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Selective Mortality or Growth after Childhood? What Really is Key to Understand the Puzzlingly Tall Adult Heights in Sub-Saharan Africa

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Abstract

Sub-Sahara African populations are tall relative to the extremely adverse disease environment and their low incomes. Selective mortality, which removes shorter individuals leaving taller individuals in the population, was proposed as an explanation. From heights of surviving and non-surviving children in Gambia, we estimate the size of the survivorship bias and find it to be too small to account for the tall adult heights observed in sub-Saharan Africa. We propose instead a different yet widely ignored explanation: African populations attain a tall adult stature, because they can make up a significant amount of the growth shortfall after age 5. This pattern is in striking contrast to other developing countries. Moreover, mortality rates are relatively low after age 5 adding further doubts about selective mortality.

1. Motivation

Mean adult height of a population is a measure of nutritional and health status. Numerous micro-level studies demonstrated that ill-health and malnutrition stunt body growth, with poverty being an important underlying determinant. One would expect to find similar results in the aggregate. However, when comparing mean adult heights across countries regional anomalies appear, particularly with respect to sub-Saharan Africa (SSA): Most African populations are tall despite their low levels of income and exposure to one of the most deadly disease environments in the world (Deaton, 2007; Moradi, 2010). Table 1 gives summary statistics of this paradox. The height-mortality paradox also exists across time: Infant mortality decreased in most parts of SSA 1950-1980, yet mean adult heights did not increase accordingly (Akachi & Canning, 2010; Moradi, 2010). Akachi and Canning (2010) argued that in SSA technological progress was centred on preventing mortality and did not much to reduce the type of morbidity that affects stunting. The 'African height paradox' is also visible in child anthropometry: Africa's prevalence of stunting (low height-for-age) is relatively moderate compared to the high levels of mortality and income poverty (Klasen, 2008).[1]

Recently, Deaton (2007) offered an explanation to reconcile high mortality and high mean heights within a 'framework of scarring and selection'. Scarring is the imprint that adverse disease and nutritional environments, proxied by mortality rates, leave in children's height. The scarring effect reduces adult height among survivors. Selection, in contrast, is the removal of frail and shorter individuals by mortality. Selective mortality increases the adult height of survivors. This is not a new idea in itself (e.g. Teller et al., 1979). However, Deaton's claim is new that the positive selection effect strongly outweighs the negative scarring effect in high-mortality environments, particularly in SSA, therefore making adults in this region so tall.

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[1] We will argue in section **Error! Reference source not found.** that the height paradox in adults is not just an 'adult version of the child malnutrition-child mortality puzzle' as reasoned by Bozzoli et al. (2009). The height paradox is much bigger in adults and is largely a result of extraordinary growth after age 5.

A large number of studies demonstrated the predictive power of anthropometric indicators on child mortality (Caulfield, Onis, Blössner, & Black, 2004; Fawzi et al., 1997; Pelletier, 1994; Rice, Sacco, Hyder, & Black, 2000). The correlation is particularly strong for weight-for-age and weight-for-height, less so for height-for-age. Nevertheless, there is no doubt that shorter children are more likely to die and that a survivorship bias exists. However, the extent of the bias is far from clear.

The question has important implications for the study of nutritional status of pre-school children and adults alike. Nutritional and health status is inferred from height measurements of living individuals, and the samples are often treated as if they were a proper representation of birth cohorts at birth. Survivorship bias can make inferences from such samples grossly misleading.

In a widely ignored study, Boerma et al. (1992) estimated the effect of the survivorship bias on the prevalence of stunting. From mortality odds ratios comparing stunted with non-stunted children Boerma et al. (1992) inferred that malnutrition rates increase by less than 1% if all children survive to age 5. Interestingly, they did not find a large difference between countries of different regions, for example the proportion of stunted children would increase by 0.1% (Sri Lanka), 0.4% (Egypt) and 0.7% (Bolivia and Mali) if all children survive to age 5.

In this article, we examine the extent of the survivorship bias on mean height of adults and whether the size is large enough to account for the puzzlingly tall stature in SSA. We propose another explanation which has not received enough attention so far: African populations attain a tall height at adults because they are able to make up a significant share of growth shortfall after age 5.

2. The extent of the puzzle

How large is the puzzle? Or in other words, how much ‘too tall’ are African populations? We can think of this as the Africa dummy. The regression coefficient of the Africa dummy indicates the average difference in height between SSA and non-SSA populations which cannot be explained by the regression model. The size of the Africa dummy may depend on i) the choice of reference category and thereby the sample composition and ii) the model specification.

We derived height data of women in developing countries from the Demographic and Health Surveys (Macro).[2] To complement our sample with richer countries, we added data from the Eurobarometer survey, which provides self-reported heights for all European Union member states (European Commission, 2005). All the surveys are nationally representative for the time when they were carried out. The mean heights are based on five-year age cohorts, with birth years centring in the early 1970s. Because Eurobarometer samples were smaller, we calculated mean heights from the age group 25-34. Our data is purely cross-sectional.

Some regression models may better explain the heights in SSA than others and reduce the coefficient of the Africa dummy.[3] We estimate a parsimonious model and focus on determinants in which context the paradox of African tall stature was placed.[4] We use protein supply and IMR, proxying nutrition and health conditions, and GDP/c (PPP) (FAOSTAT; Heston, Summers, & Aten, 2002; UN Population Division, 2009). Following the usual approach of birth cohort analyses the variables measure conditions at birth; values are averaged over the period the cohort was born.

