European University Institute
Max Weber Programme

EUI Working Papers

MWP 2008/41

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EUI Working Paper MWP No. 2008/41

ISSN 1830-7728

Printed in Italy
European University Institute
Badia Fiesolana
I – 50014 San Domenico di Fiesole (FI)
Italy

http://www.eui.eu/
http://cadmus.eui.eu/

Abstract

In most developing countries, rising levels of nutrition and improvements in public health have led to declines in infant mortality and rising adult height. In Sub-Saharan Africa, however, we see a different pattern. Sub-Saharan Africa has seen large reductions in infant mortality over the last fifty years, but without any increase in protein or energy intake, and against a background of stagnant, or even declining, adult height. Adult height is a sensitive indicator of the nutrition and morbidity prevailing during the childhood of the cohort and can be taken as a measure of population health. Declining infant mortality rates in Sub-Saharan Africa appear to be driven by medical interventions that reduce infant mortality, and may not be reflective of broad-based health improvements.

Keywords

Height, Sub-Saharan Africa, childhood health, childhood nutrition, infant mortality rate, morbidity and mortality

Mortality and Morbidity Transitions in Sub-Saharan Africa: Evidence from Adult Height

YOKO AKACHI[♣] and DAVID CANNING[♦]

1. Introduction

Over the last fifty years the world has seen enormous improvements in population health in terms of falling mortality rates. These reductions in mortality rates and gains in lifespan were occurring even in Sub-Saharan Africa until the onset of HIV/AIDS in recent decades, and they had created a large improvement in human welfare (Becker, Philipson, and Soares 2005). Historically, initial improvements in mortality in Europe and North America were associated with improved nutrition and public health measures such as the provision of clean water and sanitation (Cutler, Deaton, and Lleras-Muney 2006, McKeown 1983). These changes at the same time led to reductions in childhood morbidity and improved childhood nutrition and to increases in adult stature as children exposed to the new circumstances experienced physical development and became adults (Fogel and Costa 1997, Alter 2004, Crimmins and Finch 2006). We argue that this pattern continues to hold true today; in much of Latin America and Asia, reductions in infant mortality go hand in hand with improved nutrition, reductions in child morbidity, and rising adult height.

In Sub-Saharan Africa, however, we find a distinctively different pattern: while infant mortality has been falling, adult height has been stagnating over the last 50 years. We trace this different pattern in outcomes to two sources. Firstly, in contrast to the other developing countries where nutrition, as measured by energy (calorie) or protein intake per person, has been increasing, Sub-Saharan Africa has experienced little nutritional improvement. Secondly, while a reduction in a cohort's infant mortality rate is associated with an increase in that cohort's adult height in most regions, this linkage does not appear to occur in Sub-Saharan Africa.

Our explanation of this pattern is that the interventions that have produced reductions in the infant mortality rate in Sub-Saharan Africa have been different to those used in other regions of the world. We argue that, rather than broad-based improvements

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in nutrition and public health measures to combat the spread of disease, mortality reduction in Sub-Saharan Africa has been through measures that directly reduce mortality with limited effect on morbidity.

This idea has appeared in the literature before. Huffman and Steel (1995) and Guerrant, Carneiro-Filho, and Dillingham (2003) argue that oral rehydration therapy and measles vaccination, in particular, can have large effects on infant mortality rates, while morbidity rates remain high and the physical development of children continues to be impaired. In a study that compared the survival rates between groups vaccinated and unvaccinated for measles in former Zaire, it was found that vaccination reduced the risk of dying during the age most susceptible to the disease, but the gain in the survival probability tended to diminish afterwards, and the two survival curves approached each other later on (Kasongo 1981). In the rural part of The Gambia with a good record of infant immunization, few children died of diseases that could have been prevented by routine immunization, but little improvement in child stunting and wasting was found (Greenwood 1987). Similarly, Pinchinat et al. (2004) find that focused public health interventions such as vaccinations and malaria prevention in Senegal may improve childhood survival, but do not necessarily improve the health status of children. These researchers attribute the persistent high child morbidity rates (despite improvements in child mortality) to acute respiratory infections, malaria, and chronic diarrhea, which are associated with malnutrition.

We wish to investigate if these findings of a lack of improvement in morbidity even in the face of declining mortality are representative of Sub-Saharan Africa at the population level. We focus our analysis on adult female height. Physical growth during childhood and adolescence, or the adult height that it ultimately leads to, is an indicator of childhood nutrition and the disease environment. Although height is largely genetically determined[1], it is also significantly affected by childhood living conditions. The major proximate determinants of height are nutrition, disease environment, and work intensity (Tanner 1992, Nystroem Peck and Lundberg 1995, Steckel 1995, Brush, Harrison, and Waterlow 1997, Stephensen 1999). The main socioeconomic determinants of height include income, inequality, public health, personal hygiene, disease environment, technology, labor organization, cultural values, and food prices (Silventoinen 2003).

Population genetics studies from the medical field have looked into the relative proportions of genetic and environmental variation in body height. Most medical research on height has involved small sample sizes at individual level such as family and twin studies (Garn 1976; Langinvainio 1984; Pedersen 1984; Stunkard 1986; all in Silventoinen 2003). They focus on genetics, which relates to the unsystematic variation of body height, but there is usually less focus on how the environmental part of the variation could explain the systematic differences found in a society at the population level. Trends in cohort height have been used by economic historians (Fogel 1993, Komlos 1993, Steckel 1995) as measures of a "biological standard of living" when other indicators have not been available. It has been suggested that height can be used as an

[1] At the individual level, there is evidence from developed countries that as much as 80% of the variation in the height of individuals can be ascribed to genetic factors (Silventoinen 2003, Visscher 2006). Up to 20% of variation in body height is thus attributed to environmental variation in modern Western societies (Silventoinen 2000, Stunkard 1986). In poorer environments, this proportion is likely to be larger, with a lower hereditability of body height as well as larger socio-economic body height differences.

indicator of health status in modern populations as well (Komlos and Lauderdale 2007). Several studies in the social sciences have investigated the link between childhood health, nutrition, and adult height at the population level. Across developing countries, greater average protein intake is associated with greater average adult height (Jamison, Leslie, and Musgrove 2003). In addition, recent data has been used to examine the determinants of adult height in Sub-Saharan Africa (Moradi 2002, Moradi 2006, Deaton 2007, Akachi and Canning 2007).

Adult height could in fact be thought of not only as an indicator of childhood health but also as a measure of "health capital." The same cohorts that experienced declining infant mortality rates in Sweden, France and England in the 19th century underwent gains in adult height as well as reductions in adult mortality rates (Crimmins and Finch 2006). A review of variations in modern adult height across European countries suggests that socio-economic differences in childhood living conditions would continue to contribute to socio-economic differences in health in adulthood (Cavelaars et al 2000). Health capital is associated with health outcomes in adulthood due to the long-term effects of early childhood illness on cognitive and physical development, and on adult health. Stunting in the first two years of life has been found to be significantly associated with poor cognitive performance in later childhood (Mendez and Adair 1999). Growth retardation in early childhood is also associated with significant functional impairment in adult life and reduced work capacity, and thus affects economic productivity. A substantial number of studies from demography, medicine, and epidemiology have found links between childhood environment and health in later life (Elo and Preston 1992, Hayward and Gorman 2004, O'Rand and Hamil Luker 2005). Indicators of childhood social and economic environment such as height (Fogel 1993) and fetal and infant nutrition (Barker 1989) have been associated with adult mortality (Kuh 2002), and there is an implication of their long-term effects on healthy longevity up to advanced ages (Yi, Gu, and Land 2007).

