 (5.6, 7.3)	5.4 (4.4, 6.3)	10.1 (0.4)
		4525	4517	4517	4651
	2000	44.2 (42.0, 46.4)	5.2 (4.4, 5.9)	5.2 (4.5, 6.0)	9.9 (0.4)
		5081	5072	5072	5248
	2006	37.4 (35.2, 39.6)	6.2 (5.2, 7.3)	5.0 (3.8, 6.2)	15.1 (0.6)
		2337	2338	2338	2377
	2011	32.4 (29.7, 35.0)	4.8 (3.7, 5.9)	4.1 (3.2, 5.1)	23.2 (0.7)
		2041	2036	2036	2160
Zambia	1996	48.1 (46.1, 50.0)	5.2 (4.6, 5.9)	6.2 (5.4, 6.9)	24.1 (1.4)
		5428	5420	5420	5544
	2001	52.3 (50.4, 54.2)	6.1 (5.4, 6.9)	6.0 (5.2, 6.8)	17.0 (1.3)
		5381	5405	5405	5528
	2007	45.0 (43.0, 47.0)	5.7 (4.9, 6.4)	8.8 (7.7, 9.9)	21.8 (1.2)
		5033	5019	5019	5242
	2013	39.5 (38.2, 40.8)	6.1 (5.5, 6.8)	6.3 (5.8, 6.9)	32.0 (1.0)
		11297	11249	11249	11956
Zimbabwe	1994	27.9 (25.4, 30.3)	6.4 (5.1, 7.6)	7.4 (6.1, 8.7)	28.5 (1.6)
		2070	2056	2056	2093
	1999	31.6 (29.2, 33.9)	8.3 (6.8, 9.8)	10.9 (9.2, 12.6)	31 (1.8)
		2670	2644	2644	2989
	2005	32.8 (30.3, 35.3)	6.6 (5.6, 7.7)	9.0 (7.7, 10.3)	31.5 (1.6)
		3931	3892	3892	4423
	2010	31.5 (29.9, 33.0)	3.2 (2.7, 3.8)	5.7 (4.9, 6.5)	37.6 (1.1)
		4267	4248	4248	4657

[1] Adjusted for survey design. Stunting was defined as HAZ < -2SD; wasting was defined as WHZ < -2SD; overweight defined as WHZ > 2SD. Individual country sample sizes do not add to the final analytical sample size, as it is possible to be missing data on multiple variables. HAZ; height-for-age z-score; WHZ, weight-for-height z-score; IWI, International Wealth Index.

Table 4.2. Stunting, wasting, and overweight prevalence across household wealth tertiles, and prevalence difference between the lowest and highest household wealth tertile by country and survey year

		Stunting				**Wasting**				**Overweight**			
Country	**Year**	**T1**	**T2**	**T3**	**PD**	**T1**	**T2**	**T3**	**PD**	**T1**	**T2**	**T3**	**PD**
Armenia	2000	23.6	19.3	12.4	-11.2	2.5	2.5	2.7	0.2	13.8	16.9	16.8	2.9
	2005	16.1	18.7	14.8	-1.3	5.0	3.5	7.1	2.1	11.9	13.5	9.1	-2.8
	2010	23.1	20.5	18.6	-4.5	5.2	3.0	3.9	-1.3	17.0	15.6	16.7	-0.3
Bangladesh	2004	57.7	50.7	36.9	-20.7	16.3	14.7	12.3	-4.0	0.8	0.8	1.3	0.5
	2007	54.7	43.9	30.3	-24.4	19.4	17.4	14.8	-4.7	0.8	1.0	1.6	0.8
	2011	48.9	40.1	29.6	-19.3	17.6	15.7	13.1	-4.5	1.3	1.8	2.9	1.6
Bolivia	1998	49.0	35.9	19.5	-29.5	2.1	1.8	1.3	-0.8	11.6	9.7	11.3	-0.3
	2003	47.0	32.0	17.7	-29.3	2.1	1.9	1.1	-1.0	10.1	8.8	9.1	-1.0
	2008	43.6	26.8	11.9	-31.7	2.3	1.0	1.1	-1.2	7.2	8.1	10.3	3.1
Burkina Faso	1992	42.1	41.5	29.6	-12.5	15.8	16.7	11.2	-4.6	3.2	2.6	2.6	-0.6
	1998	49.7	44.6	37.3	-12.4	17.4	14.8	12.4	-5.0	1.2	2.3	2.5	1.2
	2003	47.8	44.1	33.2	-14.6	22.3	21.6	19.2	-3.1	7.2	4.2	3.4	-3.8
	2010	39.8	36.0	25.7	-14.1	17.0	15.2	14.7	-2.3	2.7	2.8	3.0	0.3
Cambodia	2000	51.0	53.3	39.8	-11.2	16.5	16.1	17.9	1.3	4.2	3.5	4.4	0.2
	2005	47.7	48.5	30.6	-17.0	10.3	8.4	7.1	-3.1	2.0	1.5	1.5	-0.5
	2010	46.0	39.9	27.8	-18.2	11.9	12.1	10.6	-1.4	1.7	1.2	2.8	1.0
Cameroon	1998	42.0	34.4	22.7	-19.3	9.2	9.1	6.2	-3.0	5.6	7.7	12.0	6.4
	2004	44.3	36.8	23.7	-20.6	8.1	7.8	3.9	-4.3	7.3	6.9	9.9	2.6
	2011	43.6	33.8	18.5	-25.0	8.8	6.8	2.6	-6.2	4.7	6.4	8.5	3.8
Côte d'Ivoire	1994	36.0	33.8	22.0	-14.0	12.9	10.2	9.0	-3.8	2.9	2.3	3.0	0.1
	1998	36.2	31.5	17.7	-18.5	7.4	7.7	4.7	-2.8	4.5	4.2	5.0	0.5
	2011	36.9	30.8	18.2	-18.6	8.6	8.6	6.7	-1.9	2.1	3.3	4.1	2.0
Colombia	1995	29.0	18.1	11.7	-17.3	3.0	1.5	0.6	-2.4	3.1	4.5	6.0	2.9
	2000	27.0	17.4	11.4	-15.6	1.4	1.0	0.6	-0.8	4.0	5.3	6.4	2.4
	2005	23.1	16.9	8.1	-14.9	1.9	1.5	1.4	-0.5	2.8	4.3	5.3	2.5
	2010	19.7	11.9	7.8	-11.9	1.5	0.8	0.7	-0.7	3.0	4.8	6.1	3.1
Comoros	1996	45.7	37.7	30.8	-14.8	15.3	10.4	7.9	-7.3	5.0	6.5	5.6	0.6
	2012	36.4	28.4	22.3	-14.1	12.9	11.4	9.6	-3.3	8.9	13.1	9.1	0.2