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[2] DHS surveys did not measure the height of men. We used the STATCompiler extracting summary statistics from the following DHS surveys. SSA includes Benin 2006, Burkina Faso 2003, Cameroon 2004, Central African Republic 1994-95, Chad 2004, Comoros 1996, Congo (Brazzaville) 2005, Congo Democratic Republic 2007, Cote d'Ivoire 1998-99, Eritrea 2002, Ethiopia 2000, Gabon 2000, Ghana 2003, Guinea 2005, Kenya 1998, Lesotho 2004, Liberia 2007, Madagascar 2003-04, Malawi 2004, Mali 2006, Mauritania 2000-01, Mozambique 2003, Namibia 2006-07, Niger 2006, Nigeria 2003, Rwanda 2000, Senegal 2005, Sierra Leone 2008, Swaziland 2006-07, Tanzania 2004-05, Togo 1998, Uganda 2000-01, Zambia 2001-02, Zimbabwe 2005-06.
Non-SSA includes Armenia 2005, Azerbaijan 2006, Bangladesh 2004, Bolivia 2003, Brazil 1996, Cambodia 2000, Colombia 2000, Dominican Republic 1996, Ecuador 2004, Egypt 2005, El Salvador 2002, Guatemala 1998-99, Haiti 2000, Honduras 2005-06, India 2005-06, Jordan 2002, Kazakhstan 1999, Kyrgyz Republic 1997, Moldova 2005, Morocco 2003-04, Nepal 2001, Nicaragua 2001, Peru 2000, Turkey 1998, Turkmenistan 2000, Uzbekistan 1996 and Yemen 1997.

[3] In principle, one can enter into a quest for solving the Africa dummy. More precisely, one can test various regression models; the variable that turns the Africa dummy insignificant can explain African heights and solves the puzzle. However, the methodology is ill-suited to clearly identify the cause of the tall heights. SSA is unique in many ways. High mortality is just one. Other features include unique a disease environment, diet, underreported food supply, culture, genetics and growth after age 5. The methodology may return any variable that takes more or less unique values for Africa thereby essentially substituting the same.

[4] Coefficients may well be biased. If, for example, Deaton (2007) is correct and the selection effect dominates the scarring effect at high levels of mortality, the estimated influence of health conditions as proxied by IMR will be downward biased. At the same time this would increase the Africa dummy.

Bivariate correlations hold no surprises. IMR, protein supply and GDP/c all are significant and have the expected signs (column (1)-(4), Table 2). For a better comparability, we excluded states that were created in the post-1990 era in column (2), Table 2, as we lack data on proteins and GDP/c in the 1970s for those countries. The coefficient of the African dummy in the bivariate regressions is around 4. In a multivariate regression, we find IMR and protein supply still significant and with the expected signs whereas GDP/c becomes insignificant (column (5), Table 2). It is noteworthy that the size of the Africa dummy increased by about 1. One might object that the cluster of European countries may influence our estimate of the Africa dummy. When we exclude them and switch the reference category to developing countries, IMR loses its strength but the size of the Africa dummy does not change (column (6), Table 2). We take the latter estimate for the extent of the paradox: African women are 5 cm taller than one might expect from the nutrition and health conditions present at birth.

3. Selective mortality

How large is the effect of selective mortality? Can selective mortality really explain the variation in adult height observed in SSA? Studies that report heights of surviving and deceased children alike are most informative. Such studies, however, are rare.[5] One study where this was done is from Billewicz & McGregor (1982). Children from two villages in Gambia were followed from birth to maturity and height measurements were taken annually up to age 5. It is worth a look to obtain an estimate of the survivorship bias. Gambia is a high-mortality country: In 1960, 205 of 1000 infants died before reaching age 1; 360 children died before age 5 (World Bank, 2009). Equipped with the figures from Billewicz & McGregor (1982), reported in Table 3, we can do a

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[5] Most studies, like those cited in Pelletier (1994), use binary measures of child anthropometry (stunted yes/no) to predict mortality and report odds ratios. This study design does not allow calculating the impact on mean height. For a simulation of the effect of survivorship bias on the prevalence of malnutrition, see Boerma et al. (1992).
Unfortunately, we were not able to access original data. DHS surveys do not record the heights of children who died.

counterfactual: What would adult mean height be if IMR were reduced to 0 and all children were surviving?

Height of the total child population H at age i can be easily calculated by

$$(1) \qquad H_i = \frac{N_{si} H_{si} + N_{di} H_{di}}{(N_{si} + N_{di})}$$

where N_s and N_d is the number of survivors and deaths; H_s and H_d is the mean height of survivors and deaths in age group i respectively.

A few assumptions are necessary to calculate the effect on adult height. Firstly, mortality at ages later than 5 years can be ignored. This assumption is unproblematic as most deaths before adulthood occur in the age bracket 0-5 yrs. Secondly, there is no catch-up growth after age 5 so that we can infer mean adult height from that of children. According to which rule exactly, however, is not clear. Various behavioural relationships are plausible and found support in the literature (Li, Stein, Barnhart, Ramakrishnan, & Martorell, 2003; Schmidt, Jørgensen, & Michaelsen, 1995). We describe each in turn.

Presumption 1: There is no catch-up growth in absolute terms. Every centimetre that the child population 'lost' at each age i due to selective mortality will translate into a shorter adult height of exactly the same amount. Thus, we can aggregate the effect of selective mortality on adult height SM by

$$(2) \qquad SM = \sum_{i=1} (H_i - H_{si})$$

Using equation (1) and (2) and the figures from

Table 3 we find *SM* to be 2.1 cm and 2.2 cm for the male and female population respectively.

