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THE HEIGHT OF US-BORN NON-HISPANIC CHILDREN AND ADOLESCENTS AGES 2-19, BORN 1942-2002 IN THE NHANES SAMPLES

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ABSTRACT

We examine the height of non-Hispanic US-born children born 1942-2002 on the basis of all NHES and NHANES data sets available. We use the CDC 2000 reference values to convert height into Height-for-Age z-scores stratified by gender. We decompose deviations from the reference values into an age-effect and a secular trend effect and find that after an initial increase in the 1940s, heights experienced a downward cycle to reach their early 1950s peak again only c. two decades later. After the early 1970s heights increased almost continuously until the present. Girls born in 2002 are estimated to be 0.35[sigma] and boys are 0.39[sigma] above their 1971 values implying an increase of circa 2.5 cm between birth cohorts 1971 and 2002 as an average of all ages (Table 3). Age effects are also substantial - pointing to faster tempo of growth. Girls are c. 0.23[sigma] taller at age 11 and boys 0.15[sigma] taller at age 13 than reference values (Figure 3). This translates into an age effect of circa 1.7 cm and 1.3 cm respectively. Hence, the combined estimated trend and age-effects are substantially larger than those reported hitherto. The two-decade stagnation in heights and the upward trend beginning in the early 1970s confirm the upswing in adult heights born c. 1975-1983, and implies that adults are likely to continue to increase in height. We find the expected positive correlation between height and family income, but income does not affect the secular trend or the age effects markedly.

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Introduction

While the trend in the weight of US children has been extensively reported, that of their height has been less scrutinized even though it is a useful overall measure of biological well being (Waaler; 1984; Bogin 1991). Currently there are conflicting reports on the secular trend in the height of US children. For example, the new CDC reference charts for children released in 2000 were calculated on the premise that there was no trend in the height of children (Kuczmarski et al., 2002; Ogden et al., 2002; Roche, 1995, p. 4). However, this assessment was made mostly on the basis of data from the 1960s through the 1980s, and a subsequent NCHS report suggested that "mean heights… increased between the 1960s and 2002 with the mean height of boys 6-11 years of age increasing 0.8 inches and the mean height of girls 6-11 years of age increasing 0.6 inches. Among 12-17-year-old teens, the mean height of boys increased 0.7 inches while that of girls increased 0.3 inches although these findings were not statistically significant" (Ogden et al, 2004, p. 2). The above dates refer to measurement years which make it difficult to ascertain accurately when the increase actually began or more precisely what the shape of the trend was in the second half of the 20th century. Moreover, it is unclear how much of the above reported increase is due to a faster tempo of growth. Though limited in geographic coverage, a study of children in a ward of the town of Bogalusa, Louisiana, documented an increase in height of 0.7 cm per decade for children and also found that the "trends were most pronounced among preadolescents" (Freedman et al., 2000). Thus, there is some evidence that the height of US children have increased during the course of the second half of the 20th century, but the actual trend and the size of the increase has not been well researched and documented.

In contrast, evidence on adult heights indicates that heights stagnated for almost two decades beginning with circa the birth cohorts of 1955 among women and 1960 among men, but a positive trend might have started again among those born between 1975 and 1983 (Komlos and Baur 2004, Komlos and Lauderdale 2007), but the letter inference is based on relatively few observations. The evidence on children's and adolescent's heights enables us to test if the patterns obtained for adults can be replicated and also makes it possible to continue the trend past 1983 until 2002. Using children's and adolescent's trends we can predict if adult heights will continue to increase.