Congo	2007	49.0	48.6	35.6	-13.4	10.2	10.3	11.1	1.0	6.4	7.6	8.1	1.7
	2013	49.6	44.2	32.7	-16.9	8.4	10.2	5.8	-2.6	5.1	3.8	4.4	-0.6
Congo Brazzaville	2005	32.9	29.2	26.2	-6.7	8.8	7.6	6.6	-2.2	6.2	9.3	10.7	4.5
	2011	31.6	27.5	16.6	-14.9	6.5	4.9	5.6	-0.9	3.7	2.9	3.8	0.1
Dominican Republic	1996	24.7	12.8	5.9	-18.8	2.7	1.9	1.6	-1.1	2.9	6.3	9.8	6.8
	2002	17.8	13.1	7.6	-10.2	3.4	2.2	1.4	-2.1	5.9	7.2	10.9	4.9
	2007	17.0	10.2	6.2	-10.7	2.4	2.2	2.3	-0.1	6.6	7.9	9.6	3.1
	2013	11.5	6.2	3.8	-7.7	1.7	3.0	1.5	-0.2	4.9	7.6	10.6	5.7
Egypt	1995	42.4	34.4	28.1	-14.4	6.3	5.2	5.6	-0.7	15.4	13.1	15.3	-0.2
	2000	29.7	22.4	18.8	-10.9	3.2	3.3	2.8	-0.4	17.6	18.5	18.5	0.9
	2003	21.9	19.5	18.4	-3.5	5.3	5.4	5.2	0.0	7.3	8.6	11.0	3.6
	2005	29.1	21.5	19.4	-9.7	4.9	4.9	6.9	2.0	14.5	13.8	14.7	0.2
	2008	32.0	28.8	28.6	-3.4	9.1	7.1	7.7	-1.4	18.8	21.8	21.6	2.8
	2014	22.8	21.3	21.1	-1.7	9.4	9.6	9.7	0.3	15.2	16.0	16.6	1.4
Ethiopia	2000	60.3	55.4	49.4	-10.9	13.8	12.4	10.6	-3.2	1.8	1.8	2.5	0.7
	2005	52.2	48.7	43.3	-8.9	13.1	12.6	9.7	-3.4	4.9	4.9	6.3	1.3
	2011	49.2	43.7	36.1	-13.1	12.8	9.5	5.8	-6.9	1.9	1.6	2.2	0.2
Gabon	2000	38.2	28.3	16.0	-22.2	3.3	4.6	4.3	0.9	3.9	5.9	6.4	2.5
	2012	32.4	16.8	11.9	-20.5	5.1	2.3	4.0	-1.0	7.2	8.5	8.1	1.0
Ghana	1998	36.3	35.8	21.7	-14.6	12.8	8.9	7.4	-5.4	3.0	2.7	2.6	-0.5
	2003	44.4	36.4	25.6	-18.8	8.1	8.6	8.3	0.2	5.2	4.6	3.7	-1.5
	2008	35.0	27.1	21.9	-13.1	10.8	9.6	7.2	-3.5	4.7	4.7	7.6	3.0
Guinea	1999	40.3	33.1	25.0	-15.3	11.1	9.4	8.7	-2.3	4.2	5.0	3.7	-0.5
	2005	42.4	41.5	30.2	-12.1	11.4	10.2	10.9	-0.4	5.0	4.8	6.5	1.4
	2012	36.6	31.1	21.4	-15.2	10.1	12.4	8.6	-1.5	4.4	3.6	3.2	-1.2
Haiti	1994	45.6	36.3	24.1	-21.4	10.7	8.3	7.8	-3.0	5.3	3.5	3.5	-1.9
	2000	36.3	29.4	16.0	-20.4	6.3	4.5	5.3	-1.0	2.8	2.6	2.9	0.2
	2005	41.0	28.4	15.7	-25.3	10.7	11.3	9.5	-1.2	3.9	4.7	3.8	-0.1
	2012	30.0	21.6	12.3	-17.8	4.7	5.8	4.9	0.2	3.8	4.5	3.3	-0.5
Honduras	2005	46.0	35.6	14.6	-31.5	2.3	0.9	1.1	-1.2	3.7	3.5	8.8	5.1
	2011	40.7	22.6	10.4	-30.2	1.8	1.4	1.0	-0.8	3.4	4.2	7.3	3.9

Jordan	2002	15.4	11.1	8.9	-6.5	2.2	2.4	2.4	0.3	4.3	5.3	4.0	-0.3
	2007	18.0	14.4	15.4	-2.6	7.0	7.6	8.2	1.2	12.6	12.6	12.2	-0.3
	2012	10.3	5.4	7.1	-3.3	3.2	1.7	1.7	-1.5	4.9	4.9	4.3	-0.6
Kenya	1993	46.6	40.5	32.3	-14.3	8.7	6.7	4.9	-3.8	5.5	5.3	7.0	1.6
	1998	46.4	37.8	28.0	-18.4	7.6	8.1	6.8	-0.9	5.5	6.5	8.5	3.0
	2003	42.2	35.8	25.7	-16.5	7.9	5.9	3.6	-4.3	4.7	4.7	8.8	4.1
	2008	44.9	38.0	23.1	-21.8	9.6	6.3	4.6	-5.0	4.4	5.3	5.3	0.9
Kyrgyz Republic	1997	45.1	27.4	25.9	-19.3	3.2	3.3	3.6	0.5	8.8	9.0	10.3	1.5
	2012	17.5	18.9	17.5	0.0	2.4	2.8	2.9	0.5	8.4	8.3	9.6	1.2
Lesotho	2004	51.7	42.5	33.8	-17.9	5.4	6.2	4.7	-0.7	5.9	8.3	7.7	1.8
	2009	45.7	36.8	31.1	-14.6	6.1	3.1	3.6	-2.5	5.3	8.4	9.5	4.2
Liberia	2007	40.3	40.8	31.1	-9.1	6.7	8.2	7.8	1.1	3.3	3.7	5.9	2.7
	2013	34.9	31.2	25.3	-9.5	6.1	5.9	5.6	-0.5	3.1	3.8	3.1	0.0
Malawi	1992	58.2	56.4	47.1	-11.1	7.7	6.8	4.4	-3.3	9.2	9.7	10.6	1.4
	2000	60.0	51.6	39.0	-21.1	7.4	6.3	5.9	-1.5	9.4	8.0	9.1	-0.2
	2004	54.9	54.2	41.8	-13.1	6.8	6.7	5.6	-1.2	11.3	9.7	9.0	-2.3
	2010	54.1	46.0	39.7	-14.4	5.5	4.3	2.8	-2.7	8.4	9.8	8.9	0.5
Mali	1995	39.6	37.0	31.6	-8.0	30.0	26.5	24.8	-5.2	1.9	1.9	2.6	0.7
	2001	45.8	46.0	32.6	-13.2	14.1	14.1	10.1	-4.0	3.2	2.7	3.2	0.0
	2006	40.2	43.0	31.8	-8.4	16.1	15.6	15.1	-1.0	5.2	4.8	4.6	-0.6
	2013	44.2	38.8	27.3	-16.9	16.3	12.4	10.2	-6.2	2.9	2.9	2.9	-0.1
Mozambique	1997	54.7	43.8	30.8	-23.9	14.6	12.5	8.3	-6.3	6.2	4.2	7.7	1.5
	2003	53.3	50.3	33.5	-19.8	6.9	4.8	4.0	-2.9	5.5	7.6	5.8	0.3
	2011	48.5	44.3	33.0	-15.5	6.5	6.4	5.7	-0.8	8.8	7.2	8.3	-0.4
Namibia	1992	43.7	36.7	25.7	-18.0	11.9	9.8	7.1	-4.8	5.1	4.1	4.4	-0.7
	2000	32.1	29.6	20.5	-11.6	12.3	8.0	6.8	-5.6	2.5	2.9	5.8	3.4
	2006	39.0	29.4	20.5	-18.4	9.1	8.3	5.4	-3.7	4.5	3.3	7.9	3.4
	2013	26.8	20.5	13.4	-13.4	10.1	9.6	4.7	-5.4	2.7	4.9	6.3	3.5
Nepal	1996	63.6	57.1	47.6	-16.1	15.7	17.8	11.3	-4.4	0.8	1.1	1.2	0.5
	2006	58.8	52.4	37.2	-21.6	12.9	15.8	9.3	-3.6	0.6	0.5	0.8	0.2
	2011	52.0	37.0	30.1	-21.8	14.4	11.1	7.1	-7.3	1.2	1.2	2.5	1.3
Niger	1998	47.5	47.0	41.0	-6.5	27.6	27.1	19.6	-7.9	0.9	1.8	1.0	0.1
	2006	57.2	57.5	43.5	-13.7	13.8	13.6	10.6	-3.2	3.9	4.1	3.1	-0.9