Presumption 2: There is no catch-up growth in relative terms. During the process of physical growth, a population's height distribution does not only shift to the right, its standard deviation also increases.[6] We address this issue by transforming heights into height-for-age z-scores (HAZ).[7] The trajectory of HAZ-scores in Gambia follows the pattern typical of most developing countries, whereby growth retardation starts a few months after birth and continues to an age of 2–3 years (Figure 1). Growth velocity at age 3-5 is roughly on par with the NCHS/ CDC reference population, as indicated by the nearly constant HAZ-scores. HAZ-scores of surviving males are smaller than the ones of surviving females, whereas HAZ-scores of deceased children did not substantially differ by gender. For the computation, we use equations (1) and (2) but replacing height *H* with HAZ-scores. We find *SM* to be 0.7 HAZ-scores for both, male and female population. This would imply an effect of selective mortality on adult height of about 5.2 cm and 4.4 cm for the male and female population respectively.[8]

Presumptions 1 and 2 assume a cumulative effect: As shorter than average children drop out of the population, it increases mean height of every subsequent cohort.

Presumption 3: Selective mortality does not have a cumulative effect. The child population that dies follows a specific height trajectory like the one in Figure 1. In other words, those children who died at age 1 would have achieved the same HAZ-score as children who died at later ages. At ages later than 2 yrs the HAZ-series of survivors and non-survivors run about parallel and trends in age are, if at all, negligible. We therefore use this age group to obtain an estimate of the difference in HAZ-scores. We estimate the following regression by OLS

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[6] In the Gambian sample from Billewicz & McGregor (1982), for example, standard deviations in the age groups below 5 years averaged 4.4 and 4.2 for surviving girls (boys), whereas height of adult men and women in the age group 20-45 years had a standard deviation of 5.5 and 6.4 respectively.

[7] HAZ-scores measure the distance, in standard deviations of the reference population, between the mean height of Gambia's population and the median of the reference population of equal age and sex. HAZ-scores were calculated using the command zanthro in Stata 10.1. The 2000 CDC Reference was chosen as reference population.

[8] Billewicz & McGregor (1982) found adult mean heights stagnating. Men had a mean height of 167.2 cm (HAZ: -1.35); women had a mean height of 157.7 cm (HAZ: -0.87). If presumption 3 is correct, it follows that without any deaths male population were 162 cm (HAZ: -2.08) and women were 153.3 cm (HAZ: -1.53).

$$(3) \qquad HAZ = \alpha + \beta D + u \qquad \text{for each sex}$$

where D is a dummy variable for children who died (1=yes, 0=no); β is our estimate of the difference in HAZ-scores between surviving and non surviving children. As estimate of β we obtain -1.015 (-0.685) for girls (boys) (column (1) and (3), Table 4). Our sample represents averages from a much larger sample of individual height measurements (Table 3). When weighting the data by the number of measurements, we obtain an estimate of β of -1.034 (-0.594) for girls (boys) which is very close to the unweighted regression (column (2) and (4), Table 4).[9] We now can use equation (1) to calculate the HAZ-score of the total population including those who dropped out due to mortality. From the U5MR of 360 in Gambia in 1960, we take N_d =360 and N_s=640. Then, we obtain an HAZ-score of -2.13 (-2.19) for the full population instead of the -1.77 (-1.97) for the surviving girls (boys). The *SM* of -0.37 (-0.21) for females (males) is not large. Adults with those HAZ-scores were 149.5 (161) cm instead of 151.7 (162.7) cm. This is very similar to the results under presumption 1.

To sum up, we simulated a huge reduction in mortality which has not been observed empirically. Nevertheless, the effect on adult height is large in only one of the three scenarios (under presumption 2). In the other scenarios, the effect of selective mortality is about 2 cm and too small to explain the estimated excess height of Africans of about 5 cm.[10]

While Deaton (2007) did not explicitly raise the point, there might also be a possibility of a longer run impact of selective mortality. Because growth retardation is a response to a harsh disease environment and scarce nutritional resources, in principle selective mortality does not need to select the ‘genetically short’, but the ‘environmentally disadvantaged, short’ individuals. However, it can well be that selective mortality put a continuous pressure on populations selecting the genetically tall. This type of evolutionary explanation needs some motivation however: What are the plausible

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[9] We also tested specifications where we added age and age squared to equation (2). In the weighted regressions, they were significant at the 5% level. The estimate of β decreased from -1.034 (-0.594) to -.962 (-.533) for girls (boys).

[10] Selective mortality also influences adult height in other developing regions, even if to a lesser degree. Therefore, our results cannot be interpreted as if selective mortality explains 2 of the 5 cm. It is rather an upper bound estimate.

channels for selection of genetically tall individuals?[11] It also raises questions as to why one can find tall and short populations on a relatively close neighbourhood. And finally, there is an emerging literature taking an historical perspective finding cases where adult height of African populations were remarkably transformed over a period of 50-70 years in the 20th century like the Kikuyu in Kenya (Moradi, 2009) and the population in Cote d'Ivoire (Cogneau & Rouanet, 2009).

Finally, there is another widely neglected, indirect channel of how mortality can positively influence a population's adult height. Micro studies found a negative correlation between the number of children in a household and their nutritional status (Desai, 1995; Rosenzweig, 1986). We can interpret such a relationship as sibling rivalry: When children die, the household size decreases; if total nutrition and health resources at the household level remain unchanged, the household will be able to spend more resources for the surviving siblings. This effect adds to the bias. The mean height of the same cohort of surviving children would be lower when moving to a low-mortality regime.[12]

4. Growth from childhood to maturity

In the previous section we assumed that there is no significant catch-up growth after age 5. We now present evidence that this is not the case in sub-Sahara African populations.

Originally, the issue was addressed by longitudinal studies that correlated height at different ages during childhood with height at adulthood. Studies typically found correlations between 0.2 and 0.3 at birth, rising to between 0.7 and 0.8 at age 2 and increasing only slowly afterwards, thus indicating that most of adult height is determined by age 2 (Schmidt et al., 1995). Moreover, it was observed that HAZ-scores typically decrease from delivery until approximately 24 months of age, after which they remain at the same level throughout (Li et al., 2003; Schmidt et al., 1995).

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[11] On patterns of growth and the influence of genetics, see Bogin (2001) and McEvoy and Vischer (2009).

