Childhood Health, Nutrition, and Average Adult Height in Low-Income Countries

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Background:
Adult height in individuals has been linked to health and nutrition in childhood, and to health outcomes in later life. Economists have used average adult heights as an indicator of the biological standard of living and as a measure of health human capital. However, it is unclear to what extent childhood health and nutrition are reflected in adult heights at the population level.

Methods:
We create a database of adult heights for twenty-nine low-income countries for birth cohorts born between 1945 and 1985. We study the effect of average protein and calorie consumption, and the infant mortality rate, on realized cohort adult height, allowing for country fixed effects, heteroskedasticity due to sampling variation in heights, and a time trend.

Results:
Most of the variation in height across countries is due to fixed effects, and there is a significant time trend in the relationship, while sampling variation in measured cohort height produces a low signal to noise ratio in the data. Taking account of these factors, we find that variations in cohort height over time are sensitive to changing health and nutrition at both birth and adolescence in low-income countries.

Conclusions:
The presence of large fixed effects means that it may be unwise to use population height as a measure of health and nutrition in comparisons across different populations. Changes in cohort height over time can be used as a measure of changing childhood health and nutrition, provided health is understood as morbidity rather than mortality.

Keywords: Infant Mortality, Nutrition, Height, Stature.

1. Introduction

There is extensive evidence at the individual level that childhood health and nutrition affect physical growth and height as an adult[1, 2]. In terms of nutrition, protein intake is often emphasized[3] though calorie consumption can also be a limiting factor[i, 4]. Infections in early life, particularly those that lead to diarrhea, can also affect physical development [5, 6]. Poor nutrition and disease can interact, with poor nutrition increasing the likelihood of infection and infection impairing nutrient absorption[7, 8].

The sensitivity of adult heights to childhood living conditions has led to the use of height as a measure of the "biological standard of living" in economic history when studying populations for which more conventional measures of living standards are absent[9, 1, 10]. The modern era appears to have witnessed a "techno physiological revolution" due to increased net nutrition (based on food consumption minus the demands placed on the body by work and disease) increasing physical robustness and labor productivity[11, 12, 13]. There is also evidence that in low-income countries, improvements in childhood health and nutrition that lead to greater adult height generate gains in worker productivity[14, 15].

While there is an established connection between childhood health, nutrition, and adult height at the individual level, it is less clear that population heights can be used as measures of population health and nutrition, though several studies have investigated the link[16, 17, ii, iii]. In cross section studies of counties in China, and across countries, greater average protein intake is

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[i] Hegsted, D. 1971. Protein and Calories. FAO/WHO Ad Hoc Committee of Experts on Energy and Protein: Requirements and Recommended Intakes, 22 March-2 April 1971, Rome.

[ii] Moradi A. 2002, Height and Health of Women in Sub-Saharan Africa and South-Asia 1950-1980. Paper presented at the XIII Congress of the International Economic History Association, Buenos Aires, Argentina.

[iii] Moradi A. 2006. The nutritional status of women in Sub-Saharan Africa, 1950-1980, mimeo, Centre for the Study of African Economies, Department of Economics, University of Oxford.

associated with greater average adult height[16]. Rising average cohort heights over time in Sweden, France and England in the 19th century are significantly linked to falling rates of mortality in childhood[17]. Variations in average heights in Sub-Saharan Africa are linked to economic growth, civil war, and openness to foreign trade [iii].

We investigate the relationship between nutrition, health, and cohort height in low-income countries using data from the second half of the twentieth century. We can distinguish between proximate determinants of adult height, including childhood health and nutrition, as well as genetic variation, and more distant underlying socioeconomic causes, such as income levels, cultural values, and public health measures, that operate via influencing the proximate determinants[1]. We focus exclusively on the proximate determinates of height and explain adult height by the intake of protein, calories, and the infant mortality rate during the cohort's childhood.

At the individual level there is evidence from developed countries that around 80% of variation in the heights of individuals can be ascribed to genetic factors[18, 19]. In comparisons of populations, however, there is a debate as to whether genetic variation is important; with some arguing that genetic potential for physical growth is the same across populations [iii] while others attribute variations in height and body shape between populations in different geographical areas to genetic differences caused by natural selection based on millennia of differential climatic influences[20]. We include country fixed effects to allow for genetic variation between populations, though these will also reflect any other factors that influence height that differ between countries but are fixed over time. We find these fixed effects to be highly significant. This result throws into question the literature that uses differences in adult heights between populations to make inferences about their relative nutrition and disease environment[21].