	2012	45.3	42.3	36.9	-8.4	20.9	16.8	15.8	-5.1	3.2	2.9	3.3	0.2
Nigeria	2003	52.3	46.7	28.6	-23.7	12.9	11.3	9.5	-3.4	6.2	6.6	6.1	-0.1
	2008	47.8	45.2	30.5	-17.3	19.5	14.9	10.3	-9.2	10.9	10.7	9.9	-1.0
	2013	45.7	39.2	24.4	-21.4	19.6	19.1	16.5	-3.1	5.8	5.2	4.0	-1.9
Peru	2000	51.7	36.4	13.8	-37.9	2.0	1.0	0.7	-1.3	9.1	11.5	13.9	4.8
	2005	50.8	34.3	8.8	-42.0	2.2	1.0	0.4	-1.8	6.8	5.3	13.0	6.2
	2007	51.5	33.2	13.7	-37.7	0.9	1.2	1.4	0.6	7.1	6.1	13.3	6.3
	2008	46.3	28.7	10.3	-36.0	0.7	0.7	0.6	-0.1	8.1	9.1	12.7	4.6
	2011	38.3	19.4	7.9	-30.3	0.7	0.5	0.1	-0.6	4.5	7.3	12.8	8.3
Rwanda	1992	60.2	57.0	45.2	-14.9	5.6	4.3	4.2	-1.4	3.9	3.2	5.2	1.2
	2000	50.9	49.3	33.6	-17.3	8.7	9.2	7.6	-1.1	5.6	7.7	9.5	3.9
	2005	55.9	52.7	40.3	-15.6	5.2	3.9	4.5	-0.8	6.2	7.1	7.3	1.1
	2010	51.9	44.9	32.8	-19.1	3.6	2.7	2.4	-1.1	8.4	6.1	7.5	-0.9
Senegal	1992	43.3	32.9	21.8	-21.5	10.6	9.5	7.6	-3.0	3.8	3.4	4.6	0.8
	2005	29.8	19.8	11.4	-18.5	10.9	8.6	6.7	-4.1	1.5	1.9	4.5	3.0
	2010	36.2	31.7	20.5	-15.7	10.3	9.6	9.8	-0.4	2.7	2.8	3.0	0.3
	2012	25.3	19.9	11.8	-13.5	11.1	9.5	6.9	-4.2	1.0	1.5	2.0	1.0
Sierra Leone	2008	40.5	40.0	30.0	-10.5	9.7	10.0	12.9	3.2	9.5	10.3	10.4	1.0
	2013	40.9	37.0	31.5	-9.3	9.0	10.8	8.2	-0.8	8.8	8.4	9.7	0.8
Tanzania	1991	54.5	46.9	44.1	-10.4	8.3	6.2	8.5	0.2	4.4	6.5	7.0	2.5
	1996	55.5	48.2	38.2	-17.3	8.7	8.9	7.6	-1.1	4.0	4.7	5.7	1.7
	1999	53.8	46.4	32.5	-21.3	6.0	4.7	6.2	0.2	3.8	3.2	2.3	-1.4
	2004	50.6	44.5	31.2	-19.4	4.0	3.8	2.8	-1.2	4.9	5.4	4.9	0.0
	2010	47.4	40.9	31.5	-15.9	5.5	4.5	4.6	-0.9	5.2	6.1	5.8	0.6
Togo	1998	34.1	32.1	23.3	-10.8	14.6	15.4	11.1	-3.5	2.5	2.2	2.9	0.4
	2013	33.2	31.2	16.2	-17.0	8.6	6.2	5.6	-3.0	1.7	2.7	1.7	0.0
Uganda	1995	50.1	45.7	32.5	-17.7	8.1	6.3	3.5	-4.6	5.6	5.5	4.6	-1.0
	2000	49.7	44.3	34.1	-15.6	5.5	5.7	3.4	-2.1	5.5	5.2	4.8	-0.6
	2006	41.0	40.4	30.9	-10.1	6.3	6.8	5.7	-0.6	4.5	5.4	5.1	0.6
	2011	37.3	35.9	22.9	-14.4	6.7	3.9	3.9	-2.8	3.9	4.5	4.0	0.1
Zambia	1996	58.4	51.0	37.6	-20.8	6.7	5.3	4.0	-2.7	7.2	6.1	5.4	-1.9
	2001	58.9	57.3	41.4	-17.6	6.5	5.7	6.1	-0.4	6.0	5.8	6.3	0.3
	2007	47.2	49.4	38.4	-8.8	6.6	5.7	4.7	-1.9	8.9	10.4	7.2	-1.7

	2013	44.1	41.0	33.7	-10.4	7.0	5.6	5.8	-1.2	5.9	6.3	6.8	0.9
Zimbabwe	1994	30.4	31.4	22.7	-7.7	7.8	5.7	5.4	-2.4	6.2	6.3	9.4	3.2
	1999	38.1	30.4	27.7	-10.4	9.9	10.6	5.3	-4.6	9.6	11.4	11.5	1.9
	2005	34.3	35.3	28.9	-5.3	7.8	6.0	6.1	-1.7	6.4	9.4	11.3	4.9
	2010	34.8	32.7	26.7	-8.1	3.1	3.7	2.9	-0.2	4.9	5.6	6.7	1.9

[1] Stunting was defined as HAZ < -2SD; wasting was defined as WHZ < -2SD; overweight defined as WHZ > 2SD; household wealth is tertiles of IWI; PD is calculated as prevalence in the highest wealth tertile (T3) minus the prevalence in the lowest wealth tertile (T1) for stunting, wasting, and overweight, respectively. HAZ; height-for-age z-score; IWI, International Wealth Index; PD, prevalence difference; T1, lowest wealth tertile; T2, middle wealth tertile; T3, highest wealth tertile; WHZ, weight-for-height z-score.

Figure 4.1. Mean household wealth (IWI) from lowest and highest wealth tertiles, in initial and final survey years, in middle income countries (A) and low income countries (B). Countries are sorted by mean IWI in lowest wealth tertile in initial survey year. IWI, International Wealth Index.