[12] We are not aware of any longitudinal study that has properly quantified this impact.

We essentially follow this methodology with two important modifications. Firstly, we analyse populations instead of individuals. Secondly, we lack longitudinal data following individuals over the complete growth phase. We make comparisons between child and adult populations at the same point in time. Secular trends can therefore be mistakenly interpreted as catch-up growth: if a child population enjoys improved conditions, it will achieve a greater height during childhood than the adult population actually did at the time of their childhood. The opposite is true if conditions deteriorated. Thus, upward/downward trends in height of birth cohorts will let us under/overestimate catch-up growth.

We first obtain a glimpse on growth patterns by studying the development of HAZ-scores from birth to maturity using the Ethiopian Rural Household Surveys. The surveys covered 15 villages from the various agro-ecological zones in Ethiopia (Dercon & Hoddinott, 2004).[13] Within each village random sampling was used, stratified by female headed and non-female headed households. Heights of household members were measured in 1994 and 1997.

In the 1994 survey, HAZ-scores are stable in age cohorts 3–9 indicating that growth velocity is roughly on par with the NCHS/CDC reference population (solid lines, Figure 2). In the age cohort 9-11, growth of Ethiopian girls falls behind, primarily because the reference population enters the adolescent growth spurt, which is delayed in malnourished populations. Ethiopian girls however make up the shortfall when they enter puberty. In the age cohort 15-17 HAZ-scores have improved and the improvement continues into the age cohort 18-20. The pattern for boys is very similar, except that the adolescent growth spurt of boys occurs later and so the dip and the recovery of HAZ-scores occur later too. Ethiopian boys may also benefit from prolonged growth up into their 20s, which again is normal in malnourished populations. What is important is that HAZ-scores of girls (boys) improved from -1.85 (-1.85) in the age cohort 3-5 to -1.2 (-1.4) in adulthood. In other

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[13] Data available at http://www.csae.ox.ac.uk/datasets/Ethiopia-ERHS/ERHS-main.html

words, Ethiopians are taller in adulthood, relative to a reference population of the same age and sex, than in childhood.

We strongly believe that the peculiar trend in HAZ-scores is a true ‘age pattern’ and is not hugely affected by cohort effects (that older age cohorts were born during more favourable years than younger age cohorts). Plotting HAZ-scores of the same children from a second measurement three years later we find the pattern largely stable (dashed lines, Figure 2). Moreover, the order of magnitude makes cohort effects unlikely. An increase of 0.65 HAZ-scores, as observed in Ethiopian women, corresponds to about 4 cm of adult height.[14] Secular trends in heights seldom exceed 1 cm per birth decade and only under massively improved nutrition and health conditions. In the data, for example, we find HAZ-scores of the age group 24-49 stagnating in men and women.[15] Finally, the growth pattern in rural Ethiopia, as shown in Figure 2, does not seem to represent an exception. HAZ-scores in Cote d’Ivoire and Ghana follow very similar patterns (Moradi, 2010).

For assessing whether this pattern is indeed different to other developing regions, we use height data collected by the World Bank’s Living Standard Measurement Studies for Brazil 1996/97 and Guatemala 2000 (World Bank).[16] The former covered the Northeast and Southeast Region of Brazil whereas the latter is nationally representative. While the Brazil series shows a clear downward trend in HAZ-scores, Guatemala falls rather into the typical age pattern described by Martorell & Habicht (1986), whereby growth retardation occurs in the first 2-3 years of life and children fail to significantly catch up thereafter (Figure 3). The decrease in HAZ-scores by age can be described as a continuation of the secular trend present in the data. HAZ-scores in the age group 20-49 increase almost linearly by 0.09 and 0.13 per birth decade for girls respectively boys in Brazil and 0.05 per birth decade for both sexes in Guatemala.

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[14] We take individuals at age 20 from 2000 CDC Reference to calculate HAZ-scores for adults.

[15] HAZ-scores of men increase until 23. Prolonged growth must be considered part of the age pattern.

[16] The 2000 Guatemala Encuesta Nacional Sobre Condiciones de Vida and 1996-97 Brazil Pesquisa Sobre Padrões de Vida are available at http://www.worldbank.org/lsms/

The evidence so far point to the age around puberty when African populations catch-up and become tall. We lack comprehensive height data of teens to study this further. However, even comparisons of HAZ-scores between pre-school children and adults can provide valuable insights. If there is no catch-up growth, HAZ-scores of children who survived age 5 should be similar to HAZ-scores of adults. In the data of the two Gambian villages, for example, mean HAZ-scores of surviving children aged 4-5 yrs were -1.8 (boys) and -1.5 (girls). The HAZ-scores of adults, in contrast, were -1.35 (men) and -0.87 (women). As Billewicz & McGregor (1982) claimed that there was no secular trend in the two villages, there must have been some catch-up growth that improved final height of males by 0.45 HAZ-scores and that of females by 0.62 HAZ-scores.

We now use to the DHS surveys to test more fully how much HAZ-scores change from childhood to adulthood.[17] We correlate mean HAZ-scores of countries as follows:

$$(4) \qquad HAZ_i = \alpha + \beta HAZ_{i-1} \qquad \text{for each i}$$

where i=1, 2, 3, 4 denote the age groups 3, 4, 20-24, 25-29 yrs. If $\alpha=0$ and $\beta=1$, HAZ-scores are indeed stable as frequently assumed in the literature. If $\alpha\neq0$ and $\beta=1$, HAZ-scores change by a fixed amount indicated by α. Parameters $\alpha\neq0$ and $\beta\neq1$ describe other patterns. For an easier interpretation we use scatter plots: Data points above the 45-degree diagonal indicate improvements in nutritional and health status as measured by height.