Data

We estimate for the first time the long-term trends in the height of US-born children stratified by gender and ethnicity on the basis of surveys collected between 1959 and 2004 by the National Center for Health Statistics (NCHS). The following surveys are used: National Health Examination Surveys: (NHES I: 1959-62, NHES II: 1963-65, NHES III: 1966-70) and the National Health and Nutrition Examination Surveys (NHANES I: 1970-74, NHANES II: 1976-80, NHANES III: 1988-94, and NHANES 1999-2004). Heights in the surveys are actual measurements, not self-reported values.The data pertain to birth cohorts from 1942 to 2002. We confine our analysis to non-Hispanic blacks and non-Hispanic whites born in the United States in order to obtain a degree of homogeneity in the sample. (Hitherto we drop the designation non-Hispanic for the sake of brevity.) Throughout the study we use the standardized height-for-age z-scores (HAZ) released by the Center for Health Statistics in 2000 as reference values (Kuczmarski et al., 2002). These references are based on data collected 1963-1994, i.e., the birth cohorts of c. 1942-1992.

We calculate HAZ values for each child aged 2-19 years in the surveys using the CDC 2000 reference values, stratified by gender: N = 19,143 girls and N = 19,805 boys. The HAZ values are calculated by using the nutritional component of the program "EPI Info" published by the Center for Disease Control. (If the age in months at the exam was not given, it was calculated as the difference between date of birth and date of exam.) Thereafter, we use these HAZ scores (weighted) for further analysis by gender and birth cohort. (We standardize the weights in the various surveys by dividing the weights by the average weight in that sample. We then use these weights in the further analysis.) The shortcoming of this approach is that it treats a one standard deviation (σ) change at all ages identically, whereas in actuality children's growth is not uniformly responsive to environmental effects at all ages. Nonetheless, the average HAZ values enable us to summarize trends and age effects in a convenient and easily recognizable fashion. We analyze blacks and whites together insofar as the former make up circa 15% of the total sample and therefore do not affect the main results substantially, even though their growth differs in important respects from that of whites.

Descriptive Statistics

The CDC 2000 reference values are quite close to actual mean values for the first three surveys (1959-1980) (Table 1). The slightly positive values of c. 0.07σ are due to the fact that our sample is restricted to US-born non-Hispanic children, while the reference values pertain to all children living in the US. However, the children in the most recent surveys (1988-1994 and 1999-2004) are uniformly shifted upward, i.e., are taller than the reference values by 0.21σ to 0.30σ for boys and by 0.21σ to 0.23σ for girls (Figures 1 and 2, and Table 1).

Table 1 and Figures 1 and 2 about here

However, at some ages the discrepancy is greater. Particularly at ages 4 and 5 and again at 10 and 11 the girls are 0.5σ-0.6σ taller in the most recent survey. Given that the σ's are 5-8 cm, the differences can be substantial: they are about 2.3 cm for ages 4 to 5 years and c. 4.5 cm for ages 10 and 11. This indicates that the girls experience a larger adolescent growth spurt than in the previous surveys and that their final height is also somewhat above the reference value by 0.21σ or c. 1.4 cm (Figure 1). The height of boys is more consistently above the reference values. The greatest increases of about 0.5σ are at age 5, 11, and 15 (Figure 2). This implies an upward shift at these ages similar to that of girls, and the final height of boys is also around 0.16σ above the reference values (if one averages the values obtained at ages 18 and 19).

Method of Decomposing age and time effects

The upward shift of the HAZ values described above is composed of an age and a time effect. To study these more systematically we use a non-linear regression model that enables us to estimate these effects by smoothing adjacent values of a coefficient using polynomial splines for non-linear effects. We use BayesX, a “freeware” computer program (Brezger, Kneib, Lang, 2005; Brezger, Lang, 2006; Lang, Sunder 2003). BayesX estimates fixed effects as well as the functional relationships between the dependent and independent variables of interest. The advantage of these models is that a parametric structure is not superimposed upon the data, i.e., it is not specified *a-priori*. Thus, we do not assume, for example, that the height increased linearly or as a polynomial. Rather, the functional relationship (in addition to the fixed effects) is flexibly determined by the data rather than being determined in advance. In the basic model we allow only for ethnic fixed effects, as well as for flexible functions of age (f_1) and of the year of birth (f_2) to influence the HAZ-scores. We estimate the following additive model separately for males and females:

(Eq. 1) $$HAZ = \gamma_0 + \gamma_1 \cdot Black + f_1(AGE) + f_2(BYEAR) + \varepsilon$$

where γ_0 and γ_1 are constants, *Black* is a dummy variable for African-Americans, *AGE* is the age of the person at the examination in months, *BYEAR* is the year of birth and f_1 and f_2 are functions to be estimated.