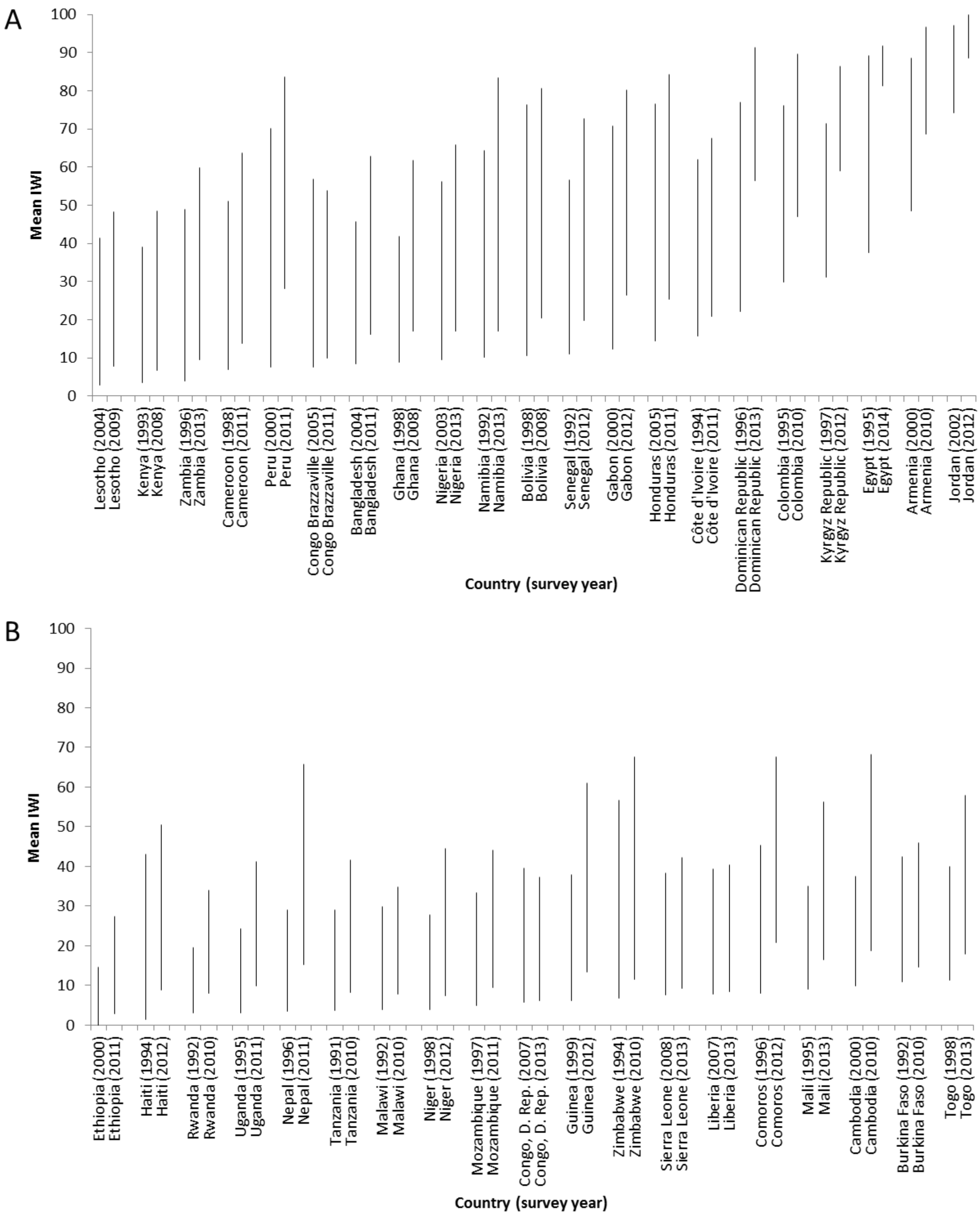

Table 4.3. Meta-regression results of the association of childhood anthropometry and time, within tertiles of household wealth[1]

	Between-country variance (τ^2)	**OR_{RE} (95% CI)**	**95% prediction interval**	**Opposite effects proportion**
Stunting				
T1	0.000184	0.987 (0.982, 0.992)	0.959, 1.02	17%
T2	0.000109	0.991 (0.986, 0.995)	0.969, 1.01	18%
T3	0.000269	0.992 (0.986, 0.998)	0.958, 1.03	31%
Wasting				
T1	0.000859	0.987 (0.977, 0.998)	0.928, 1.05	34%
T2	0.000624	0.993 (0.984, 1.00)	0.942, 1.05	40%
T3	0.000972	0.990 (0.979, 1.00)	0.926, 1.05	38%
Overweight				
T1	0.00136	0.996 (0.983, 1.01)	0.920, 1.07	46%
T2	0.00120	0.990 (0.978, 1.00)	0.919, 1.06	39%
T3	0.00154	0.987 (0.974, 1.00)	0.906, 1.07	36%

[1] T1, lowest tertile; T2, middle tertile; T3, highest tertile; OR_{RE}, random-effects summary odds ratio

Table 4.4. Meta-regression results of the association of childhood anthropometry and time, within tertiles of household wealth, by country-level income[1]

	All countries		Income Group				Prop. of variance explained
			Low-income (*n*=19)		Middle-income (*n*=21)		
	OR (95%CI)	**95% PEI**	**OR (95%CI)**	**95% PEI**	**OR (95%CI)**	**95% PEI**	
Stunting							
T1	0.987 (0.982, 0.992)	(0.961, 1.01)	0.990 (0.984, 0.998)	(0.965, 1.02)	0.984 (0.977, 0.991)	(0.958, 1.01)	0.04
T2	0.991 (0.986, 0.995)	(0.970, 1.01)	0.990 (0.984, 0.996)	(0.969, 1.01)	0.991 (0.985, 0.998)	(0.965, 1.02)	-0.07
T3	0.992 (0.986, 0.998)	(0.960, 1.02)	0.996 (0.988, 1.00)	(0.965, 1.03)	0.987 (0.979, 0.996)	(0.956, 1.02)	0.07
Wasting							
T1	0.987 (0.977, 0.998)	(0.930, 1.02)	0.973 (0.960, 0.985)	(0.925, 1.02)	1.00 (0.991, 1.02)	(0.957, 1.05)	0.32
T2	0.993 (0.984, 1.00)	(0.945, 1.04)	0.984 (0.973, 0.996)	(0.940, 1.03)	1.01 (0.992, 1.02)	(0.960, 1.05)	0.19
T3	0.990 (0.979, 1.00)	(0.929, 1.05)	0.978 (0.964, 0.993)	(0.923, 1.03)	1.01 (0.989, 1.02)	(0.949, 1.06)	0.18
Overweight							
T1	0.996 (0.983, 1.01)	(0.924, 1.07)	1.01 (0.988, 1.03)	(0.939, 1.08)	0.987 (0.970, 1.00)	(0.919, 1.06)	0.11
T2	0.990 (0.978, 1.00)	(0.922, 1.06)	1.00 (0.984, 1.02)	(0.937, 1.07)	0.981 (0.965, 0.997)	(0.917, 1.05)	0.11
T3	0.987 (0.974, 1.00)	(0.912, 1.06)	0.988 (0.969, 1.01)	(0.912, 1.07)	0.985 (0.967, 1.00)	(0.909, 1.06)	-0.04

[1] OR, odds ratio; 95% PEI, 95% population effects interval;T1, lowest tertile; T2, middle tertile; T3, highest tertile.

CHAPTER V: EFFECT OF MOTHER-DAUGHTER DYAD HEIGHT DIFFERENCES ON DAUGHTER'S ADULT CENTRAL ADIPOSITY

A. Introduction

Stunting, or linear growth failure, is a prevalent public health concern in many low and middle income countries (LMIC), both historically and currently. In 2011, 165 million children under 5y were stunted worldwide (2). Stunting has been linked to long-term outcomes such as reduced cognitive function, diminished adult earnings and increased risk of metabolic disease (115). Stunted children are more likely to mature into mothers of short stature, who then give birth to small babies, who grow into short children, thereby propagating an intergenerational cycle of undernutrition (116–118). As the nutrition transition progresses in LMIC, however, overweight and obesity have become well-established problems, producing a dual burden of malnutrition (44,119). The onset of obesity is related to rapid urbanization, Westernization of the diet, and increasing levels of sedentary behavior. The opposing nutrition states of under- and overnutrition have been reported within the same household (5,6).

The dual burden household is typically defined by a stunted child and overweight mother pair, and a growing body of evidence documents this phenomenon in many LMIC (120–122). However, given the intergenerational cycle of malnutrition, we may wish to explore the circumstances which give rise to children born from a constrained fetal environment but who go on to amass excess adiposity as adults. This household typology would be consistent with the Developmental Origins of Health and Disease (DOHaD) mismatch theory, which suggests that children born from constrained fetal environments (i.e.: a short stature mother) were primed for a life outside the uterus of poor nutritional resources. When these conditions are not encountered (as would be the case when these children grow up in less constrained postnatal environments typified by energy-rich and nutrient poor diets characteristic of the nutrition transition) the child is at increased risk for overweight and obesity later in life (123–125).

We are interested in the children who surpass their mother's adult height, as examples of mismatch, that is, children who experienced maternal constraint, but who nonetheless had sufficient postnatal resources to have improved growth relative to what might be expected from maternal size. A key question is whether such children are also at increased risk of having higher levels of adiposity and thus increased risk of obesity and related cardiometabolic diseases.

Accompanying the nutrition transition, there may be changes in desired body image that often accompany westernization, and may influence a girl's weight management behavior and thereby her weight status (126,127). Studying the adult children born to undernourished mothers will shed light on how exposures during critical periods of growth may result in differences in nutritional status for the mother and child. Research linking the role of intergenerational growth improvements in the dual burden to future overweight and SES is scarce; providing such information will improve the ability of nutrition interventions to target at-risk households.