We first study the sample of SSA countries only. There is little change in HAZ-scores between the age groups 3 yrs (hollow circles in Figure 4, horizontal axis) and 4 yrs (vertical axis). Correlation is very strong (Table 5). Improvements in HAZ-scores occur especially in those

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[17] We use the same DHS surveys as in footnote 2. Unfortunately, the STATCompiler does not report summary statistics of by age and gender. We therefore had the extract the HAZ-scores from the original data sets. This reduced the sample. Ecuador 2004, El Salvador 2002 and Turkmenistan 2000 were not available for download; Eritrea 2002 and Mauritania 2000-01 required special authorisation. Central African Republic 1994-95, Comoros 1996, Kenya 1998, Kyrgyz Republic 1997, Togo 1998 and Uzbekistan 1996 were dropped from the analysis, because they did not record heights of children older than 3 years.

countries with extremely low HAZ-scores; when excluding countries with a HAZ-score of less than -2 at age 3 yrs, the regression line almost perfectly fits the 45-degree diagonal.

The relationship between HAZ-scores of 4-year-old girls and women aged 20-24 yrs, in contrast, is very different (black squares in Figure 4). Firstly, all African countries are above the 45-degree line indicating that without exception HAZ-scores improved from child to adulthood. The extent of the improvement is by no means trivial: the difference in HAZ-scores averages 0.85 and is statistically significant (std: 0.36); if adult African women had the same HAZ-score like 4-year-old girls (-1.67), they would measure 152.5 cm instead of the 158 cm that they actually attained. Secondly, while there is a significant positive correlation, HAZ-scores are a not as strongly correlated as between 3 and 4 year olds or between 20-24 and 25-29 year olds (Table 5). This indicates a wide range of growth experiences: populations with very similar HAZ-scores at age 4 such as in Madagascar (-2.04), Democratic Republic of Congo (-2.12), Zambia (-2.01) and Niger (-2.07) have very different HAZ-scores of adults (-1.71, -1.19, -0.95 and -0.59 respectively).

Secular trends are unlikely to affect conclusions. Firstly, in the majority of sub-Sahara African countries the proportion of stunted children (with a HAZ-score below -2) hardly changed over the period 1990 to 2005 (de Onis, Blössner, Borghi, Morris, & Frongillo, 2004).[18] Secondly, trends in mean height in SSA rarely exceed one centimetre per birth decade (Moradi, 2010). In our sample for example, the HAZ-scores between the age groups 25-29 and 20-24 decreased by 0.08 on average. Secular trends can therefore not account for the improvement in height from age 4 to age 20.

The pattern in SSA stands in striking contrast to populations in other regions. When repeating the exercise for other developing countries, we find HAZ–scores across all the age groups 3, 4, 20-24 and 25-29 closely related (

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[18] De Onis et al. (2004) reported a noteworthy improvement only for Middle Africa, where the prevalence of stunted children (0-5 yrs) decreased from 42.2% in 1990 to 35.8% in 2005. Other regions in Africa were rather stagnant, e.g. Western (34.7% to 32.0%), Eastern (44.4% to 44.4%) and Southern Africa (25.4% to 24.3%).

Table 5, Figure 5). HAZ-scores are stable between age 3 and 4, and 20-24 and 25-29 with regression lines fitting the 45-degree line ($\alpha=0$ and $\beta=1$); the correlation between age 4 and 20-24 is somewhat shallower ($\alpha<0$ and $\beta<1$). For countries other than Africa a secular trend exists and may indeed systematically lift HAZ-scores of children (de Onis et al., 2004). Taking this into account, children in at least some of the non-African developing countries may even loose further on their way to adulthood (as HAZ-scores of adults exceed the ones of children even though the adult birth cohorts enjoyed less favourable conditions). Nevertheless, the general pattern comes relatively close to the common idea that height is determined at age 3.

Overall, our findings support a different explanation of tall statures in SSA: adult populations in SSA are not primarily tall because they were tall as children, but because growth velocity exceeded the one of the reference population and populations in other developing countries at ages later than childhood. We do not believe that the African growth pattern is due to genetics suddenly kicking in after childhood (though this cannot be ruled out). It could rather be a result of an improved diet and age-specific health environment at later ages. This could also explain why IMR is a poor predictor of adult height: the indicator simply fails to proxy for conditions at later ages. Moradi (2010), for example, found indeed that changes in mean adult height in SSA are strongly influenced by conditions around puberty, particularly economic growth: falling mean heights in mid-1960s and 1970s birth cohorts in SSA can be attributed to the economic crisis in the late 1970s and 1980s.

5. Conclusions

Current explanations for the ‘African height paradox’ have focused on missing or weak correlations between IMR and adult height. Akachi and Canning (2010) argued that there is a general discrepancy between health environments that lead to death and to stunted height. However, what seems to contradict their idea is that the correlation between height and IMR is essentially ‘lost’ on the way to adulthood. While Klasen (2008) demonstrated that the Africa height paradox also exists for child anthropometry, the paradox is much smaller. When applying the same explanatory models as in Table 2 for children, we always find IMR negatively correlated with height and highly significant (with t-statistics larger than 4). Thus, the link between morbidity, mortality and stunting seems to work in children.

Deaton (2007) argued that selective mortality outweighs the scarring effect caused by morbidity which is positively associated with mortality. We calculated the size of the effect of selective mortality on height of the surviving population in Gambia. Though we found that selective mortality makes the surviving population taller, the effect is too small to explain much of the excess height in SSA populations.