The effect of nutrition on height may start as early as fetal life[22] and nutrition and health in the first three years of life are highly significant for physical development[23, 24]. On the other hand, there are findings that health and nutrition in puberty also play a significant role in determining final height, with the possibility of catch-up growth if stunting takes place in early life[25]. We look at the effect of health and nutrition at birth, and ages five, ten, and fifteen and find that conditions at birth and age fifteen appear to be the dominant factors. We find that both infant mortality and nutrition in childhood play a role in determining cohort height though our aggregate data cannot distinguish whether calories or protein is more important.

Even after controlling for changes in health and nutrition we find a significant time trend in heights. This may be evidence of a changing relationship between health, as measured by mortality rates, and height. Some health advances may reduce mortality with little effect on morbidity and the stature of the survivors, while others may affect morbidity but not mortality. Even though heights may have a stable relationship with childhood morbidity, the link to infant mortality appears to change over time.

2. Data

All our data are taken from Demographic and Health Surveys (DHS)[iv]. All available DHS surveys for low income countries (as defined by the World Bank[v]) that include height as a variable were employed. Standing height, without shoes, is measured by the interviewer using a headboard. The typical DHS dataset measures the height of women from age 15 to 49. These are nationally representative samples; we use the sampling weights provided to construct average

[iv] Demographic and Health Surveys website 2005: http://www.measuredhs.com/

[v] World Bank website:
http://web.worldbank.org/WBSITE/EXTERNAL/DATASTATISTICS/0,,contentMDK:20420458~menuPK:64133156~pagePK:64133150~piPK:64133175~theSitePK:239419,00.html

height for each cohort. We use heights of women only from age twenty and above on the grounds that, in most cases, physical development has ceased by age twenty, and make no adjustments for shrinkage in height with age, which is likely to be very small over this range. The number of observations in a typical DHS data set is around 4000, though there is variation in sample size by age within a survey as well as across countries and time.

A complication is that while in later DHS surveys the height of all women 15 to 49 was measured, in earlier surveys only the height of mothers with children under 5 were taken. This creates a sample selection problem since mothers are not randomly selected; for example, if height is positively linked to high socioeconomic status, and high socioeconomic status is linked to low fertility, mothers will tend to be shorter than average. However, the almost universal high fertility found in low-income countries means that the bias will be small[iii]. In our check of data consistency we examine the height of each cohort as measured in different DHS surveys and find them remarkably similar despite some being for mothers while others include all women.

We examined the distribution of heights for each of our surveys. Table 1 shows some descriptive statistics for the distribution of cohort heights for cohorts born in 1960, 1965, 1970, and 1975 from the Bangladesh 2004 DHS survey. The standard deviation of individuals' heights is around 6 centimeters. There is some evidence of a positive (right) skew in recent cohorts and positive kurtosis (so that the peak of the distribution is higher and narrower, with fatter tails, than the normal). Tests of the hypothesis that the distribution is normal are accepted for 1960 but rejected for 1965, 1970, and 1975. Figure 1 shows the estimated distribution of heights of the cohort born in 1975 in Bangladesh, generated using a kernel estimator, showing a slight right skew and positive kurtosis relative to the normal distribution. 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[vi].

We construct 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. Examples for the DHS surveys of Bangladesh in 1996, 1999, and 2004 are shown in Figure 2. In most cases the results for different surveys were very similar. Note that the large differences in average heights between the early birth cohorts are based on small sample sizes.

In order to examine trends in height we ran a simple ordinary least squares regression separately for each country including a constant and a time trend. The results of these regressions are reported in Table 2. Most of the sample of low-income countries is in Africa, where trends in height are mixed. In Kenya and Senegal, we find evidence of an upward trend in cohort height; however, Chad, Ethiopia, and Rwanda appear to have a downward trend in height. Other low-income countries in Africa have no significant time trends. In Asia, India and Nepal have upward trends in height while heights in Bangladesh appear stable over time. Both the low-income Latin American countries in our sample, Nicaragua and Haiti, have upward trends in height. In addition to examining time trends, we also tested for autocorrelation. We found no evidence of pervasive negative autocorrelation in cohort heights[ii,iii] instead finding no autocorrelation (or in a small number of countries, very mild positive autocorrelation).