We examine a cohort mothers and their daughters to determine if improving upon the previous generation's adult height is associated with these adult central adiposity in the children. We explore multiple factors, including socioeconomic status, body image and weight management behaviors, and the timing of pubertal development as predictors of this phenomenon. The Cebu Longitudinal Health and Nutrition Survey provides the opportunity to closely examine intergenerational dynamics in mother-daughter dyads, capturing a period of great economic change in the Philippines, a LMIC.

B. Methods

Data source and study population

The Cebu Longitudinal Health and Nutrition Survey (CLHNS) is a community-based cohort of women and their index children (IC) followed since 1983 (128). The original participants included all pregnant women in 33 randomly selected communities of Metro Cebu, who gave birth between May 1, 1983, and April 30, 1984. A baseline interview was conducted among 3,327 women during mid to late pregnancy. Subsequent surveys took place immediately after birth, bimonthly for 2 years, in 1991, 1994–95, 1998–99, 2002, and 2005. The birth cohort consisted of 3,080 singleton live births, and 61% of these IC were still enrolled in 2005 (n=1,888). Our analytic sample consists of the 822 mother-daughter dyads with data on maternal height at baseline, IC height in 2005, and IC adiposity in 2005. Pregnant IC in 2005 were not included in this sample.

Measures

The primary exposure is the absolute height difference between maternal height and IC adult height ($ht_{maternal} - ht_{IC}$). Maternal height was measured in-home at baseline by trained field staff with a folding stadiometer to the nearest 0.1cm. IC height was measured at each survey by trained field staff with a folding stadiometer to the nearest 0.1cm. In 2005 the IC have a mean age of 21.5y, and therefore the height measured at this survey is the final adult height.

The primary outcome is a measure of IC adult central adiposity, waist circumference (WC). IC waist circumference was measured in-home by trained field staff using a measuring tape to the nearest mm, at the midpoint between the bottom of the ribs and the top of the iliac crest.

Maternal variables were self-reported during the baseline interview; age at menarche was recalled in whole years, education was recorded as the highest year of education completed.

IC birthweight was measured by trained birth attendants with Salter hanging scales for infants born at home (62%) and with clinical scales for infants born in a hospital or clinic. Birth length was measured by trained staff using custom length boards. Gestational age was estimated from the mother's self-reported date of her last menstrual period (LMP). If LMP was unknown, if there were pregnancy complications, or if birthweight was <2.5 kg, gestational age was assessed using the Ballard method (129). Birth order was assessed at the baseline interview. Stunting at age 2y was defined according to the 2006 WHO Growth Standards as length-for-age z-score <-2SD (62). Education status was recorded as the highest year of education completed at the 2005 survey. Urbanicity at birth and adulthood was defined using a community level composite score, with the maximum value of 70 representing the most urban community (130).

We attempted to capture when the IC surpassed her mother's height with respect to her age at menarche, as pubertal maturation is affected by the fetal environment, but also affects future risk of chronic disease. Specifically, early maturation has been linked to increased later risk of overweight (131,132). IC age at menarche was assessed in the 1994-95, 1998-99, and 2002 surveys as self-reported month and year of the first menstrual cycle. We first extracted the age at which IC reached maternal height ($ht_{maternal} - ht_{IC} < 0$), and then compared it to the age at menarche. We then established a 3 category timing variable: 1) IC reached maternal height pre-menarche, 2) IC reached maternal height post-menarche, or 3) IC never reached maternal height.

We created a variable to jointly capture body image satisfaction and weight management behavior in early adulthood. In the 2005 survey, IC were asked if they wanted to be thinner, be heavier, or maintain their current weight. An additional question ascertained which, if any, action the IC was taking to achieve that desired weight. From these two questions, we constructed a single dichotomous variable: 1) IC wants to be thinner or maintain present weight and is engaging in weight-related behavior, or 2) IC wants to be thinner or maintain her present weight but is not engaging in weight-related behavior, or the IC wants to be heavier, regardless of weight-related behavior.

A key covariate of interest was the IC's SES, measured both at birth and in adulthood using an assets based score. Tetrachoric factor analysis of 37 household assets reported in 2005 was performed, using a varimax orthogonal rotation. Three factors with eigenvalues >1.5 were retained. Factor 1 represents urban assets (e.g. car, appliances), factor 2 represents modernization (e.g. TV, videogames), and factor 3 represents rural assets (e.g. animals, land). This 2005 factor structure was then back applied to score the household assets reported at the baseline survey.

Statistical analysis

Descriptive characteristics are presented as means and standard deviations for continuous variables or as percentages for categorical variables.

Differences in the distribution of continuous and categorical variables across the spread of the dyad's height differences were assessed via ANOVA and chi square tests, respectively. To assess changes in characteristics across the distribution of height differences, we categorized the dyad's height difference for this analysis as follows: 1) $ht_{maternal-IC}$: minimum value to -7.5cm, 2) -7.5 to -2.5cm, 3) -2.5 to 2.5cm, 4) 2.5 to 7.5cm, and 5) 7.5cm to maximum value.

Multivariate regression models were conducted to investigate the association between the dyad's height difference and IC adult adiposity, accounting for various covariates. Due to a non-linear relationship with the outcome, we included a height difference-squared term. We first ran a crude model to estimate the net effect of the mismatch theory, and then sequentially adjusted for birth SES and adult SES variables.

All analyses were performed in Stata (Version 14, StataCorp, College Station, TX). The level of significance was set at $\alpha = 0.05$ in all analyses.

C. Results

Descriptive characteristics of the 822 mother-daughter dyads in the analytic sample are shown in **Table 5.1**. Almost half of the mothers in the sample had short stature (height < 150.1 cm), and almost two-thirds of the daughters were stunted at age 2y. Compared to their mothers, daughters were taller as adults, had an earlier age at menarche, and completed more years of schooling. Daughters' urbanicity score and all three wealth factors increased from birth to early adulthood.

Figure 5.1 illustrates the timing of daughters attaining their mother's height across the survey waves, according to menarchal status. Overall, 59% of daughters attained maternal height by early adulthood. No daughter had reached her mother's height by the 1991 survey (mean age = 8.5y). 25 daughters reached maternal height by the 1994 survey (mean age = 11.5y), 12 of whom were pre-menarchal. The majority of daughters reached their mothers' height by the 1998-99 survey (mean age = 15), and all were post-menarchal by that survey (n=296). By the 2002 (mean age = 18.7y) and 2005 surveys (mean age = 21.5y), an additional 130 and 34 daughters reached their mothers' height, respectively.

Group means and proportions of various explanatory variables across the range of the dyad's height difference are in **Table 5.2**. Statistically significant differences between categories of dyad's height difference were found for maternal height, birth order, birth length, HAZ at age 2y, daughter's height in early adulthood, daughter's WC in early adulthood, the age at which the daughter attained maternal height, daughter's completed years of education, and the daughter's rural SES in early adulthood.

Results of the different regression model specifications of offspring central adiposity on the dyad's height differences and other explanatory variables are displayed in **Table 5.3**. There was evidence of a positive, non-linear association between height difference and WC, as indicated by significant quadratic terms in all three models ($p<0.05$). Model 1 is the net effect of dyad's height difference on the daughter's adult WC. Larger differences in dyad's height were not significantly associated with daughter's adult WC, although only just so (coefficient = -0.09, 95%CI: -0.19, 0.00). Model 2 added birth socioeconomic variables. Dyad's height difference was inversely associated with daughter's WC (coefficient = -0.10, 95%CI -0.19, 0.00). Urbanicity at birth was associated with WC, but the various components of SES at birth were not. Model 3 added adult socioeconomic variables. Dyad's height difference was still inversely associated with daughter's WC (coefficient = -0.13, 95%CI -0.23, -0.04). Urbanicity score at birth remained associated with WC, as was the level of completed education.