As an extension of the above model we consider that part of the secular trend in height could be due to an increase in income insofar as household income is generally associated positively with taller children. We can control for income by estimating the following model again separately for males and females:

(Eq. 2) $$HAZ = \gamma_0 + \gamma_1 \cdot Black + f_1(AGE) + f_2(BYEAR) + f_3(PIR) + \varepsilon$$

where the symbols are the same as in Eq. 1, and f_3 is a function to be estimated and *PIR* is the household's poverty income ratio, a measure of income adjusted for inflation and for household size (http://www.census.gov/hhes/www/poverty/threshld/thresh05.html). (In order to explore the validity of these models we also estimated ordinary least square regression models with 2nd degree polynomials in both age and PIR. We find that heteroscedasticity-robust standard errors only deviate marginally from the original ones, so that heteroscedasticity is not likely to be a serious problem for our estimation. We clearly prefer the spline approach, however, because the age-specific differences from the reference standard (Figures 1 and 2) exhibit much more non-linearity than a parsimonious polynomial specification could capture.)

Results of the Multivariate Analysis

The estimated constant in Eq. 1, γ_0, is 0.057 for girls and 0.075 for boys. They imply that on average children are taller than the reference values (all ages for the whole period) by these amounts (Table 2). This is due in part to the fact that we are considering only US-born children, but also because the reference values are for a shorter period than the sample we are using. The coefficient of ethnicity implies that on average black girls are 0.169σ taller than white girls and that black boys are 0.062σ taller than white boys (Table 2).

Table 2 about here

We report the estimated values of the function f_1 in Eq. 1 by way of a graph (Figure 3). We added γ_0 to the estimated values of f_1 as γ_0 pertains to all ages. We do the same with γ_1 except we weight it with the share of blacks in the sample (0.152). The age effects are smaller than those implied by the descriptive statistics as one would expect because the descriptive statistics also include the secular trend. However, both genders are markedly taller than the reference values at age 5 among girls and at age 6 among boys. The age effect is particularly large among girls ages 10-12 years: they are nearly 0.23σ above the reference values. Among boys the effect occurs somewhat later and is less pronounced but lasts longer throughout adolescence. Their maximum of 0.15σ is reached at ages 13 and 14 years. The 95% confidence intervals are also sketched for boys in order to show that the age effect is significantly different from zero at most ages. The confidence intervals are not shown for girls nor in the other graphs for sake of clarity, but they are all about the same magnitude as those for the boys shown in this diagram. The age effects are in addition to the secular trends depicted in Figure 4 which affect all ages.

Figures 3 and 4 and Table 3 about here

The secular trend is estimated by f_2 in Eq. 1 (Figure 4). These reflect the trend in height of the children in our sample averaged for ages 2-19. (The graph has been adjusted for the estimated coefficients of the black dummy variable weighted by their share in the population.) The estimates indicate that heights increased until c. 1950 among girls and 1951 among the boys (Table 3). Thereafter, there was a declining tendency and more so among boys than girls. The trends again reached their previous peak among boys around 1969 and among girls in c. 1971. Thereafter height of girls increased until 2002, while boys increased somewhat faster after the late 1970s but ceased to grow toward the very end of the period under consideration. There was a short period in the early 1980s when the rate of change slowed for both genders. In 2002 girls end up being 0.26σ above and boys 0.29σ above the CDC 2000 reference values.

The predicted HAZ level for a certain age and birth year can be obtained by adding the respective values from Figures 3 and 4. The combined HAZ levels are to be multiplied by the standard deviations for that age in order to convert the HAZ values into centimetres. For example, for a two-year-old girl born in 2002 the combined HAZ value becomes 0.19 (=0.26-0.07) and given the σ of 5.1 cm, the estimated level becomes c. 1.0 cm above the reference value.