[vi] Jacobs J, Katzur T, Tassenaar V. On the efficiency of estimators in truncated height samples. University of Groningen, CCSO Centre for Economic Research, Working Paper 200408. 2004.

Our average height estimates are based on samples and are subject to sampling variation For an average based on a sample of size n the standard deviation in estimated average height is $\sigma/\sqrt{n}$, where σ is the standard deviation of heights in the population. The average cohort sample size is 315, but it varies from as low as 47 to as high as 1016. With a standard deviation in heights of around 6 centimeters this gives us a standard deviation in estimated cohort height of around 0.33 centimeters for cohorts with an average sample size, but a standard deviation as high as 0.87 centimeters for cohorts with small sample sizes and as low as 0.19 centimeters for cohorts with averages based on large samples. This sampling variation produces noise in the data and implies a low signal to noise ratio in short run movements in average height; most of the variation in average heights from year to year shown in Figure 2 is due to sampling error.

We compare heights with a number of indicators for health, nutrition, and income. For health we use infant mortality rate from the World Bank's World Development Indicators[vii], which gives data back to 1960; we linearly interpolated over gaps of one to two years to derive an annual time series. We use this as our measure of population health, though infant mortality depends on nutrition as well as the disease environment and so is not a pure health measure[24]. For nutrition we use daily average consumption of calories and protein from the World Food Organization FAOSTAT database[viii], with annual data going back to 1961.

[vii] World Bank 2005, *World Development Indicators*, Washington DC.

[viii] Food and Agricultural Organization, 2006, FAOSTAT data, online at http://faostat.fao.org/faostat/

3. Proximate Determinants of Height

We began by regressing average cohort height on the infant mortality rate, average protein intake, and average calorie intake at birth and ages five, ten, and fifteen. We also included a time trend and country fixed effects. The country fixed-effects were jointly highly significant. In all our reported regression we include fixed effects. In addition, we found strong evidence of heteroskedasticity, with the variance of the residual being inversely proportional to the sample size. We therefore use weighted least squares, with the weights being the sample size on which the average height is based (which is inversely proportional to the variance of the estimated average height). This gives more weight to observations for which the average height is based on large samples and which have a higher ratio of signal to noise.

Due to the high degree of multicollinearity between protein and calorie intake we found it difficult to precisely estimate the effect of either, though a joint test of the coefficients on protein and calorie intake rejected that they are all zero. We therefore construct a nutrition index by undertaking a factor analysis of calorie and protein intake and using the first principal component (which explains about 77% of the variation in these nutrient intakes).

Table 3 reports our results. In the regression reported in column 1 we find that the infant mortality rate at age fifteen is negatively related while nutrition at birth is positively related to adult height. Nutrition at age five appears to be negatively related to height, but a joint test that the coefficients on all the age five and ten variables were zero failed to be rejected. We therefore drop these variables from the regression. Column 2 reports a regression containing only health and nutrition indicators at birth and age fifteen. We now find that high infant mortality at both birth and age fifteen appears to reduce adult stature while good nutrition at birth increases final height. Nutrition at age 15 does not appear to be significant and is dropped in the regression reported in column 3.

We find a significant negative time trend. This time trends may reflect omitted variables. They may also reflect a changing relationship between health as measured by mortality rates and stature. This suggests the need for a more detailed measure of health than a mortality rate in understanding the evolution of heights.

There are large, and highly statistically significant, country fixed-effects in the data; the fixed effects account for around 90% of the explanatory power of our model. Table 6 gives the estimated fixed effect for each country in the regression reported in column 3 of Table 3. The fixed effects tend to be negative for countries in Latin America and Asia, but positive for countries in Africa. They are very large in magnitude, with a range of over 13 centimeters between Mali, where people are, on average, tall given its health and nutrition indicators and Bangladesh, where people are short given the environment. These fixed effects may reflect genetic differences between the populations, or some simple country specific factors that affect height but are not captured in our regressions. Whatever the cause, the fixed effects suggest that it is difficult to draw inferences about nutrition and health from comparisons of average height between populations from different countries. In addition, we find that excluding the fixed effects results in parameter estimates for the effects of infant mortality and nutrition that are very different, and sometimes the opposite sign, to those that we report, suggesting that including the fixed effects is important for understanding the relationship.