In microeconomic studies, the variations in adult height that are the result of childhood health and nutrition have a large impact on adult worker productivity and wages (Schultz 2002, Schultz 2005). In macroeconomic studies, until recently worldwide data on the evolution of adult heights has been lacking. Macroeconomic studies tend to use mortality measures, such as life expectancy or adult survival rates, as a measure of population health capital. This, however, presupposes a one-to-one link between health capital as determined by height and health capital as determined by mortality measures. Although Weil (2007) argues that in the long run such a link holds in many countries, our analysis suggests this link may have been broken in Sub-Saharan Africa. In the field of social sciences, especially in economic history, research has focused on country-level studies, and there are few global studies such as this paper. In the field of medicine and demography, height and its association with childhood nutrition and the health environment has rarely been analyzed at the population level.

There is controversy over the extent to which height is a good measure of health. Our research implies that adult cohort height can be used, with caution, as an independent measure of population health, supplementing other conventional health indicators such as the infant mortality rate and life expectancy. Health is multi-dimensional, and we may need more than mortality rates to measure its varying aspects. It may be dangerous to take improvements in infant mortality in Africa as indicative of broad-based improvements in population health.

2. Data

Data Sources

Most of the height data we use come from Demographic and Health Surveys (DHS), although we also use Family Life Surveys (FLS) for Mexico and Indonesia, and World Bank Living Standard Measurement Surveys (LSMS) for Albania. All the available Demographic and Health Surveys that include height as a variable were employed in this analysis (with the exception of Egypt - see later section). Not all countries with DHS had adult height data. Height in Demographic and Health Surveys is measured by the interviewer using a headboard. The typical Demographic and Health Survey dataset contains the heights of women from age 15 to 49. Though the probability of being sampled is usually unequal for different observations, these are nationally representative samples. We use the sampling weights provided to construct a nationally representative average height for each cohort by birth year, and we extract the height of women only from age 20 and above on the grounds that at that age physical developments have ceased.

One complication is that in earlier surveys only the height of mothers with children under 5 was measured (in later Demographic and Health Surveys the height of all women aged 15 to 49 was measured). This creates a sample selection problem since mothers are not a random sample. For example, assuming that higher socio-economic status is associated with fewer children, if height is positively linked to socioeconomic status then the average height of mothers may be lower. In our data consistency check, we examined the average height of each cohort as measured in different DHS surveys and found them to be remarkably similar, independently of whether the data were for all women or just mothers. These findings agree with those of Moradi (2006), who argues that there is little selection bias due to this issue in developing countries because the vast majority of adult women have children.

While we have large samples from FLS and LSMS, these are often not nationally representative samples and are available only for a small number of countries. The only countries for which we use the FLS are Mexico and Indonesia. The only country where we use the LSMS is Albania. In these cases the FLS and LSMS surveys are nationally representative (or close to being so). This leads to average female height data from a total of 41 countries.

Distribution of Height

Table 1 shows, as examples, some descriptive statistics for the distribution of cohort height for cohorts born in 1960, 1965, 1970 and 1975 from the Bangladesh 2004, Bolivia 2003, and Ghana 2003 DHS. The standard deviation of individual height is around 6 centimeters. There is some evidence of a positive (right) skew in recent cohorts for the Bangladesh and Bolivia DHS while it is mostly negative for the Ghana DHS. Positive kurtosis (so that the peak of the distribution is higher and narrower, with fatter tails, than the normal) was observed for each cohort for all three countries' DHS. Tests of the hypothesis that the distribution is normal fail to be rejected for the three 1960 cohorts and the 1970 Ghana cohort, but it is rejected for the rest of the cohorts. Figure 1 shows the estimated distribution of heights of the cohort born in 1970 in Ghana from the 2003 DHS. The distributions are also shown for the 1975 cohort in Bolivia from the 2003 DHS (Figure 2).

The rejection of normality was common in many of our datasets. The deviation from normality could be taken as evidence of a selection effect, which could potentially be corrected by statistical methods. However, it is possible that differential health and nutrition across individuals creates a non-normal distribution and that a selection "correction" would bias the results (e.g. see Jacobs, Katzur, and Tassenaar 2004).

Comparing Data Sources and Averaging

We construct the average height for each cohort by year of birth from each survey. For each country with multiple DHS surveys, cohort heights by birth years were graphed to check for consistency when the same cohort is included in different surveys. An example for the three DHS surveys of Ghana is shown in Figure 3, and for Bolivia in Figure 4. In most cases the results for different surveys were very similar. The only country in which we found considerable variation was Egypt. Egypt has three DHS surveys, one of which, the 2003 survey, consistently and considerably differs from the other two in 1995 and 2000 (Figure 5). Therefore the surveys from Egypt were discarded.

In order to construct figures for average cohort height, we average over available DHS surveys for each country when multiples of them are available (the same was done for the two FLS Indonesia surveys). This gives larger sample sizes except at the beginning and end of the series, where often only data from one survey is available. The newer DHS survey with a larger sample size has less volatility compared to the earlier ones. A larger sample size reduces the measurement error in the cohort average and results in noticeably lower volatility in average height.

In principle, different DHS surveys should give comparable results for the same cohort (same birth year) in a country, since the samples are nationally representative, however, the survey design is based on clustered random sampling, and sampling variation depends on the number of clusters as well as the number of observations. We find that while surveys usually agree quite well there is substantial measurement error in our estimate of average cohort height due to sampling. The number of observations for each cohort from a survey is used for weighting when taking the averages for a particular cohort across different surveys.[2] For each country the number of cohorts varies according to that country's DHS sample size, but there is a maximum of 30 as we are calculating the height of women between the ages of 20 and 50.[3]

Health and Nutrition Data

We compare heights with indicators for health and nutrition. Data on the percentage of children who are stunted also come from Demographic and Health Surveys. We use the infant mortality rate from the World Bank's World Development Indicators (2005), with data going back to 1960, as a health measure, interpolating over gaps of one to two years to derive an annual time series.

For nutrition, we use the daily average consumption of calories and protein from the World Food Organization (2006) FAOSTAT database, with data going back to 1961.

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[2] For example, for country A, there are two DHS surveys. For the cohort born in 1975, one survey estimates the average cohort height from 320 women while the other estimates it from 250 women. We use these numbers of observations as weights to estimate the final average cohort height for the birth year 1975 in country A.

[3] For example, a country with just one DHS conducted with a small sample may only have about 20 cohorts, while countries with multiple surveys over time may provide 30 cohorts.

The Food and Agriculture Organization (FAO) food balance sheets calculate the consumption of each foodstuff. Consumption of foodstuffs is calculated from two sources: national food supplies given by production plus imports minus exports and wastage, and data on food consumption from household surveys. Jacobs and Sumner (2002), discuss the construction of the food balance sheets, problems in constructing the data, and their appropriate use. Calories and Protein consumed per capita are calculated from the national consumption of each foodstuff using nutritional tables of calorie and protein content, and dividing by the population. The nutritional data from the FAO is suitable for our analysis as the FAO suggests that the data may be used to: a) observe a country's food supply and its trends, b) compare food supply to nutritional requirements for healthy diets, c) estimate supply/shortage measures, d) evaluate food and nutrition policies, e) measure the degree of chronic under-nutrition, e) examine changes in diet patterns, and f) investigate relationships between food supplies, famine, and malnutrition, among other objectives. The FAO cautions that the estimates for national food or nutrient availability do not take into account the distribution of food or nutrient supply between regions within a country, or among other groups or households. The methodology has recently been revised to use the latest estimation techniques and the new database was uploaded to the FAO website early in 2007. We however used the food balance sheets available from the archives to construct our cross-country panel of nutrition data. This data provided the daily average consumption of calories and protein for each country from 1961 to 2002.