D. Discussion

This explorative study investigated the association of the mother-daughter dyad height difference with a measure of the daughter's adult central adiposity, WC. By early adulthood (mean age 21.5y), 59% of daughters reached their mother's height, of which 2.5% were pre-menarchal. After adjusting for sociodemographic factors at birth and in early adulthood, dyad's height difference was significantly associated with the daughter's central adiposity in a non-linear manner.

Body composition is shaped by both genetics and the environment, with the environment influencing growth at critical periods in the life cycle, including the uterine environment and the one encountered after birth. The uterine environment is influenced by a mother's own nutritional history as well as her nutrition status and actions while pregnant. In the typical context of the obesity epidemic, excess adiposity is associated with normal to tall height. However, consistent with the mismatch theory, daughters born to the shortest mothers (i.e.: exposed to the worst fetal conditions) and who encountered substantially improved post-natal environments would be expected to have the highest risk of adult central adiposity (124,133). Our results suggest that daughters who were approximately the same height as their mothers had the lowest risk of central adiposity, with risk of adult central adiposity increasing as the difference in height between the mother and daughter increased. The U-shaped nature of this relationship can be further demonstrated by estimating predicted values of WC from across the distribution of height differences (analysis not shown). According to model 3, which includes birth and adult sociodemographic variables, a daughter 10cm taller than her mother (mismatch) would have a predicted WC of 70.2cm, a daughter who matched her mother's height would have a WC of 67.3cm, and a daughter 10cm shorter than her mother would have a WC of 68.3cm. A similar U-shaped relationship has been reported between another indicator of maternal constraint, birthweight, and offspring adult obesity (134). Others have only found an association of maternal height with boys adiposity, not girls (135).

Daughters who are the shortest compared to their mother present the opposite scenario to mismatch; they did not improve upon the nutritional status of the previous generation and their fetal exposures. These daughters experienced the poorest growth trajectories, as evidenced by the lowest birth weights, shortest birth lengths, and lowest LAZ at age 2y. Their adult circumstances matched their early life exposures, as they completed the least amount of education and the lowest SES scores. However, they were from communities with the highest urbanicity scores in adulthood, indicating they lived in urban barangays with the worst conditions. These daughters started life behind, stayed behind through early adulthood, and in fact ended up doubly burdened by poor linear growth and excess adiposity.

Other developmental and behavioral factors should be considered, including timing of pubertal maturation and weight management behavior. Daughters in our sample achieved menarche on average 1 year earlier than their mothers, likely due to an improved nutritional status (136), although in our sample the daughter's age at menarche did not differ across the distribution of dyad's height difference. Earlier age at menarche is associated with increased BMI and central adiposity (137–139), as well as participation in weight management behavior (140). Traditionally considered a problem of developed societies, a drive for thinness, body image dissatisfaction, and eating disorders are being reported in adolescent and young adult Asian females (141–143). This has been hypothesized to be due in part to exposure to images and messages via Western media that accompany globalization and the nutrition transition (144). Indeed, 72% of our sample reported a desire to be thinner or maintain body weight and taking at least one action to achieve the desired weight. Daughters engaging in this behavior had higher WC than those who did not (70.4cm versus 63.3cm, respectively). These are just two of the factors which more broadly suggest both past and current socioeconomic conditions can influence the daughter's nutrition status.

These results must be interpreted in the context of the study population. This birth cohort was born in the early 1980s, when undernutrition predominated and when historically they would have continued along a path of poor nutrition. Nearly half the mothers were short stature, resulting in fetal and infant metabolic adaptations which would influence the daughter's future growth and health. The Philippines experienced substantial economic development as the daughters matured, as reflected by increased urbanicity and SES factor scores from birth to adulthood, which provides a contrast to the nutritional status at birth. The observed WC elevations should be considered in light of the low prevalence of excess adiposity in this sample; the prevalence of overweight/obesity in early adulthood is low (8%), as is the prevalence of high WC (6.7%). At the 2005 survey, the mean age of the daughters was 21.5y, so enough time may not have passed to see substantial excess adiposity. Risk of overweight/obesity is cumulative, so we may be able to observe a more robust association at higher outcome prevalence in the future.

This study is not without limitations. As with most longitudinal cohort studies that accrue decades of follow-up, loss to follow-up is of concern. Attrition was mostly due to moving out the sample area (especially by the more educated into urban areas), whereas refusal rates in the mothers were low and decreased over time. Children lost to follow up after 12 months of age or who had missing data did not differ in height or weight significantly (145). In 2005, 65.5% of mothers and 61.3% of the original birth cohort members were located and interviewed (128). Additionally, this analysis did not assess daughter's reproductive history. Recently post-partum daughters may have elevated WC due to pregnancy-related weight gain, which may have spuriously inflated our estimates. Future work should address the influence of reproductive history on the relationship of dyad's height difference and daughter's central adiposity.

In our sample of mother-daughter dyads in a rapidly changing economic setting, the dyad's height difference had a U-shaped relationship with daughter's early adult waist circumference, suggesting the mismatch theory may apply to some dyads. Additionally, this work contributes a novel approach to the dual burden literature, as the undernourished mother and overweight child is an understudied household typology. Integration of information about a mother's height with respect to her daughter's height could help identify young women most at risk of excess central adiposity. Studies further investigating intergenerational differences in nutrition status and how they relate to offspring risk of adiposity should be promoted.

Table 5.1. Descriptive characteristics of 822 mother-daughter dyads

Characteristic	Mean (SD)
Mothers	
Age at delivery (y)	26.7 (5.9)
Age at menarche (y)	14.1 (1.6)
Completed education (y)	7.4 (3.6)
Height (cm)	150.5 (5.0)
% short stature[1]	48.8
Daughters	
Birth weight (g)	2991.2 (415.6)
Birth length (cm)	48.9 (2.0)
Birth urbanicity score[2]	29.3 (12.8)
Birth SES score (urban)	0.7 (1.6)
Birth SES score (modernization)	2.7 (2.9)
Birth SES score (rural)	1.6 (1.7)
% stunted at age 2y[2]	65.7
Age at menarche (y)	13.1 (1.0)
Age at early adulthood (y)	21.5 (0.3)
Adult weight (kg)	46.3 (8.1)
Adult height (cm)	151.2 (5.5)
Timing of maternal height attainment	
Never	41.0
Pre-menarche	1.5
Post-menarche	57.5
Completed education (y)	11.7 (2.8)
Adult urbanicity score[2]	41.2 (13.1)
Adult SES score (urban)	2.3 (4.3)
Adult SES score (modernization)	9.4 (7.8)
Adult SES score (rural)	5.0 (4.4)

[1] Short stature defined as height < 150.1cm
[2] Stunting defined as HAZ < -2SD

Figure 5.1. Number of IC who reached maternal height at each survey wave, by menarche status

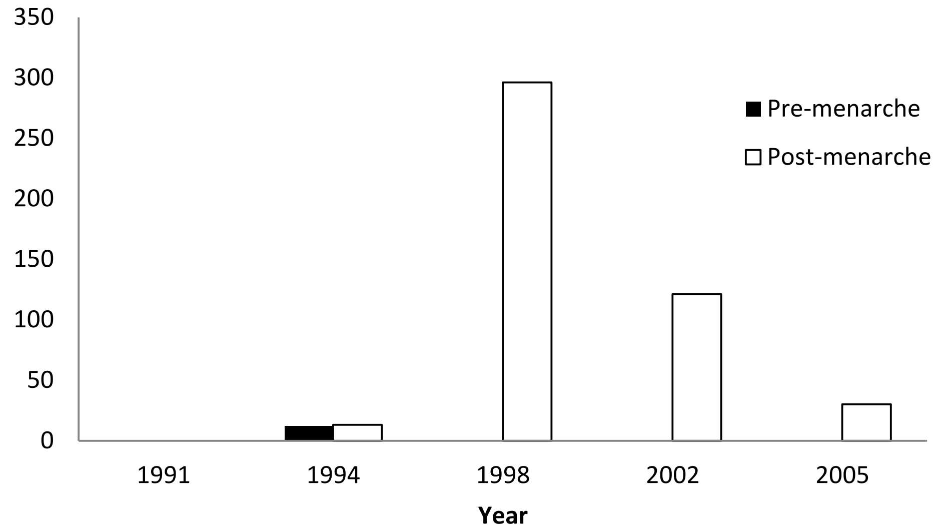

Table 5.2. Characteristics of mothers and daughters across categories of dyad's height difference