Comparing the height of children and adults suggest that growth after childhood is key to understand the puzzlingly tall adult heights in sub-Saharan Africa. At the current stage, we are not able to say what exactly it is that allows populations in SSA to catch-up. Childhood diseases play an important role in child undernutrition and adolescents might be less vulnerable to the adverse disease environment. It might be that children acquired some form of immunity after surviving childhood. In this case, the exposure to diseases is similar in adolescents and children but the impact on growth is reduced at the older ages. Alternatively, the disease environment varies with age and diarrhoea episodes, respiratory infections, etc. are less frequent in adolescents. One can also imagine that the intra-household allocation is more favourable to teens, e.g. because they contribute to household income. This suggests an important avenue of research. Longitudinal studies that follow individuals from birth to maturity are best suited to find answers. The strong emphasis on infant mortality to explain adult height, however, is misplaced. After all, it is the age after childhood, when African populations achieve their tall adult height, which is least affected by mortality.

Table 1: Adult height, mortality and income across regions

Region	Adult height (cm)	IMR	U5MR	GDP/c (PPP) $
Central Asia	159.1	80	120	
Sub-Saharan Africa	158.8	122	220	1,672
Middle East & North Africa	156.9	128	206	2,708
Latin America & Caribbean	153.3	95	151	3,208
South Asia	150.9	138	209	963

Note: Figures represent simple unweighted averages of country data within regions. Height data is based on women of 5-year age groups born in the early 1970s, see footnote 2 for details (Macro). Figures for mortality and income refer to conditions at birth (FAOSTAT; Heston et al., 2002; UN Population Division, 2009).

Table 2: OLS regression of adult height (in cm)

	(1)	(2)	(3)	(4)	(5)	(6)
Africa dummy	3.886***	4.109***	3.837***	4.526***	5.030***	5.037***
	(4.418)	(4.330)	(4.713)	(3.375)	(5.658)	(5.608)
IMR	-0.090***	-0.087***			-0.051***	-0.019
	(-11.708)	(-10.765)			(-4.258)	(-1.542)
Protein supply			0.213***		0.142***	0.099***
(gr/cap/day)			(11.862)		(5.916)	(3.578)
LnGDP/c				4.027***	-0.224	-0.478
				(7.456)	(-0.384)	(-0.854)
Constant	165.89***	165.43***	143.55***	125.37***	153.94***	154.20***
	(355.18)	(304.87)	(95.11)	(25.63)	(28.55)	(32.40)
Sample		Excl. newly formed states				Developing countries only
N	92	79	75	70	68	47
R^2-adj.	0.63	0.61	0.68	0.42	0.73	0.52

Estimator is OLS; robust t-statistics in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Note: See Table 1.

Table 3 Selective mortality in two Gambian villages (age 0-5 years)

	Males				Females			
Age	Height (survivors)	Height (deaths)	N Survivors	N deaths	Height (survivors)	Height (deaths)	N Survivors	N deaths
0.0-	59.9	57.5	135	44	57.8	56.9	133	51
0.5-	68.4	66.4	150	26	66.7	66.3	133	42
1.0-	74.1	70.2	158	24	72.9	69.7	153	32
1.5-	77.1	77.1	172	17	76.8	74.9	143	17
2.0-	82.1	79.1	150	24	80.9	76.0	149	17
2.5-	84.8	84.1	181	15	84.3	82.8	146	7
3.0-	88.9	86.9	154	5	88.6	84.5	142	7
3.5-	92.6	90.9	184	11	91.7	89.3	147	13
4.0-	96.0	96.7	151	3	95.8	89.7	147	4
4.5-5.0	99.2	88.9	181	1	98.7		135	0

Source: Billewicz & McGregor (1982).

Note: The study was longitudinal with children surveyed annually. Therefore, values in every second age group represent the progress of a cohort of largely the same children.

Table 4 Difference in HAZ-scores between surviving and non-surviving children (age 2-5 yrs)

	Girls		Boys	
	(1)	(2)	(3)	(4)
Died (0=no, 1=yes)	-1.015*** (-6.134)	-1.034*** (-3.843)	-0.685* (-2.160)	-0.594** (-2.299)
Constant	-1.763*** (-15.81)	-1.765*** (-28.64)	-1.969*** (-8.786)	-1.972*** (-32.32)
Weighted		Yes		Yes
N	11	11	12	12
R^2-adj	0.786	0.579	0.250	0.280

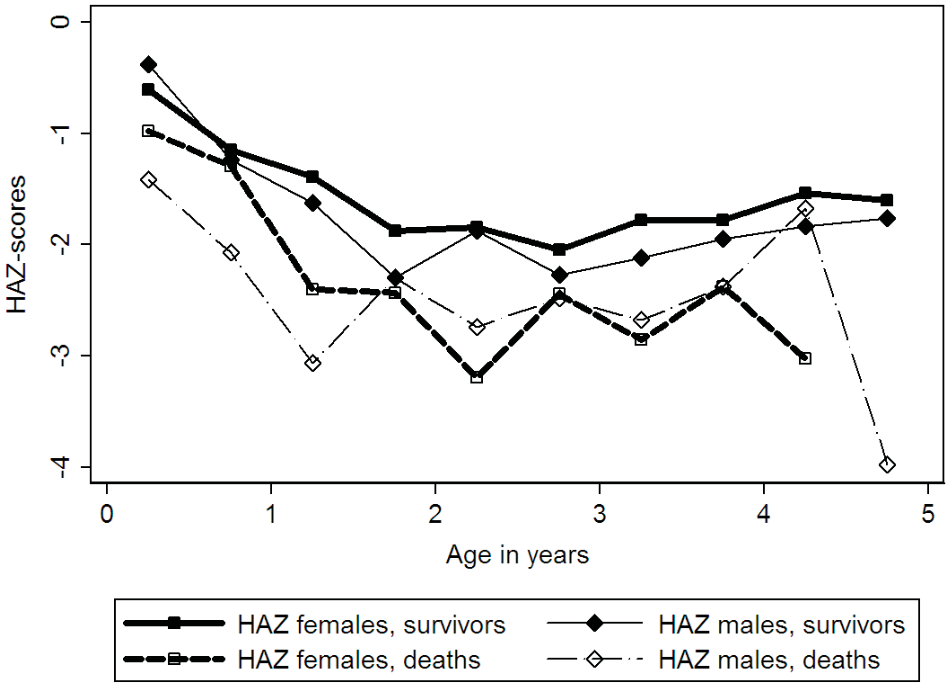
Estimator is OLS; t-statistics in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 5 Correlation matrix of HAZ-scores across age groups