The actual data analysis conducted in this paper is at aggregate country-level despite drawing on DHS data. Direct individual-level DHS analysis will be carried out in future research.

3. Results

We begin by investigating the link between physical development, infant mortality, and nutrition, looking at how these change over time in developing countries. Table 2 shows the time trends for infant mortality rates, and protein and calorie intake for countries in Sub-Saharan Africa, from 1961 to 1985, matched with the trends in adult height for cohorts born during that period. In every country in the region except Rwanda, we see statistically significant declines in the infant mortality rate. In terms of protein and calorie intake, the picture in Sub-Saharan Africa is much more mixed: as many countries have seen declines in nutritional intake as have seen increases. Finally, adult heights have risen significantly in only two countries, Kenya and Senegal, whereas three countries, Chad, Ethiopia and Rwanda, have seen heights decrease.

We can compare these trends with those in developing countries outside Sub-Saharan Africa over the same time period, as shown in Table 3. Infant mortality rates fell significantly in every country outside Sub-Saharan Africa. Nutrition in the form of either calorie or protein intake increased significantly in every country except Bangladesh, Nicaragua, and Peru. Adult height also increased significantly in every country except Bangladesh, where it stagnated.

These national trends are summarized in Table 4, where we report regional time trends that represent the average annual change in the variable in the region (averaged over the country averages). In terms of infant mortality, we find very similar rates of decline in Sub-Saharan Africa and developing countries in other regions: a decrease of about 2.1 versus 2.4 infant deaths per thousand live births each year.[4] On the other hand, while both protein and calorie consumption have been increasing significantly elsewhere, within Sub-Saharan Africa protein and calorie consumption remained virtually unchanged over the whole period. The trends in height are also quite distinct. In Sub-Saharan Africa, height overall has been decreasing: the cohort born in 1985 is about 0.5 centimeters shorter than the one born in 1961. In contrast, in the rest of the developing world the height of adult women has risen by approximately 1.6 centimeters on average during the same twenty-four year period.

The mortality rate, especially that of infants and children, has been one of the most commonly used indictors of population health, as can be seen in the Millennium Development Goals. Also in the field of social science, mortality rates and life expectancy (which are estimated from mortality rates) are commonly used as indicator of population health (e.g. Preston 1975, Pritchett and Summers 1996, Bloom and Canning 2000). Weil (2007) argues that in a simplified macroeconomic model we can think of health as a single, uni-dimensional, concept and that in the long run both population height and mortality rates respond to a single impulse. In this case, height and mortality rates should tell the same story about the underlying health of the population, with a stable relationship between the two. Our data suggests that this is not true for Sub-Saharan Africa, since average adult height is declining while infant mortality rates are falling. We think both adult height and infant mortality rates respond to nutritional intakes and the underlying disease burden when young, meaning that they will be linked. This allows us to study two possible reasons why adult heights have not increased in Sub-Saharan Africa. The first possibility is that it is due to the lack of growth in nutritional intake. The second is that the relationship between the disease burden, mortality, and adult height is different in Sub-Saharan Africa to in other regions of the world.

Many studies take anthropometric measures as indicators of nutritional status, however, it is both nutrition and diseases in childhood that are usually regarded as the main factors affecting body height, in addition to the genetic component (Silventoinen 2003). We prefer to measure nutritional intake more directly in terms of protein and calorie consumption. We assume that adult height depends on nutrition intake when young and the morbidity experienced in childhood due to the disease environment.[5] More formally, let us suppose that average height, h, in country i of the cohort born at time t depends on the nutrition level, n, and the disease burden, d, when the cohort is young according to the equation

$$h_{it} = f_i + \alpha n_{it} + \beta d_{it} + \varepsilon_{it}, \tag{1}$$

where f_i represents a country-specific fixed effect and ε_{it} is an error term.

Infant mortality rates depend on nutrition as well as the disease environment (UNICEF 2008, Bryce 2006, Black, 2003, Baten 2000). Formally, we assume that the infant mortality rate varies with nutrition and the disease burden according to

[4] This estimate is based on 1961-1985. Using the same dataset, Adetunji and Bos (2006) find that in Sub-Saharan Africa as a whole, infant mortality rates declined from 149 per 1,000 live births in the 1960s to about 101 in 2005, an annual change of 1.2, about half our estimate. The difference in the estimates is likely due to the HIV/AIDS epidemic that has affected the region since the 1990's, during which the decline in infant mortality stagnated.

[5] The net nutrition approach would also include the effect of labor and other physical activity in childhood that consumes energy and reduces the remaining energy balance available for physical growth.

$$m_{it} = \sigma_t + \delta n_{it} + \gamma d_{it}, \tag{2}$$

where the time dummy σ_t reflects worldwide technological progress that may improve mortality outcomes, even with the same level of nutrition and disease environment.

The disease burden is not observed in our dataset. However, combining these two equations we can derive a relationship between adult height, nutrition and infant mortality when young.

$$h_{it} = f_i - \frac{\beta}{\gamma}\sigma_t + (\alpha - \frac{\delta}{\gamma})n_{it} + \frac{\beta}{\gamma}m_{it} + \varepsilon_{it} \tag{3}$$

This is the relationship we estimate. Note that technical progress in medicine that reduces infant mortality at a given level of nutrition and disease burden will show up as a downward time trend in height (controlling for nutrition and infant mortality).

To investigate this relationship, we run a regression showing how cohort adult height varies with infant mortality rates and average nutritional intake when the cohort was young. We do not assume a causal link running from infant mortality rates to adult height. Rather, as the equations above make clear, both should move together because they both reflect underlying changes in nutrition and the disease burden.

In our regression we include country-specific fixed effects. If we simply consider average height across countries, there is little evidence that better fed and healthier populations are taller. Indeed the opposite is true; Africa has the least healthy and most malnourished population, but it has the tallest adults (Deaton 2007). However, Akachi and Canning (2007) show that, when controlling for country-specific fixed effects, a higher level of nutritional intake and a lower infant mortality rate go hand in hand with a cohort having greater height. The country fixed effect may reflect genetic or environmental sources of variation in height across countries (Ruff 2002). At this point, there is little we can infer from the fixed effects and what they may mean. In principle, they represent country-specific, time-invariant, omitted variables that affect height. They may reflect genetic differences between the populations, but genetic effects alone are unlikely to be the sole cause of these significant fixed effects. There is also the omitted variable problem; the country fixed effects could capture forces such as inequality in nutrition, which are omitted from the model. It is also possible that a systematic measurement error in one of our variables creates country-specific shifts in the relationship, which are corrected by the fixed effects.

We also include a worldwide time trend to allow for technical progress that might change the relationship between the disease environment and infant mortality (for example, the development and use of oral rehydration therapy (da Cunha Ferreira and Cash 1990)). We estimate using weighted least squares, weighting each observation by the number of observations that go into our calculation of the average cohort height for that birth year, since larger samples give more accurate measures of the cohort's average height.