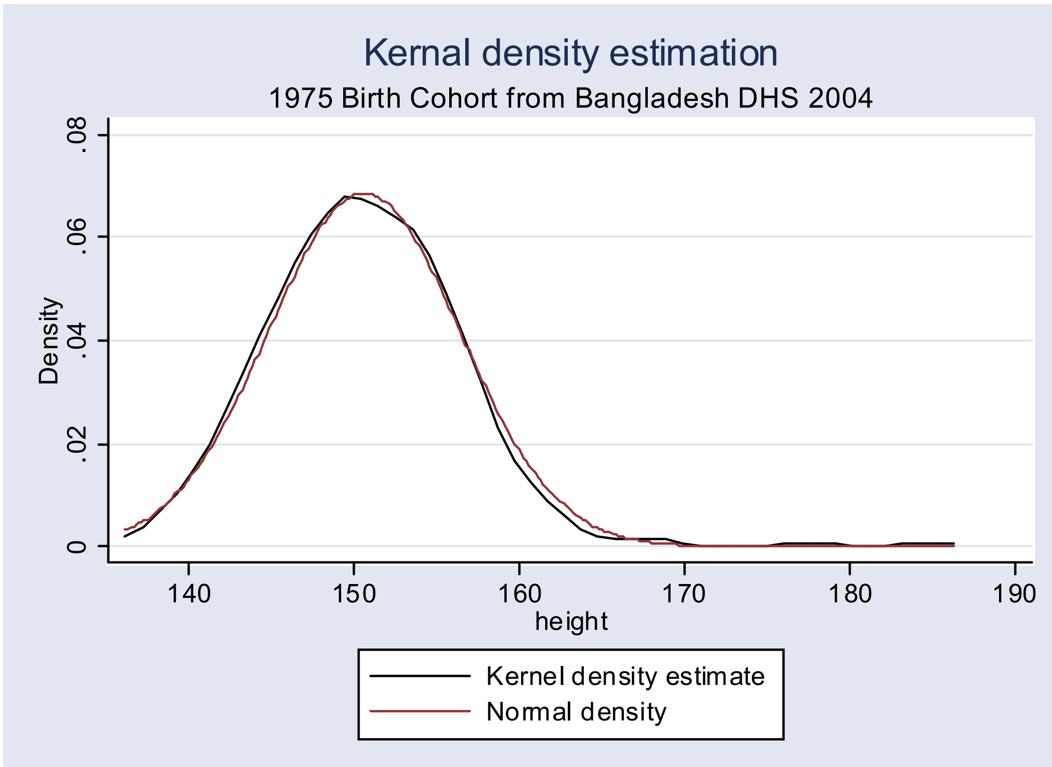
4. Conclusion

Cohort heights vary systematically with health and nutrition in low-income countries. Good nutrition and health conditions in infancy and in adolescence are positively related to average adult height. Our findings at the population levels are in agreement with studies at the individual level in finding nutrition and disease around the time of birth, and in adolescence, as being crucial to physical development. However, our understanding of the relationship at the population level is complicated by the presence of country fixed effects and a time trend. The country fixed effects indicate that care must be taken in using differences in height between countries as an indicator of differences in health and nutrition. The time trend suggests that the relationship also changes over time. This may be due to mortality rates and average height reflecting different dimensions of population health that advance at different rates during the epidemiologic transition. Adult height may be better thought as a different measure of population health than infant mortality rates, rather than simply a proxy for mortality when data is missing.

A weakness in our approach is that we do not take account of differences in the distribution of health and nutrition within countries and the impact of inequality on average heights. We lack the data on the distribution of health and nutrition required for such a study though it is likely that distribution matters for average outcomes.