The estimated constants for Eq. 2, γ_0 and γ_1, are reported in Table 4. The inclusion of PIR does not change appreciably the shape of the estimated secular trend effects (Figure 5). Holding income constant the trend among girls would have been somewhat lower by 2002 (0.04σ), and it would have taken both boys and girls a few years longer to regain the height losses that they experienced in the 1950s and early 1960s (Table 3). The age effects change very little and are therefore not reported here.

Figure 5 and Table 4 about here

The income effect is estimated by the function f_3 (Figure 6). As one would expect height increases with income in most range of income and the effect is substantial; the difference is about 0.4-0.5σ between the poor and the rich. In other words, the income effect is about the order of magnitude of the combined age and trend effects that have been experienced between 1942 and 2002. However, the pattern has two unusual aspects to it: a) the decline in height among the boys between 0 and 0.4 PIR, which may well be due to misclassification, to small number of observations, or perhaps because these are children of students who do not yet earn much income; and b) the heights of both boys and girls decline with very high incomes: maximum is reached among girls at c. 3.7 PIR and among boys at c. 4.4 PIR. This suggests that there are diminishing returns to income but the slight decline is mysterious and needs further investigation.

Figure 6 about here

Conclusion

We document the secular trend and age-dependent shifts in the height of US-born black and white children born 1942-2002 by comparing their HAZ scores on the basis of the CDC 2000 reference values. We find that heights increased in the 1940s, only to decline in the 1950s but did recover by c. 1971 (Figure 4). The cause of this fluctuation is mysterious, but insofar as it coincides with the baby-boom generation it might well be related to that development. The period of stagnation become longer when we control for household income, implying that the rise in income did contribute to overcoming the declining tendency (Figure 5). After c. 1971 a positive secular trend in height was continuous until 1999 among boys and until 2002 among girls.

The CDC reported a change of 2.0 cm and 1.5 cm in the mean height of boys and girls aged 6-11 years between the 1960s and 2002. Among 12-17-year-old teens, the mean height of boys has reportedly increased by 1.8 cm and of girls by 0.8 cm respectively (Ogden et al, 2004, p. 2). In contrast, our results for the secular trend for black and white non-Hispanic US-born children are: 0.35σ for girls and 0.39σ for boys as an average of all ages (Table 3). This implies an increase on the order of c. 2.5 cm between 1971 and 2002, which is markedly larger than the one reported by the CDC team possibly because we exclude Hispanics and foreign born (Ogden et al, 2004, p. 2).

In addition, we find that pre-adolescent girls tend to be taller than reference values by about 0.23σ at age 11 and adolescent boys by about 0.15σ at ages 13 and 14 (Figure 3). This translates into an age effect of c. 1.7 cm and 1.3 cm respectively. Hence, our combined estimated trend and age-effects are larger than those reported by the CDC, but are more conforming to the results reported in the Bogalusa study which posited a 0.7 cm increase per decade (Freedman et al., 2000).

The results of this study tend to confirm the patterns found on the basis of adult heights (Komlos and Lauderdale 2007). There was a two-decade period of stagnation from the early 1950s to the early 1970s among the height of children similarly to those of adults, and heights tended to increase thereafter among both children and adults, although adult height seems to lag children's height by about a quinquennium. (The stagnation of adult height began a few years after that of children's height and the stagnation ended among adults a few years after it ended among children.) On the basis of the trend in the children's height it appears that adult height will continue to increase in the near future.