	Sub-Sahara Africa				Other developing countries			
Age groups (years)	3	4	20-24	25-29	3	4	20-24	25-29
3	1.00				1.00			
4	0.89***	1.00			0.98***	1.00		
20-24	0.31	0.54***	1.00		0.84***	0.85***	1.00	
25-29	0.27	0.49***	0.98***	1.00	0.81***	0.82***	0.99***	1.00

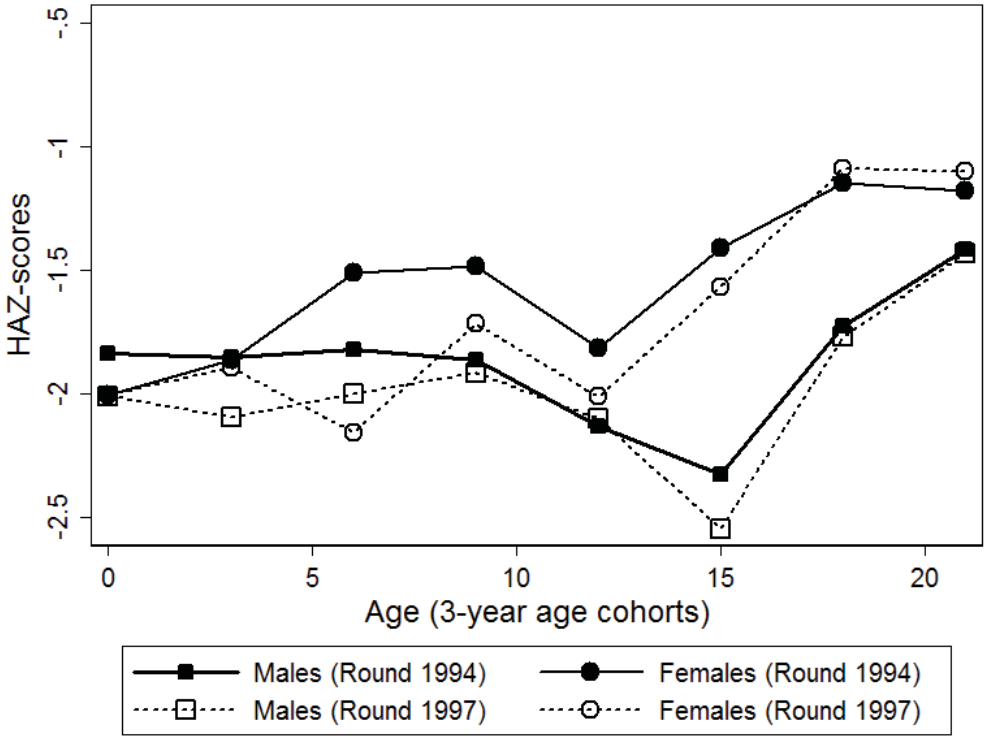
*** p<0.01, ** p<0.05, * p<0.1. N(Sub-Saharan Africa)=28, N(Other developing countries)=21.

Figure 1: HAZ-scores of survivors and deaths in two Gambian villages (age 0-5 years)



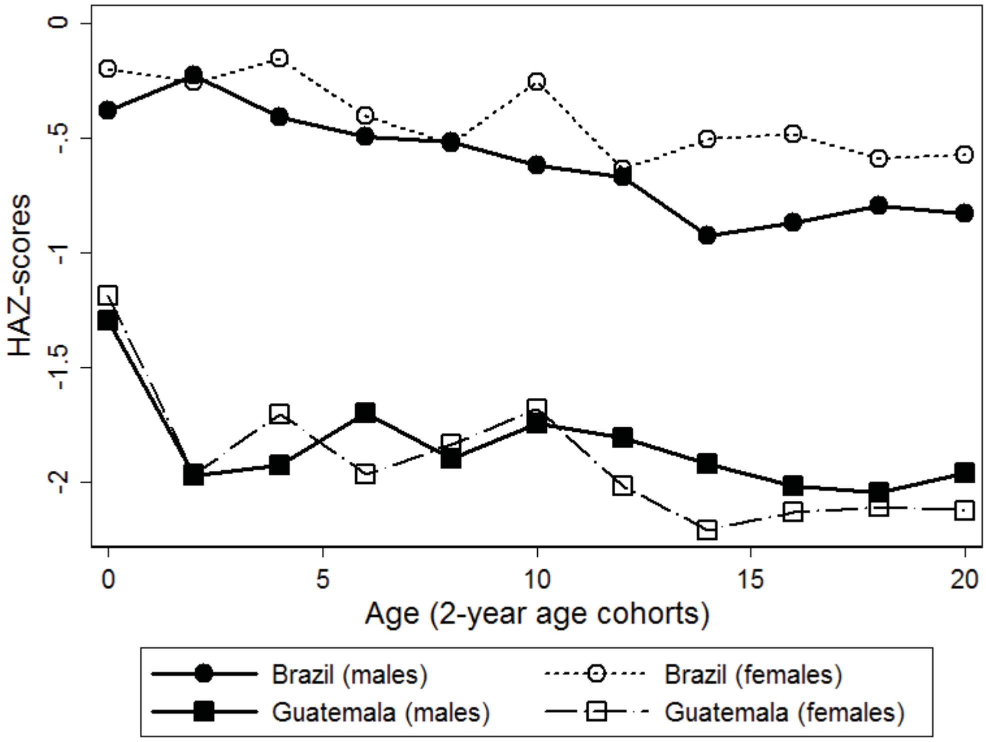
Source: Table 3.