Figure 1

Distribution of Heights



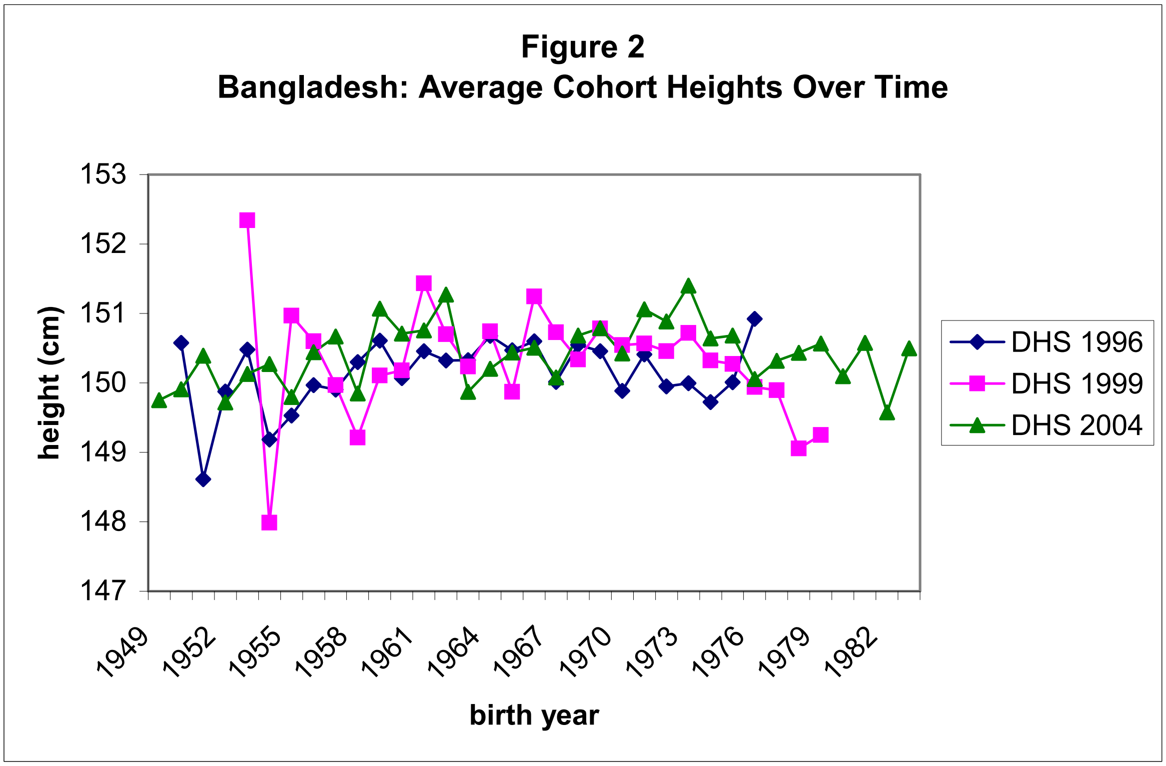


Figure 2
Bangladesh: Average Cohort Heights Over Time
153
152
151
150
149
148
147
height (cm)
1949
1952
1955
1958
1961
1964
1967
1970
1973
1976
1979
1982
birth year
DHS 1996
DHS 1999
DHS 2004

Table 1

Descriptive Statistics and Distributional Tests
Bangladesh DHS 2004

Birth Cohort	**1960**	**1965**	**1970**	**1975**
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

Table 2

Time Trends in Cohort Height

Africa

Country	Time	Constant	Cohorts	Data Source
Benin	-0.001 (0.014)	158.69*** (0.281)	1952-1981	DHS 1996 DHS 2001
Burkina Faso	0.007 (0.007)	161.44*** (0.169)	1958-1985	DHS 1998 DHS 2003
Cameroon	0.010 (0.012)	159.91*** (0.306)	1953-1984	DHS 1998 DHS 2004
Central Africa Republic	0.069 (0.042)	157.33*** (0.833)	1954-1974	DHS 1994
Chad	-0.034** (0.016)	163.35*** (0.372)	1949-1984	DHS 1997 DHS 2004
Comoros	-0.054 (0.042)	155.91*** (0.871)	1959-1972	DHS 1996
Cote d'Ivoire	0.024 (0.023)	158.55*** (0.447)	1953-1974	DHS1994
Ethiopia	-0.054*** (0.015)	156.97*** (0.285)	1945-1977	DHS 2000
Ghana	0.018 (0.015)	158.26*** (0.355)	1949-1984	DHS1993 DHS 1998 DHS 2003
Guinea	-0.021 (0.023)	159.17*** (0.489)	1949-1979	DHS 1999
Kenya	0.050*** (0.010)	158.39*** (0.231)	1945-1983	DHS1993 DHS 2003
Madagascar	-0.024 (0.017)	153.63*** (0.355)	1951-1977	DHS1997
Malawi	-0.005 (0.009)	156.18*** (0.191)	1950-1980	DHS 2000
Mali	0.015 (0.015)	161.18*** (0.287)	1949-1975	DHS 1995
Mozambique	-0.011 (0.020)	155.73*** (0.468)	1978-1983	DHS 1992 DHS 2003
Niger	-0.015 (0.001)	160.60*** (0.187)	1946-1978	DHS 1992 DHS 1998
Nigeria	-0.010 (0.017)	158.75*** (0.409)	1952-1983	DHS 1999 DHS 2003
Rwanda	-0.023* (0.012)	158.37*** (0.268)	1950-1980	DHS 2000
Senegal	0.074*** (0.025)	161.11*** (0.389)	1945-1972	DHS 1992