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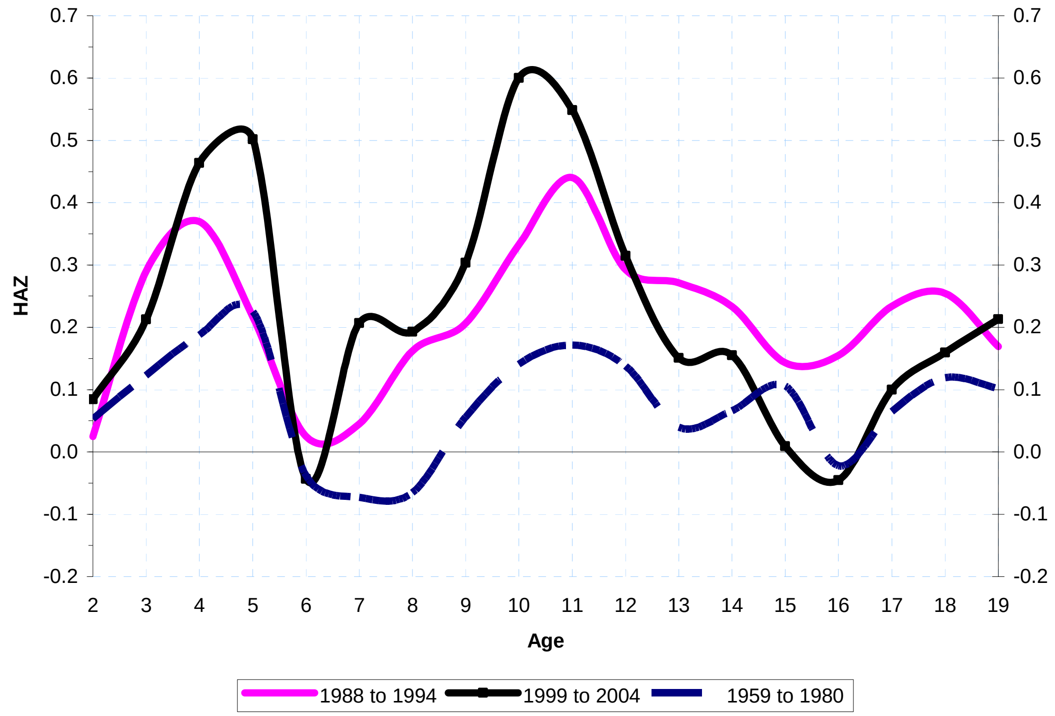
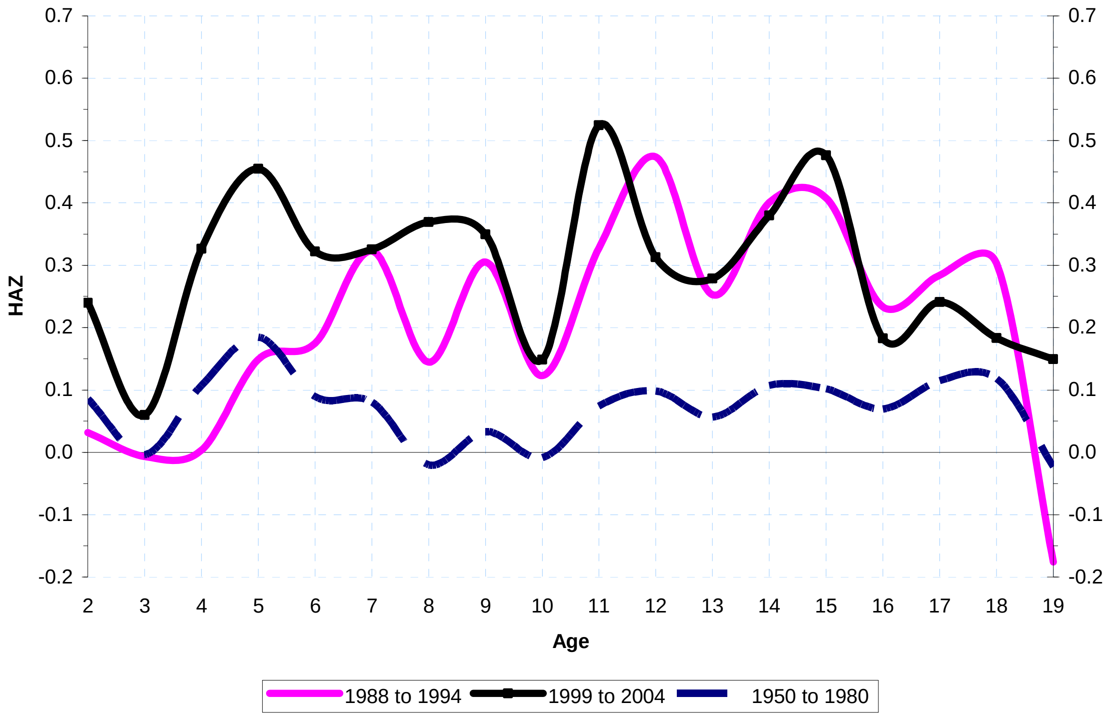
Figure 1: HAZ-scores of non-Hispanic US-born Black and White Girls ages 2 to 19 years, born 1942-2002 compared to CDC 2000 reference values