The regression result of the full model is shown in Table 5. This estimates a model where the infant mortality rate, and calorie and protein consumption when young determine adult height. We include these influences at birth and ages 5, 10 and 15, since exposures at different times during the process of physical growth can affect final height. The effects are estimated separately for Sub-Saharan Africa and the other developing countries. Table 6 reports a test of the joint hypothesis that infant mortality at any age during childhood has no effect on adult height (all coefficients on infant mortality in the regression are zero). We reject the null of no effect. A test that protein consumption does not matter is likewise rejected. However, we fail to reject the hypothesis that calorie consumption has no effect (that is, that all coefficients on calorie variables are zero). We therefore remove the calorie variables from the regression.

There has been some discussion on whether it is the protein or the calorie intake that matters more to physical growth. The literature review by Martorell (1976) concluded that protein-calorie supplementation is causally related to growth, and that the relative contribution of calories and proteins to the association depends upon which nutrient is limiting in the current diet. In other words, if protein intake is limiting, proteins and not calories are apparently beneficial for growth rates, and in contrast if calories are limiting, they alone seem to improve growth rates. On the other hand, the conclusion Hegsted (1971) draws from his review of the literature puts more weight on the calorie intake, saying that calorie needs eventually dominate all other needs and that the addition of protein to the diet is not useful in overcoming caloric deficits except as an expensive source of calories.

However, protein is often considered as the most important single nutrient affecting growth, and many experimental studies have covered its effect (Zerfas 1986, Allen 1994). In developing countries, protein deficiency is regarded as the main contributor to the stunting of growth in infants (Martorell & Habicht 1986). The impact of a high-protein diet on catch-up growth after recovery from shigellosis was evaluated in malnourished children by Kabir (1998), and the study found that it enhanced linear growth during the 6 months follow-up period.

The regression was then re-estimated without the calorie variables. Table 7 reports the results of tests for the age at which influences on adult height occur. We reject both the hypotheses that the environment at birth and the environment at age five have no effect. However, we cannot reject the hypotheses that factors measured at age ten and fifteen have no effect. Since these tests suggest that calorie consumption, and variables measured after age 5, do not have a significant effect on adult height, we remove them from our analysis.

Table 8 reports a regression on the relationship between average cohort height, the infant mortality rate, and average protein intake in the country in the year of the cohort's birth and at age five. In Sub-Saharan Africa, we find that lower infant mortality is associated with increased adult height; however, the individual coefficients on infant mortality at birth and age five are not statistically significant. Outside Sub-Saharan Africa, we find a much stronger link between low infant mortality rates at birth and adult height, both in terms of the size of the coefficients and their statistical significance. In both areas, we find average protein intake in childhood to be significantly associated with height in adulthood. In Sub-Saharan Africa, protein intake at birth seems most relevant, whereas in the rest of the developing world, protein intake at age five appears to be more important.

We find a significantly negative worldwide time trend. This negative time trend effect may reflect a changing relationship between health as measured by mortality rates and stature. This suggests the need for more detailed measures of health than mortality rates, in particular measures that reflect the disease environment and morbidity, to understand the evolution of height. However, the interpretation of the time trend remains an open question.

In Table 9 we report the sum of the estimated effects of each variable reported in Table 8, adding the effects at birth and at age five. This shows how much we would expect adult height to increase if protein consumption rose both at birth and at age five by the same amount. For protein intake, the cumulative effects are roughly similar in Sub-Saharan Africa and the rest of the developing world; the difference is not statistically significant. We estimate that an additional 100 grams of protein consumption per day per person throughout childhood is associated with an increase in height of approximately 2.6 centimeters in Sub-Saharan Africa and an increase of approximately 1.9 centimeters in the rest of the developing world.

The relationship between infant mortality decline and adult height in Sub-Saharan Africa appears to be different from that found in the rest of the developing world. A reduction in the infant mortality rate by 100 per thousand births is associated with an increase in adult height of approximately 1.5 centimeters in Sub-Saharan Africa but approximately 5 centimeters in other developing countries. This difference is statistically significant. The finding that the coefficient on infant mortality, β/γ in equation (3), is different in Sub-Saharan Africa and other developing countries means that either β, the effect of the disease environment on adult height, or γ, the effect of the disease environment on the infant mortality rate, differs across regions.

As Table 5 (and perhaps Table 8) estimates a model with considerable multicollinearity (with many coefficients non-significant), we run the same model but with just the health and nutrition variables at birth with no lagged variables. The results, shown in Table 10, are similar to those in Table 8. In addition, we conduct a test of coefficients with the null hypothesis that the effect for Sub-Saharan Africa does not differ from the effect for countries in other non-SSA countries. As expected, the tests for infant mortality rate and protein both reject the hypothesis that the effects for SSA countries do not differ from non-SSA countries. The test for calories marginally fails to be rejected (p-value=0.056).

These results suggest that the stagnation in adult height in Sub-Saharan Africa has two causes. The first is that while protein intake in childhood is significantly related to gains in adult height, there was little or no improvement in average food consumption in Africa between 1960 and 1985. The second is that in other regions of the world, reductions in infant mortality reflect a falling disease burden and are associated with lower childhood morbidity, the improved physical development of children, and greater stature in adulthood. In Sub-Saharan Africa, there have been large improvements in infant mortality rates, but these have translated into only small improvements in adult height. Therefore, reductions in infant mortality in Sub-Saharan Africa do not seem to have been strongly associated with a falling burden of disease and lower childhood morbidity. As close links have been found between adult height and adult survival rates (Crimmins and Finch 2006), this suggests that a different pattern of health improvements, focused on mortality rather than morbidity is emerging in Africa.

Recent Trends

Data on adult height are only available for cohorts born before 1985. For cohorts born after 1985, we do not yet know what their adult height will be, but can observe their early physical development. Table 12 shows changes in the percentage of children under five who are stunted (low height for age) as well as the time trends in infant mortality rates, calorie intake and protein consumption during the period 1985 – 2002. We find that the prevalence of childhood stunting is continuing unabated in Sub-Saharan Africa, while it is falling significantly in the rest of the developing world. This suggests that the stagnation in adult height in Sub-Saharan Africa will continue. The rate of decline in infant mortality rates, while remaining rapid in the rest of the developing world, has slowed in sub-Saharan Africa, reflecting HIV/AIDS mortality among children. The only bright spot is the significant increase in average calorie consumption in Africa, although this does not seem to be paralleled by any rise in protein intake. Pelletier and Frongillo (2003) find that, whereas around the world reductions in infant mortality rates tend to go hand in hand with reductions in the percentage of stunted children, in Sub-Saharan Africa this link breaks down: reductions in infant mortality do not lead to a lower percentage of stunted children. Harttgen and Misselhorn (2006) find a different relationship between infant mortality rates and children's physical development in Asia and Africa. Their results are consistent with our finding for adult heights.

4. Conclusion

In most of the developing world, and in the historical record of developed countries, there has been a steady picture of advances in infant mortality rates, improvements in nutrition, and increases in adult height, with all of these developments proceeding together. In Sub-Saharan Africa, however, we are seeing a very different pattern unfold. While there have been large reductions in infant mortality, nutrition intake and adult stature have not improved.