Variable	Mom ht << IC ht *n=82*	Mom ht < IC ht *n=218*	Mom ht ≈ IC ht *n=304*	Mom ht > IC ht *n=164*	Mom ht >> IC ht *n=54*	*P*
Maternal						
Height, cm	147.1	148.7	150.7	153.0	154.4	0.00
Age at menarche, y	14.0	14.0	14.0	14.2	14.2	0.58
Infancy [1]						
Birth order	3.2	3.1	3.2	3.7	3.8	0.04
Weight, g	3066.9	2998.1	2980.4	3005.7	2863.8	0.09
Length, cm	49.4	49.1	48.9	48.7	48.0	0.00
Gestational age, w	38.8	39.0	38.9	39.2	38.6	0.42
Urbanicity score	29.2	29.9	28.4	29.3	31.6	0.45
SES score (urban)	0.4	0.9	0.7	0.5	0.5	0.05
SES score (modernization)	2.4	2.7	2.8	2.7	2.3	0.66
SES score (rural)	1.5	1.9	1.6	1.5	1.3	0.10
LAZ at 2y	-1.8	-2.2	-2.5	-2.9	-3.2	0.00
Adulthood [2]						
Height, cm	156.9	153.4	150.8	148.4	144.3	0.00
Waist circumference, cm	71.01	67.4	67.7	67.4	68.0	0.00
Age at menarche, y	13.0	13.2	13.2	13.1	13.1	0.62
Age attained maternal ht, y	14.4	15.4	18.3			0.00
Education completed, y	12.0	12.0	11.6	11.4	10.9	0.02
Weight management behavior, %	72.0	60.1	64.8	68.9	64.8	0.27
Urbanicity score	41.7	41.3	41.2	40.2	43.5	0.59
SES score (urban)	1.6	2.9	2.3	1.9	1.9	0.11
SES score (modernization)	9.7	9.3	9.7	9.2	8.2	0.75
SES score (rural)	4.7	5.6	5.2	4.5	4.1	0.04

[1] At birth, unless otherwise noted

[2] Mean age 21.5y, unless otherwise noted

Table 5.3. Multivariable regression of daughter's adult central adiposity status (WC) on dyadic height differences and sociodemographic and anthropometric characteristics

	Model 1		Model 2		Model 3	
	Mismatch effect		Model 1 + birth socioeconomic variables		Model 2 + adult socioeconomic variables	
Variable	Coeff.	95% CI	Coeff.	95% CI	Coeff.	95% CI
Dyad's height difference, cm	-0.09	-0.19,0.00	-0.10*	-0.19,-0.00	-0.13**	-0.23,-0.04
Dyad's height difference, squared	0.02**	0.01,0.03	0.02**	0.01,0.03	0.02*	0.00,0.03
Birth urbanicity score			0.10***	0.06,0.14	0.14***	0.09,0.19
Birth SES score (urban)			0.08	-0.27,0.44	0.55	-0.15,1.24
Birth SES score (modernization)			-0.19	-0.39,0.00	0.04	-0.25,0.33
Birth SES score (rural)			0.14	-0.23,0.51	-0.16	-0.76,0.44
Years of completed education					-0.47***	-0.68,-0.27
Adult urbanicity score					-0.05	-0.10,0.00
Adult SES score (urban)					-0.08	-0.34,0.18
Adult SES score (modernization)					-0.05	-0.17,0.06
Adult SES score (rural)					0.07	-0.16,0.31

* p<0.05, ** p<0.01, *** p<0.001

CHAPTER VI: SYNTHESIS

A. Overview

This research investigates community and household level dual burden of malnutrition in children in low- and middle-income countries (LMIC), and touches upon the individual level. First, we described trends in country- and individual-level dual burden of malnutrition in children <5 years, and age-stratified (<2 years, ≥2 years) country-level trends in LMIC. Second, assessed if the burden of malnutrition in children <5y in LMIC is shifting between wealth sub-groups, by summarizing the association of each of three anthropometric indicators (stunting, wasting, overweight) with household wealth within countries over time and exploring the extent to which country-level wealth affects our summary estimates. Finally, we explored the relationship between mother-daughter dyad height differences and daughter's adult central adiposity status, and considered the role of socioeconomic status, body image and weight management behaviors, and the timing of pubertal development.

To address our research aims, we used two datasets, each uniquely suited to answer our questions: 1) Demographic and Health Surveys from xx countries which contributed over 600,000 children <5y from around the globe, and 2) the Cebu Longitudinal Health and Nutrition Survey (CLHNS), a community-based birth cohort of mothers and their children born from 1982-1983 in a metropolitan area of the Philippines which provided the opportunity to assess mother-daughter dyads

Prevalence and trends in the childhood dual burden

This was the first study to directly compare the prevalence of stunting, wasting and overweight in children <5 years, to estimate the dual burden of malnutrition in children <5 years, and to examine differences between children <2 years and ≥2 years for multiple LMIC. Our findings suggest that overall malnutrition is decreasing in children <5 years, but trends varied for the three individual forms of malnutrition; declines in stunting are occurring alongside increases in overweight among young children in many settings. Consequently, the dual burden is becoming a reality in an increasing number of countries, particularly middle-income countries.

Globally, stunting decreased by similar magnitude before 2000 and after 2000 in children <5 years. Reductions in wasting occurred before 2000, but plateaued after the millennium. Overweight increased similarly before and after 2000. These opposing individual trends mirror the results of our estimation of the dual burden, with more countries manifesting the dual burden over time. The country-level dual burden ratios indicate that although stunting prevalence is still higher than overweight in many countries, the difference between the two is getting smaller.

A key contribution of this work is the exploration of trends before and after age 2 years, which have not been investigated previously. We showed differences between children <2 years and ≥2 years, with children <2 years in a worse situation regarding both under- and overnutrition.

We also document individual level dual burden. We observed a substantial number of children within a country who were simultaneously stunted and overweight, as well as elevated levels of overweight among stunted children. This occurred alongside the already large numbers of the population who were only stunted or only overweight.

The relationship between wealth and the dual burden of malnutrition in children

We expand upon the descriptive analysis above to explore how SES dynamics within a country may shape the dual burden profile of a country. Although there is a growing body of evidence debating this phenomenon in adult women in LMIC, this is the first study of this relationship in children. We document a widening wealth gap between the poorest and richest households in a majority of countries over time. We did not observe a pronounced shift in anthropometry with respect to wealth status as has been noted in adults. However, there was considerable between-country heterogeneity which may have influenced our ability to draw conclusions on a global scale.

We demonstrate that the prevalence trends documented in aim 1 are occurring within a context of rising wealth inequality, as the gap between the poorest and richest households increased in two-thirds of the countries. Although absolute household wealth increased across the entire wealth distribution, relative shifts in wealth may have different health implications for different segments of a population. In a country with similar levels of wealth in the poorest and richest households, the nutritional status of children within categories of wealth were more similar to each other, whereas the nutritional status of children in countries with a large gap between the poorest and richest households varied greatly according to household wealth.