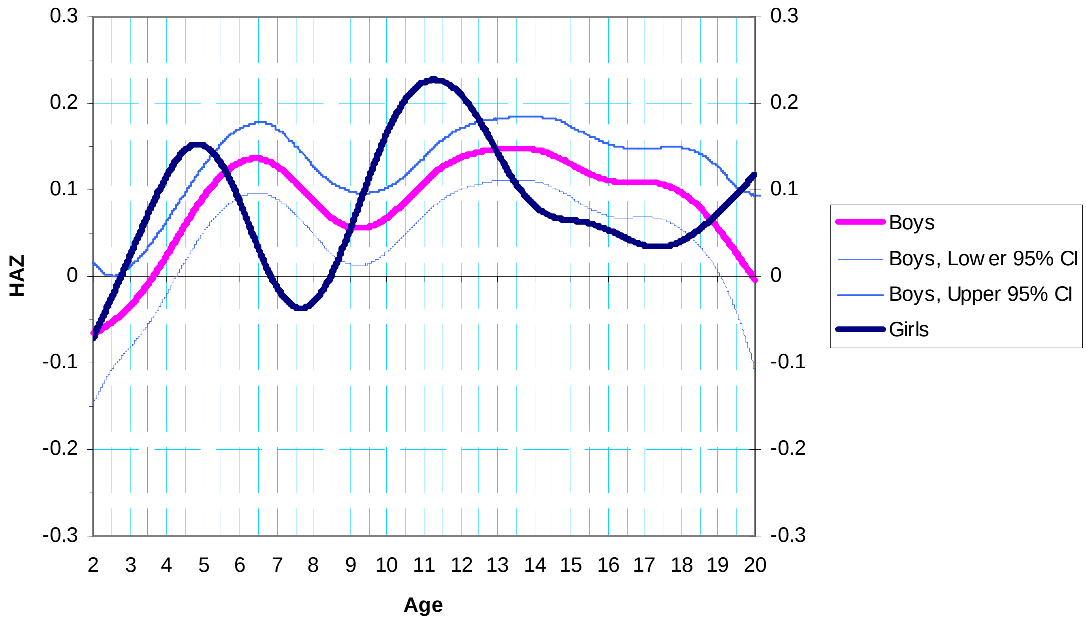
Note: Dates refer to measurement years. Note: Zero implies that the value equals the CDC 2000 reference values.

Figure 2: HAZ-scores of non-Hispanic US-born Black and White Boys ages 2 to 19 years, born 1942-2002 compared to CDC 2000 reference values