The health transition in terms of mortality-morbidity taking place in Sub-Saharan Africa appears to be driven by medical interventions that reduce mortality, rather than by nutrition improvements and broad based reductions in exposure to infectious diseases that would reduce morbidity. This has several implications. It reinforces the view that population health is multidimensional. Movements in mortality measures, such as infant mortality rates and life expectancy, may give a limited picture of how broader population health is changing. It appears that adult cohort height can be used, with caution, as an independent measure of population health in addition to other conventional health indicators such as infant mortality rate. Health is multi-dimensional, and each indicator of health could be measuring varying aspects of health.

This has implications for studies of the effect of health on worker productivity. In macroeconomic studies of the effect of health on economic growth (Bloom, Canning, and Sevilla 2004) life expectancy or adult mortality rates are often used as measures of population health, assuming that these measures are closely linked to adult height (Shastry and Weil 2003) as used in microeconomic studies (Schultz 2002). This assumption may be unwarranted. This also questions the convention of focusing on the use of mortality rate as an indicator of population health in international efforts, notably in the Millennium Development Goals (MDG), where the focal point has been on reducing the mortality rate and where nutrition has been seen as the "forgotten" MDG.[6]

Finally, the continuing child morbidity and lack of physical development may be highly significant for the future of the aging population in Africa. While the African population is aging (National Research Council 2006), there is strong evidence that the health of adults and the elderly is affected by their childhood health and nutritional status (Fogel and Costa 1997, Catalano and Bruckner 2006, Brush, Harrison, and Waterlow 1997, Blackwell, Hayward, and Crimmins 2001, Yi, Gu, and Land 2007). This suggests that the lack of nutrition and high levels of morbidity among children in

[6]World Bank, 2008:
http://web.worldbank.org/WBSITE/EXTERNAL/NEWS/0,,contentMDK:21627646~pagePK:34370~piPK:34424~theSitePK:4607,00.html

Sub-Saharan Africa may be producing unhealthy adults and a growing future health burden.

Table 1

Descriptive Statistics and Distributional Tests

Birth Cohort	**1960**	**1965**	**1970**	**1975**
Bangladesh DHS 2004				
Observations	201	285	368	396
Mean height	149.96	150.50	150.33	150.62
Standard Deviation	5.35	5.60	5.60	5.82
Skewness	-0.218	0.372	0.482	0.807
Kurtosis	2.63	4.16	4.24	6.33
Normality test: Shapiro-Wilk p-value	0.17	0.0012	0.0007	<0.00001
Bolivia DHS 2003				
Observations	376	440	496	538
Mean height	150.93	151.29	151.75	151.71
Standard Deviation	5.72	6.38	5.91	5.91
Skewness	-0.03	0.43	0.36	0.26
Kurtosis	3.42	4.29	3.20	4.02
Normality test Shapiro-Wilk p-value	0.215	0.00004	0.002	0.0005
Ghana DHS 2003				
Observations	102	144	151	187
Mean height	158.59	159.61	160.04	158.57
Standard Deviation	5.36	7.27	5.97	6.92
Skewness	0.23	-2.44	-0.08	-2.49
Kurtosis	2.56	20.90	2.90	21.27
Normality test: Shapiro-Wilk p-value	0.41	0.0001<	0.93	0.0001<

Table 2

Time Trends in Adult Height, Infant Mortality, and Nutrition Sub-Saharan Africa, 1961- 1985

Country	Adult Height (cm)	Infant Mortality Rate (deaths per 1,000 live births)	Calories (calories per capita per day)	Protein (grams per capita per day)
Benin	-0.001 (0.014)	-2.310** (0.037)	4.466 (2.486)	0.119 (0.068)
Burkina Faso	0.007 (0.007)	-2.110** (0.023)	0.643 (2.904)	-0.135 (0.088)
Cameroon	0.010 (0.012)	-2.249** (0.014)	8.697** (2.809)	0.008 (0.096)
Central Africa	0.069 (0.042)	-2.905** (0.098)	-2.321 (4.265)	0.180** (0.026)
Chad	-0.034* (0.016)	-3.033** (0.140)	-36.048** (2.845)	-1.360** (0.87)
Comoros	-0.054 (0.042)	-3.710** (0.040)	-8.055** (1.361)	0.371** (0.026)
Cote d'Ivoire	0.024 (0.023)	-3.806** (0.069)	22.622** (2.998)	0.403** (0.074)
Ethiopia	-0.068** (0.017)	-1.784** (0.018)	-3.795 (3.273)	-0.391** (0.109)
Gabon	0.016 (0.032)	-4.365** (0.112)	27.524** (1.725)	1.076** (0.069)
Ghana	0.018 (0.015)	-1.763** (0.026)	-18.089** (5.527)	-0.129 (0.148)
Guinea	-0.021 (0.023)	-2.149** (0.037)	-6.328* (2.119)	-0.051 (0.042)
Kenya	0.050** (0.010)	-2.258** (0.046)	-0.493 (2.248)	-0.319** (0.086)
Madagascar	-0.024 (0.017)	-0.300** (0.0001)	0.118 (1.565)	-0.234** (0.052)
Malawi	-0.005 (0.009)	-2.388** (0.063)	3.552 (3.536)	-0.018 (0.122)
Mali	0.015 (0.015)	-5.431** (0.172)	-13.782** (3.376)	-0.404** (0.090)
Mozambique	-0.011 (0.020)	-1.788** (0.060)	-2.912* (1.284)	-0.155** (0.036)
Niger	-0.015 (0.001)	-0.817** (0.048)	19.282** (2.399)	0.577** (0.107)
Nigeria	-0.010 (0.017)	-0.300** (0.0001)	-12.487** (2.781)	-0.280** (0.083)
Rwanda	-0.023 (0.012)	0.125 (0.071)	18.585** (2.419)	0.230* (0.091)
Senegal	0.074** (0.025)	-2.658** (0.134)	-6.115 (3.287)	0.012 (0.097)
Tanzania	0.005 (0.021)	-1.817** (0.039)	28.325** (3.361)	0.783** (0.081)
Togo	-0.008 (0.025)	-2.578** (0.031)	-9.458** (3.237)	-0.014 (0.081)

Uganda	-0.008 (0.018)	-1.019** (0.093)	-5.479 (2.781)	-0.124 (0.133)
Zambia	0.013 (0.013)	-1.322** (0.092)	-0.272 (2.781)	-0.334** (0.098)
Zimbabwe	-0.009 (0.023)	-1.474** (0.027)	1.673 (2.107)	-0.295** (0.084)

Coefficient of the time trend by country.
Coefficients represent per annum change. Standard errors in parentheses. Significance level indicated as *(5%), **(1%).
Height trends estimated with weighted least squares: weighted by the number of individuals used to calculate the cohort average height.