Tanzania	0.005 (0.021)	156.30*** (0.398)	1947-1976	DHS 1996
Togo	-0.008 (0.025)	158.97*** (0.505)	1948-1978	DHS 1998
Uganda	-0.008 (0.018)	158.51*** (0.388)	1946-1981	DHS 1995 DHS 2000
Zambia	0.013 (0.013)	157.90*** (0.283)	1948-1981	DHS 1996 DHS 2001
Zimbabwe	-0.009 (0.023)	159.55*** (0.417)	1949-1974	DHS 1994

Asia

Country	Time	Constant	Cohorts	Data Source
Bangladesh	0.007 (0.006)	150.16*** (0.133)	1949-1984	DHS 1996 DHS 1999 DHS 2004
India	0.027*** (0.009)	150.58*** (0.180)	1949-1978	DHS 1998
Nepal	0.046*** (0.010)	149.14*** (0.230)	1951-1981	DHS 2001

Latin America

Country	Time	Constant	Cohorts	Data Source
Haiti	0.044** (0.020)	157.43*** (0.357)	1948-1974	DHS 1994
Nicaragua	0.028*** (0.005)	153.44*** (0.112)	1953-1985	DHS 1997 DHS 2001

Coefficients, standard errors in parentheses, significance level indicated as *(10%), **(5%), ***(1%)
Time=Year-1950.

Table 3
The Proximate Determinants of Cohort Height

	1	2	3
Constant	162.15*** (1.16)	162.53*** (1.15)	162.33*** (1.14)
Year	-0.094*** (0.009)	-0.093*** (0.009)	-0.094*** (0.009)
Infant Mortality Rate at birth	-1.236 (0.933)	-1.928*** (0.396)	-1.922*** (0.397)
Infant Mortality Rate at age 5	-1.096 (1.571)		
Infant Mortality Rate at age 10	0.546 (1.296)		
Infant Mortality Rate at age 15	-1.597** (0.657)	-1.556*** (0.328)	-1.628*** (0.325)
Nutrition at birth	0.438*** (0.097)	0.395*** (0.095)	0.349*** (0.090)
Nutrition at age 5	-0.233** (0.097)		
Nutrition at age 10	0.121 (0.090)		
Nutrition at age 15	0.069 (0.083)	0.106 (0.072)	
N	535	535	535
R-squared	0.981	0.981	0.981

Data from 29 countries. Infant mortality rate divided by 100. Coefficients estimates with standard errors in parentheses, significance level indicated as *(10%), **(5%), ***(1%). We include a fixed effect for each country and each observation weighted by the number of heights used to calculate the cohort average height. The infant mortality rate is deaths (per 10 births) before age one, while nutrition is the first principle component of average protein and calorie intake.

Table 4
Estimated Country Fixed effects

Country	Fixed Effects
Bangladesh	-4.52***
India	-4.20***
Nepal	-3.90***
Madagascar	-3.03***
Nicaragua	-2.32***
Comoros	0.00(ref)
Tanzania	1.21
Mozambique	1.43*
Ethiopia	1.69*
Malawi	2.25**
Zimbabwe	2.31**
Zambia	2.51***
Uganda	2.53***
Rwanda	2.68***
Ghana	2.97***
Togo	3.17***
Kenya	3.29***
Nigeria	3.30***
Haiti	3.63***
Cote d'Ivoire	3.85***
Central African Republic	3.93***
Benin	3.98***
Cameroon	4.76***
Guinea	5.13***
Niger	7.42***
Burkina Faso	7.58***
Senegal	7.74***
Chad	8.15***
Mali	8.86***

From regression 3 in Table 3. Coefficients, significance level indicated as *(10%), **(5%), ***(1%)

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