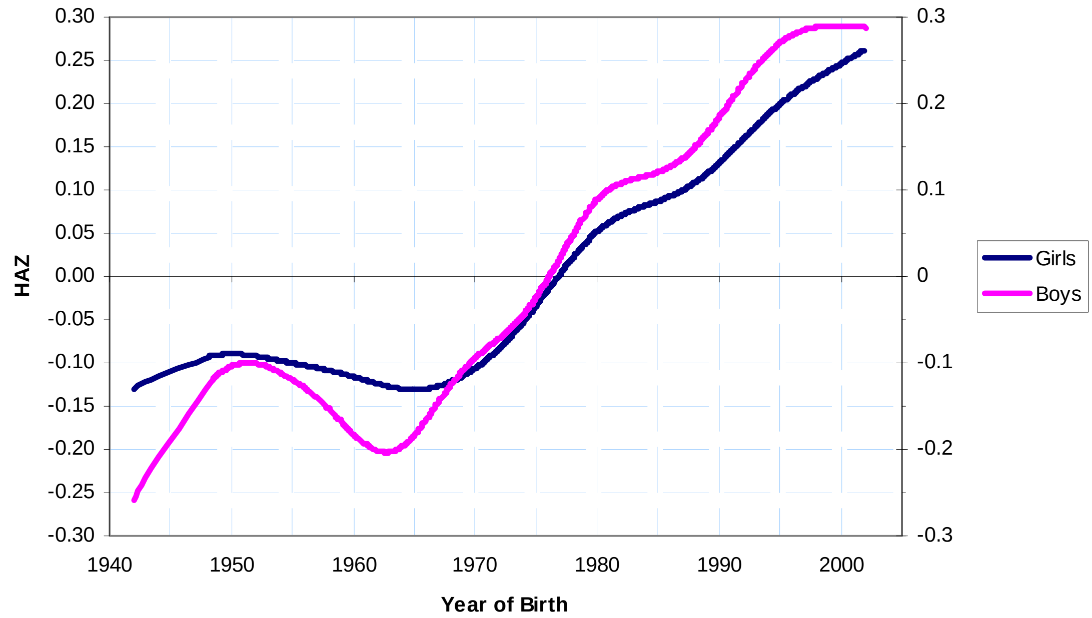
Note: Dates refer to measurement years. Zero implies reference values.

Figure 3. Estimated values of the function f_1 from Eq. 1: Age Effects of Height of non-Hispanic US-born black and white boys and girls born 1942-2002 compared to CDC 2000 reference values



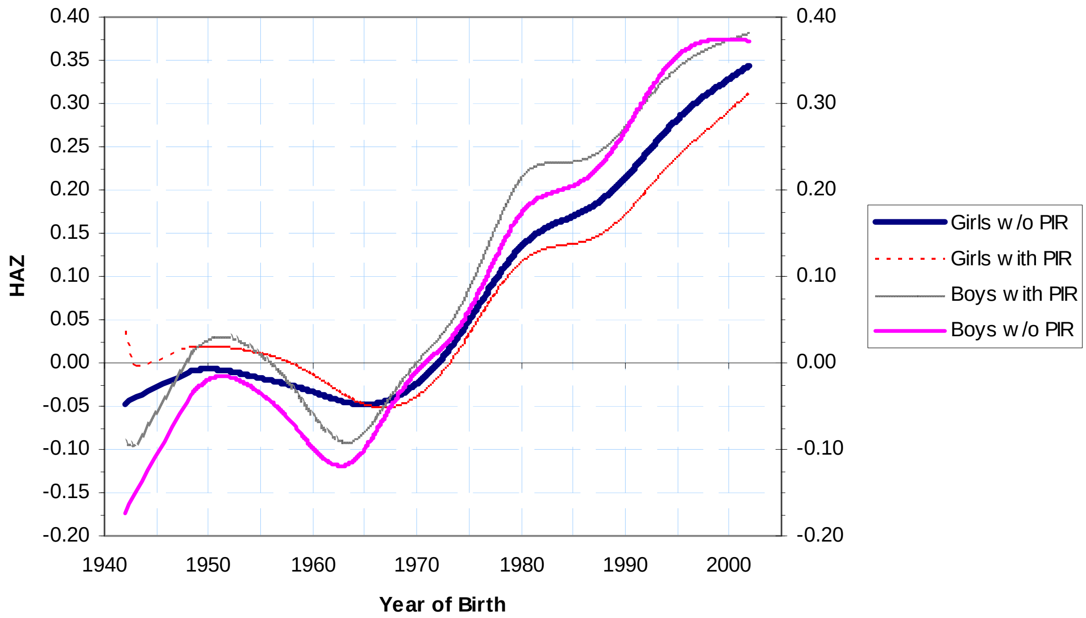
Note: Zero implies that the value equals the CDC 2000 reference values.
The 95% upper and lower bound confidence intervals are shown for the boys in order to indicate the range of probable values. For the sake of clarity these are not included for the girls, or in the other figures, as the range is approximately the same.
γ_0 and $0.15*\gamma_1$ has been added to the values of f_1 estimated from Eq. 1. (0.15 is the weighted proportion of blacks in the sample.)