Table 3
Time Trends in Adult Height, Infant Mortality, and Nutrition
Non Sub-Saharan African Developing Countries, 1961- 1985

Country	Adult Height (cm)	Infant Mortality Rate (deaths per 1,000 live births)	Calories (calories per capita per day)	Protein (grams per capita per day)
Albania	0.179*	-2.058**	26.641**	0.801
	(0.050)	(0.096)	(2.356)	(0.070)
Bangladesh	0.007	-1.366**	-5.519*	-0.0007
	(0.006)	(0.094)	(2.119)	(0.037)
Bolivia	0.071**	-2.262**	15.255**	0.357**
	(0.005)	(0.106)	(1.981)	(0.048)
Brazil	0.062**	-2.264**	18.466**	0.217**
	(0.017)	(0.019)	(1.384)	(0.039)
Colombia	0.096**	-2.139**	16.721**	0.152**
	(0.004)	(0.070)	(2.334)	(0.004)
Dominican Republic	0.068**	-1.656**	23.076**	0.434**
	(0.001)	(0.040)	(1.055)	(0.030)
Guatemala	0.040	-2.125**	13.117**	0.091
	(0.024)	(0.046)	(2.068)	(0.046)
Haiti	0.044	-1.939**	3.085**	0.185**
	(0.020)	(0.031)	(0.905)	(0.023)
India	0.027**	-1.753**	6.021*	0.054
	(0.009)	(0.038)	(2.245)	(0.058)
Indonesia	0.081**	-2.396**	28.626**	0.753**
	(0.010)	(0.014)	(2.028)	(0.047)
Mexico	0.121**	-1.968**	37.350**	0.950**
	(0.011)	(0.033)	(1.846)	(0.092)
Morocco	0.085**	-1.899**	30.844**	0.734**
	(0.008)	(0.063)	(1.126)	(0.065)
Nepal	0.046**	-3.747**	7.908**	0.253**
	(0.010)	(0.071)	(1.557)	(0.036)
Nicaragua	0.028**	-2.464**	0.752	-0.331**
	(0.005)	(0.062)	(1.619)	(0.102)
Peru	0.086**	-2.991**	-2.154	-0.079
	(0.006)	(0.067)	(2.329)	(0.061)
Turkey	0.074**	-3.428**	19.735**	0.383**
	(0.019)	(0.156)	(1.348)	(0.049)

Coefficient of the time trend by country.
Coefficients represent per annum change. Standard errors in parentheses. Significance level indicated as *(5%), **(1%).
Height trends estimated with weighted least squares: weighted by the number of individuals used to calculate the cohort average height.

Table 4
Regional Time Trends in Adult Height, Infant Mortality, and Nutrition, 1961-1985

Region	Adult Height (cm)	Infant Mortality Rate (deaths per 1,000 live births)	Calories (calories per capita per day)	Protein (grams per capita per day)
Sub-Saharan Africa	-0.021** (0.003)	-2.120** (0.052)	0.394 (0.820)	-0.019 (0.025)
Other Developing Countries	0.066** (0.003)	-2.359** (0 037)	16.488** (0.795)	0.333** (0.022)

Coefficient reported on common regional time trend with country fixed effects.
Coefficients represent per annum change. Standard errors in parentheses. Significance level indicated as *(5%), **(1%).
Height trends estimated with weighted least squares: weighted by the number of individuals used to calculate the cohort average height.

Table 5
Determinants of Cohort Height: Full Model
Dependent Variables: Cohort Average Adult Height

	Sub-Saharan Africa	Other Developing Countries
Infant mortality rate at birth/100	-1.337 (1.114)	-3.230** (0.872)
Infant mortality rate at age five/100	-0.727 (1.811)	-1.301 (1.569)
Infant mortality rate at age ten/100	0.927 (1.495)	-0.885 (1.827)
Infant mortality rate at age fifteen/100	-0.237 (0.886)	0.677 (1.098)
Protein consumption at birth/100	4.312* (1.678)	-3.227* (1.637)
Protein consumption at age five/100	-1.556 (1.588)	0.878 (1.586)
Protein consumption at age ten/100	2.327 (1.545)	-0.458 (1.621)
Protein consumption at age fifteen/100	0.353 (1.417)	2.740 (1.588)
Calorie consumption at birth/100	-0.021 (0.056)	0.089 (0.051)
Calorie consumption at age five/100	0.018 (0.052)	0.030 (0.052)
Calorie consumption at age ten/100	-0.035 (0.046)	0.008 (0.053)
Calorie consumption at age fifteen/100	0.022 (0.042)	-0.083 (0.052)
Worldwide time trend (year)	-0.066** (0.010)	
Constant	165.408**(1.305)	
R^2	0.983	
N	754	

Data for 41 countries. Country fixed effects and worldwide time trend included. Coefficient estimates with standard errors in parentheses. Significance level indicated as *(5%), **(1%). Estimation with weighted least squares: weighted by the number of individuals used to calculate the cohort average height.

Table 6
Test of Coefficients for Infant Mortality Rate, Protein, and Calories

	Infant Mortality Rate	**Protein**	**Calories**
F test	F(8,688) = 18.55	F(8,688) = 2.06	F(8, 688) = 1.20
p-value	0.0000	0.038	0.293
Ho	Reject	Reject	Fail to reject

Table 7
Test of Coefficients for Ages

	Birth	**Age five**	**Age ten**	**Age fifteen**
F test	F(4,696) = 9.58	F(4,696) = 2.65	F(4, 696) = 1.16	F(4, 696) = 1.49
p-value	0.0000	0.032	0.328	0.204
Ho	Reject	Reject	Fail to reject	Fail to reject

Table 8
Determinants of Cohort Height: Final Model
Dependent Variables: Cohort Average Adult Height

	Sub-Saharan Africa	Other Developing Countries
Infant mortality rate at birth/100	-1.369 (0.904)	-3.343** ((0.743)
Infant mortality rate at age five/100	-0.165 (0.980)	-1.648* (0.766)
Protein consumption at birth/100	3.076** (0.715)	0.833 (0.912)
Protein consumption at age five/100	-0.475 (0.706)	2.704** (0.796)
Worldwide time trend	-0.068** (0.009)	
Constant	165.271** (1.058)	
R^2	0.983	
N	754	

Data for 41 countries. Country fixed effects and worldwide time trend included. Coefficient estimates with standard errors in parentheses. Significance level indicated as *(5%), **(1%). Estimation with weighted least squares: weighted by the number of individuals used to calculate the cohort average height.

Table 9
Long-Run Relationship between Infant Mortality, Nutrition and Adult Height in Developing Countries

	Sub-Saharan Africa	Other Developing Countries	Difference
Infant mortality rate (deaths per 1,000 live births)	-1.535** (0.449)	-4.992** (0.395)	3.457** (0 .332)
Protein consumption (grams per capita per day)	2.600** (0.895)	1.870 (0.843)	0.730 (1.238)

Calculated by summing the age specific coefficients in Table 7.
Standard errors in parentheses. Significance level indicated as *(5%), ** (1%).

Table 10
Determinants of Cohort Height: Environment at Birth Model
Dependent Variable: Cohort Average Adult Height

	Sub-Saharan Africa	Other Developing Countries
Infant mortality rate at birth/100	-0.620 (0.403)	-3.392** (0.375)
Protein consumption at birth/100	5.017** (1.553)	-1.385 (1.427)
Calorie consumption at birth/100	-0.073 (0.049)	0.073 (0.039)
Worldwide time trend (year)	-0.042** (0.008)	
Constant	164.082**(1.075)	
R^2	0.981	
N	774	

Data for 41 countries. Country fixed effects and worldwide time trend included. Coefficient estimates with standard errors in parentheses. Significance level indicated as *(5%), **(1%). Estimation with weighted least squares: weighted by the number of individuals used to calculate the cohort average height.