Figure 2: HAZ-scores from birth to maturity in 15 Ethiopian villages



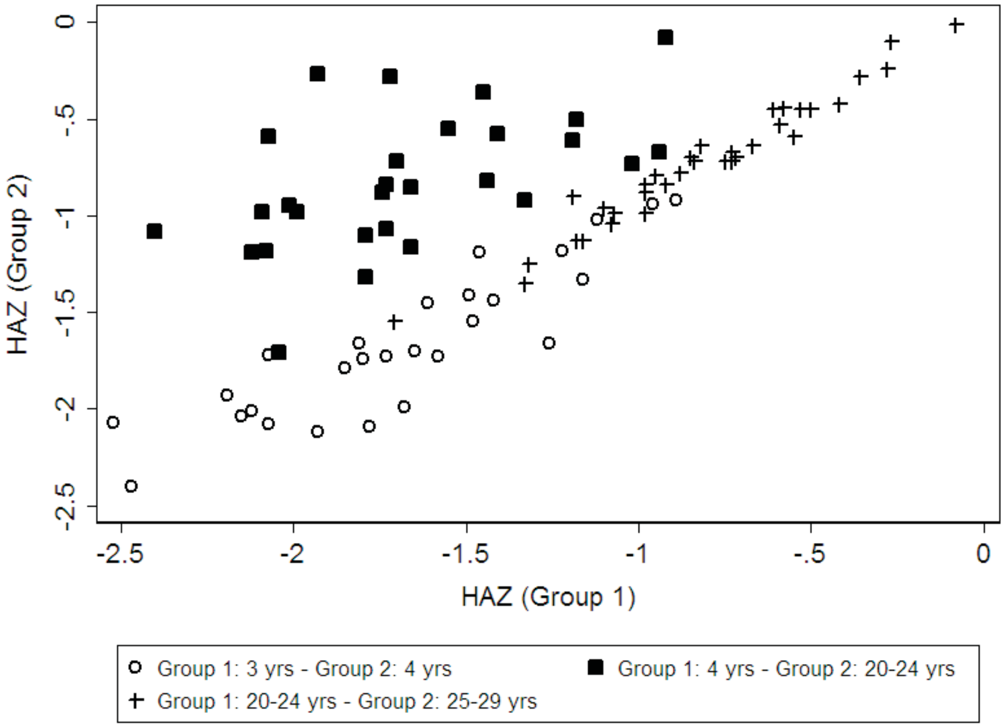
Source: Ethiopian Rural Household Surveys Round 1994 & 1997 (Dercon & Hoddinott, 2004). N(Round 1994 / 1997)=4152 / 3423. The study was longitudinal. Therefore, HAZ-scores in the next 3-age cohort of the subsequent round represent the progress of a cohort of largely the same children.

Figure 3: HAZ-scores from birth to maturity in Guatemala and Brazil



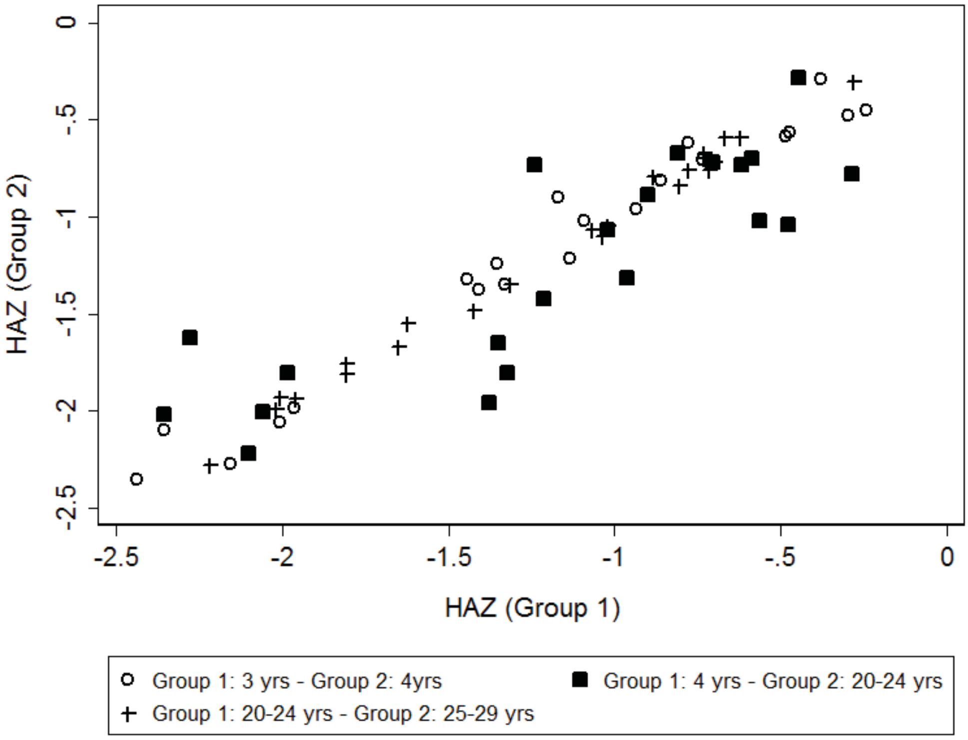
Source: 2000 Guatemala Encuesta Nacional Sobre Condiciones de Vida and the 1996-97 Brazil Pesquisa Sobre Padrões de Vida (World Bank). Studies are cross-sectional. N(Brazil /Guatemala)= 19799/ 8015.

Figure 4: Correlation between HAZ-scores across age groups in SSA populations (females)



Note: For data source and countries, see footnote 2 and 17. N=28.

Figure 5: Correlation between HAZ-scores across age groups in other developing countries (females)



Note: For data source and countries, see footnote 2 and 17. N=21.

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