We hypothesized that over time, stunting and wasting would remain the burden of the poorest children within a country, while overweight would initially be concentrated in the wealthiest children and then shift down the SES gradient to ultimately produce a dual burden of malnutrition among the most economically disadvantaged children, echoing the SES dynamics observed in adults. However, we did not find evidence of this phenomenon. We used meta-regression as a method to obtain a global summary of the within-country SES dynamics, which may have obscured the considerable between-country heterogeneity. Inclusion of country-level income did not appreciably influence the stunting results, whereas wasting and overweight estimates did change in some instances. Assessing heterogeneity was not particularly informative.

Effect of mother-daughter dyad height differences on daughter's adult central adiposity

This explorative study using mother and daughter pairs from the CLHNS investigated the association of the mother-daughter dyad height difference with a measure of the daughter's adult central adiposity, waist circumference (WC). By early adulthood, more than half of the daughters reached or surpassed their mother's height, of which only a small number were pre-menarchal. After adjusting for sociodemographic factors at birth and in early adulthood, we documented a non-linear relationship between dyad's height difference and the daughter's central adiposity.

We assessed various factors which could influence these intergenerational dynamics.

B. Strengths and limitations

There are limitations in this work that should be considered when interpreting the results. Use of DHS data presented certain limitations. First, that the selected countries are not truly globally representative, since certain regions are over-represented (Africa) while others are under-represented (Asia). This limits the generalizability of our findings but was a trade-off with our inclusion criteria, which ensured we were able to assess contemporary trends over time. Second, a few country-years do not include children across the entire age range of 0-5y. This was due to how each country carried out their DHS (i.e.: only children <3y or <4y were measured a handful of surveys). This could give the impression of lower rates in these country-years, as anthropometric deficits tend to accumulate over time. Third, the data were cross-sectional so we cannot make statements about age-specific trends within the same children.

In the analysis of dual burden and SES, we observed a fair amount of heterogeneity between countries. This heterogeneity may explain why some report finding evidence of overweigh/obesity shifting between SES groups and others do not. It could also be due to use of individual-level SES, which we attempted to address by running a meta-regression with a country-level income status indicator. Additional research that incorporates other macro- and country-level factors to explain some of the country-level variation is needed.

Use of CLHNS has its limitations, as well. As with most longitudinal cohort studies that accrue decades of follow-up, loss to follow-up is of concern and may affect generalizability. Attrition was mostly due to moving out the sample area (especially by the more educated into urban areas), whereas refusal rates in the mothers were low and decreased over time. Children lost to follow up after 12 months of age or who had missing data did not differ in height or weight significantly. In 2005, 65.5% of mothers and 61.3% of the original birth cohort members were located and interviewed.

Despite these limitations, this research has various strengths and we fill critical gaps in the field of childhood dual burden research. The first portion of this work contributes a much needed contemporary, precise, and in depth update of the global prevalence and trends of the dual burden in children. We uniquely extend this work to an even more refined level of detail by assessing trends before and after 2y, a critical milestone in a child's development. The DHS data we utilized afforded the opportunity to compare tremendous numbers of children from across the globe, representing almost every continent. DHS are rigorously collected and standardized to provide comparable measures of childhood anthropometrics across countries and time, and have been used extensively to establish dual burden trends in other demographics.

The second aim builds upon the descriptive analysis and seeks to address the role of SES on the global dynamics of the dual burden in children, a question which has created much debate in adults but is yet to be assessed in children. First, the use of DHS data allowed us to explore both between and within-country changes and investigate the role of macro-level processes on the shifting burden of disease by SES. Second, instead of using the DHS wealth index commonly used in analyses of SES conducted with DHS data, we took advantage of a novel new wealth indicator, International Wealth Index (IWI). Although often used in this type of application, the DHS wealth index is an inappropriate choice, as it is tailored to the specific wealth distribution in the given country and survey year in which it was created. In contrast, IWI is an asset based index for household's long-term economic status that can be used for all LMIC. It is similar to the DHS wealth index, but is directly comparable across country and time. Third, meta-regression allows us to use all available survey years, instead of being restricted to the same number of surveys per country (for example, first and last year). This allows us to make a more accurate and nuanced assessment of the relationship.

The third and final aim takes advantage of a rich longitudinal dataset, the CLHNS. It was designed to examine biological and social factors that may influence birth outcomes and early life growth and development, establishing an ideal dataset in which to explore our objective of assessing adult outcomes of fetal and early life exposures. Use of this dataset allows us to increase our understanding of the mother-daughter dyad and intergenerational aspects of growth and development. Given the longitudinal nature of CLHNS which spanned a period of rapid economic development, we can assess factors related to economic development and westernization, such as SES and body image.

C. Public health significance

Childhood nutritional diseases are a significant global problem, but the distribution of under- and overnutrition is changing, especially in LMIC. Undernutrition in children <5y continue to pose a substantial public health concern. As the nutrition transition progresses, childhood overnutrition becomes a concern. Despite economic development, substantial economic disparities remain and nutritional insufficiencies continue to affect many children in LMICs. In concert, the under- and overnutrition trends produce a dual burden of malnutrition. This dual burden manifests in communities, households, and individuals and presents a unique and complex public health challenge.

As in any area of public health, the first step towards understanding and addressing an emerging problem is having reliable, accurate, precise, and current data. With the first part of our work, we provide a necessary update of the global context. This work will help the international community start to understand the extent and severity of the problem, as it is not one that many LMIC are currently addressing or willing to acknowledge. It is also important to know who is most at risk; we have identified while the dual burden occurs in many LMIC, middle-income countries have higher levels of the dual burden and children <2y are at higher risk than children 2-5y. With active within-country surveillance, governments will better understand the magnitude of the childhood nutritional problem and be better informed making choices regarding resource allocation. When designing programs and policies, both under- and overnutrition must be considered so as not to unintentionally add to the burden of overweight in the same children the program is striving to help.

Exploring the role of SES in the dual burden adds a critical layer of understanding in the global context, especially with regards to the widening wealth gap we document in many countries. Although we did not observe the same SES shifts as have been documented in adults, we did note that countries with lower wealth disparities were less likely to experience undernutrition and overnutrition occurring in siloed segments of the population. This is valuable information when drafting policy and creating nutrition interventions and programs.

Understanding the additional complexities of how intergenerational dynamics influence nutritional status provides the opportunity for integration of a person's family history for a more detailed assessment of their future risk. The U-shaped relationship we observed between the mother-daughter dyad's height difference and daughter's central adiposity highlights two high risk groups: daughters who are either much shorter or taller than their mothers. This work provides further motivation for halting the intergenerational cycle of undernutrition, as it not only propagates undernutrition but we show evidence of increased risk of excess adiposity to daughters born from poor fetal nutritional environments.

D. Future directions

Further research is needed to understand the full range of factors that have produced the dual burden of malnutrition, and how to improve the nutritional status of children before levels of overweight reach those of adults while simultaneously reducing the persistent undernutrition.

DHS regularly collects new waves of data, and therefore the descriptive work from our first aim should be repeated as new surveys become available to continue to monitor global prevalence trends. Active surveillance and tracking of the global situation is necessary to staying ahead of any major developments that may develop in the future.

Although we did not find evidence of the same SES dynamics documented in adults, SES has a large role in determining health outcomes. Therefore to ensure a child's optimal development SES should be a component of programs and interventions. This is especially important in countries where we observed widening wealth disparity. Additionally, our assessment of the dual burden was made with respect to the distinct anthropometric indicators stunting and overweight. A different approach would be to run a similar analysis with a single indicator that explicitly captures the dual burden, for example the ratio of stunting overweight prevalence.

Additional studies assessing intergenerational dynamics should be undertaken in other LMIC, and specifically in countries with a higher prevalence of overweight or other adiposity indicators than CLHNS. It is possible we may see a different relationship if the analytic sample had a higher occurrence of the outcome of interest. To better understand determinants of adult body composition, the daughter's reproductive history could be included in future analyses.

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