Table 11
Test of Coefficients for Infant Mortality Rate, Protein, and Calories between Sub-Saharan Africa and Other Developing Countries

	Infant Mortality Rate	Protein	Calories
F test	F(2,725) = 56.24	F(2,725) = 5.68	F(2, 725) = 2.89
p-value	0.0000	0.0036	0.0562
Ho	Reject	Reject	Fail to reject

Table 12
Regional Time Trends in Stunting (low height for age), Infant Mortality, and Nutrition, 1985- 2002

Region	Percentage of Children Stunted	Infant Mortality Rate (deaths per 1,000 live births)	Calories (calories per capita per day)	Protein (grams per capita per day)
Sub-Saharan Africa	-0.054 (0.123)	-0.669* (0.313)	7.740** (2.393)	0.072 (0.082)
Non Sub-Saharan Africa	-0.819** (0.118)	-2.230** (0.313)	7.006 (5.397)	0.246 (0.182)

Coefficient reported on common regional time trend with country fixed effects.
Coefficients represent per annum change. Standard errors in parentheses. Significance level indicated as *(5%), ** (1%).

Figure 1

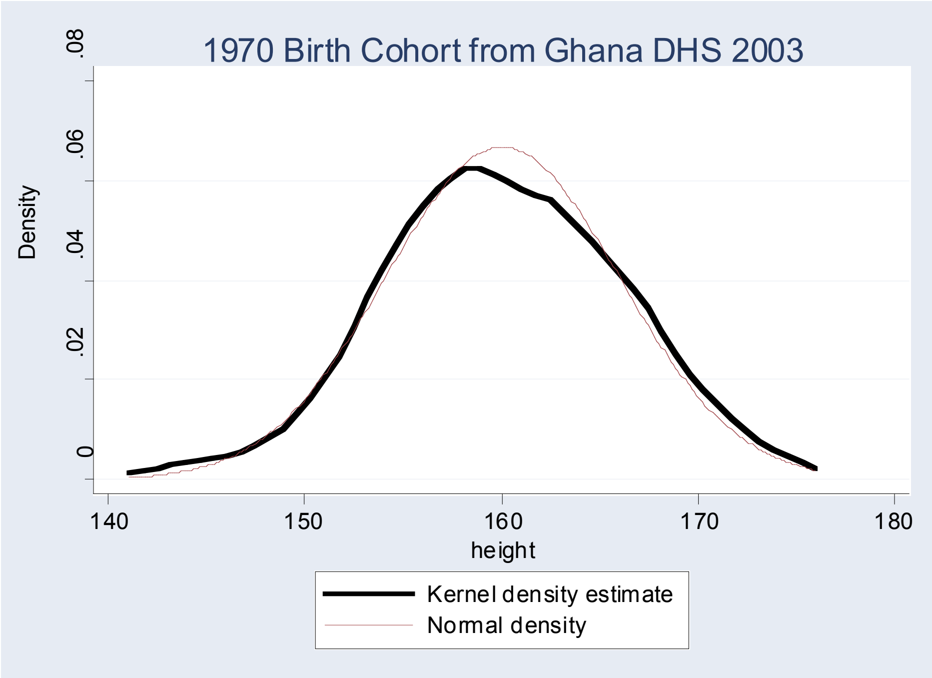


Figure 2

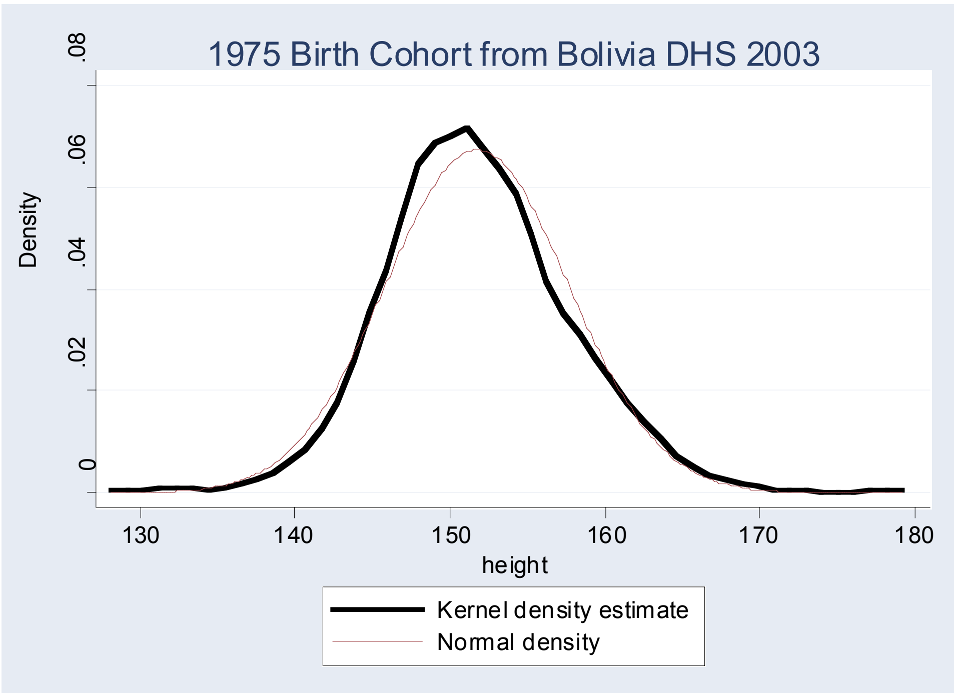


Figure 3

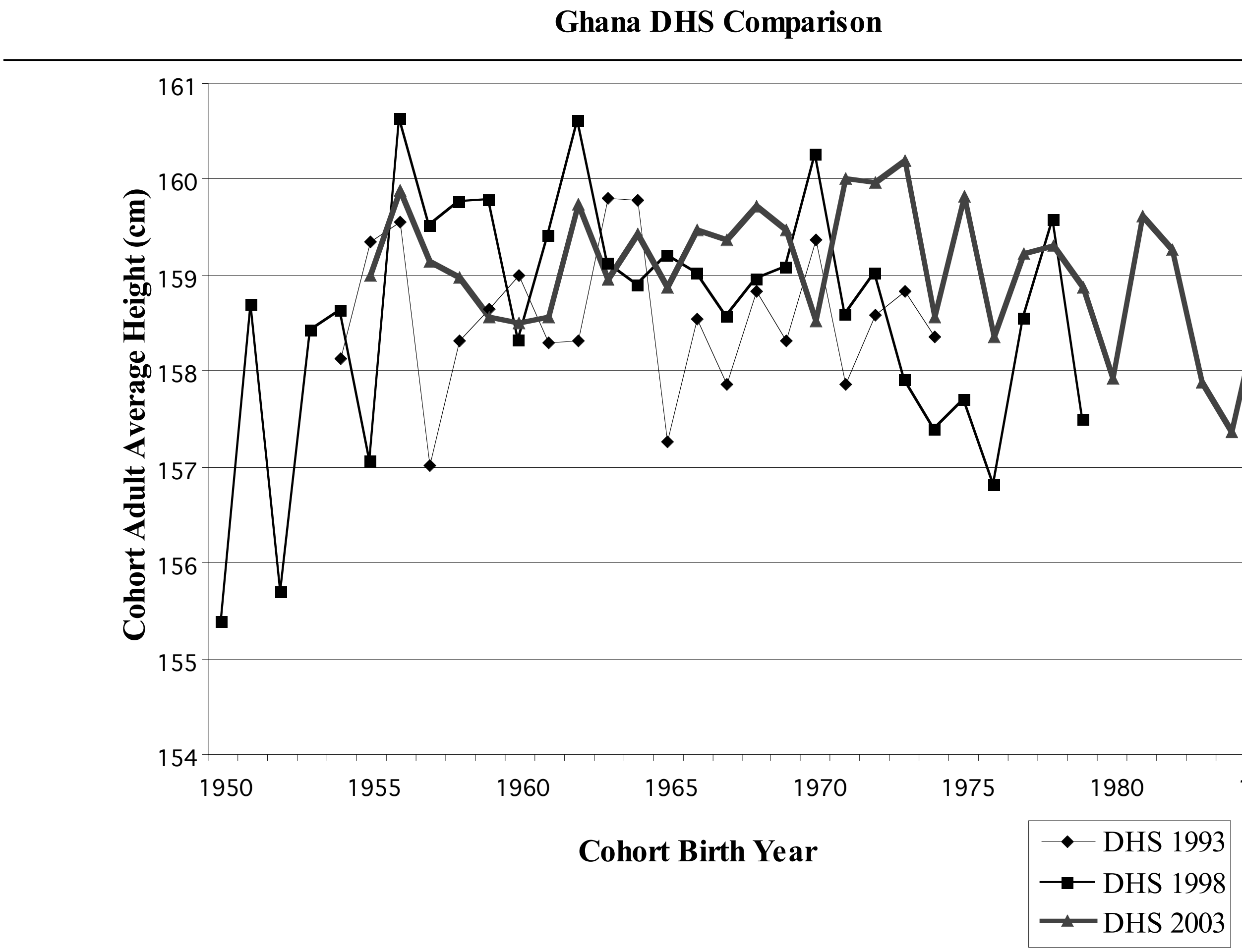

Ghana DHS Comparison
161
160
159
158
157
156
155
154
Cohort Adult Average Height (cm)
1950
1955
1960
1965
1970
1975
1980
1985
Cohort Birth Year
DHS 1993
DHS 1998
DHS 2003

Figure 4

Bolivia DHS Comparison

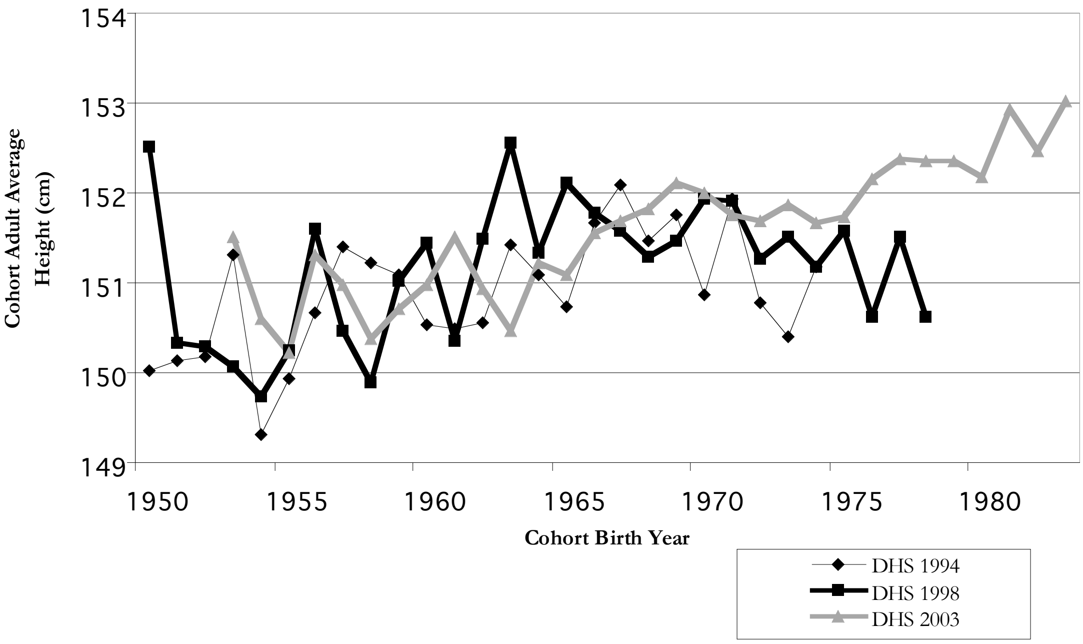
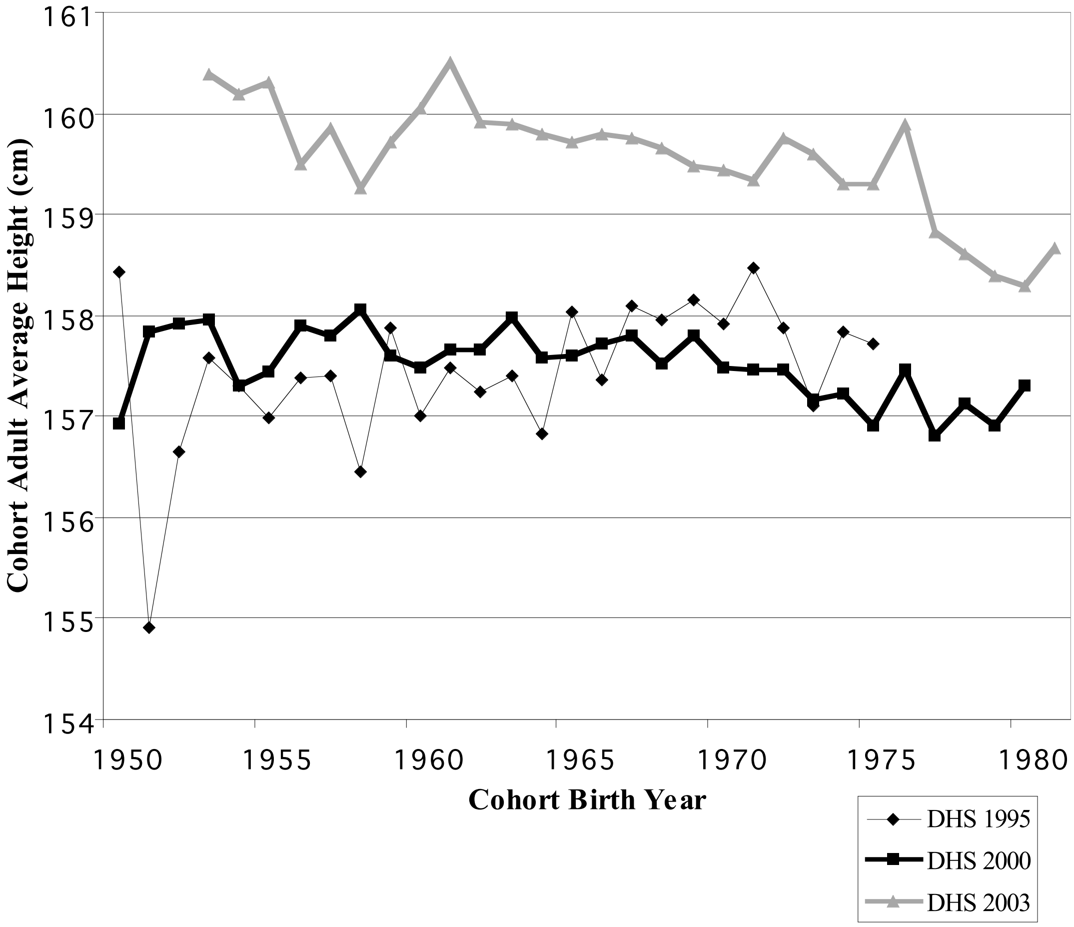


Figure 5

Egypt DHS Comparison



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