Figure 4. Estimated values of the function f_2 of Eq. 1: The Secular Trend in the Height of non-Hispanic US-born black and white boys and girls born 1942-2002 compared to CDC 2000 reference values



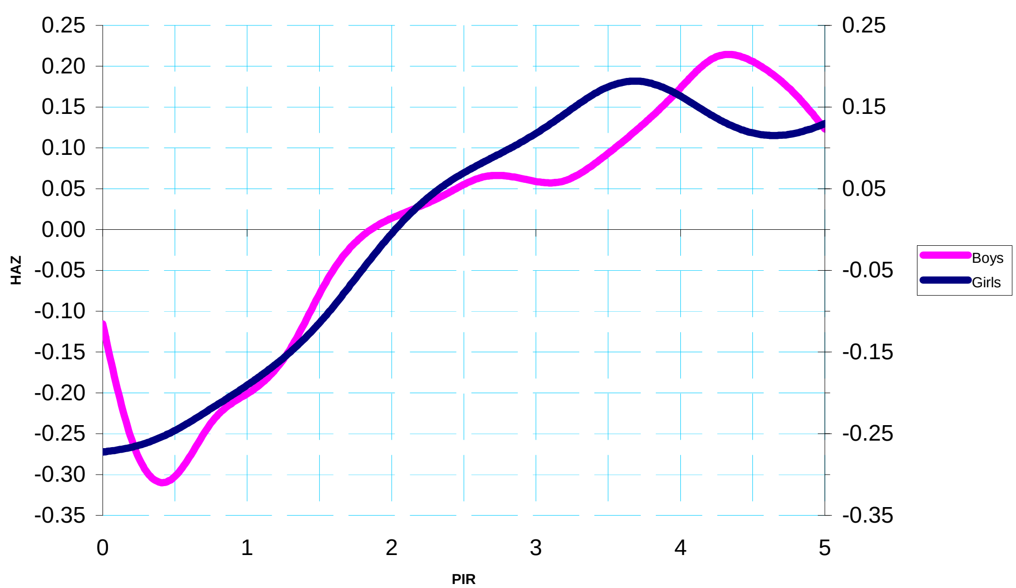
Note: Zero implies that the value equals the CDC 2000 reference values. For a particular age, the value in Figure 3 has to be added to these values in order to obtain predicted HAZ values.

Figure 5. Estimated values of the function f_2 from Eq. 1 and Eq 2: The Secular Trend in the Height of non-Hispanic US-born black and white children born 1942-2002 compared to CDC 2000 reference values, with and without holding income constant



Note: Zero implies reference values. For a particular age, the value in Figure 3 has to be added to these values in order to obtain predicted HAZ values.

Figure 6. Estimated values of the function f_3 from Eqs. 1: Effect of Income (PIR) on the Height (HAZ) of US-born black and white children 1942-2002.



Note: PIR = 1 is poverty level.

Table 1. HAZ scores (σ) for US-born children by year of Measurement, averages for ages 2-19

Years of Measurement	Boys	Girls
1959 to 1980	0.07	0.08
1988 to 1994	0.21	0.21
1999 to 2004	0.30	0.23

Table 2: Estimates of γ_0 and γ_1 of Eq. 1 (σ)

Females	γ_0	γ_1		Males	γ_0	γ_1
Coefficient	0.057*	0.169*		Mean	0.075*	0.062*
Sd	0.012	0.017		Sd	0.013	0.017

Note: * denotes significance at the 5% level.

Table 3. Periodization of Children's growth, 1942-2002

	Girls		Boys	
	Dates	Amount (σ)	Dates	Amount (σ)
Increase	1942 - 1950	0.04	1942 - 1951	0.16
Decrease	1950 - 1965	0.04	1951 - 1962	0.01
Constant	1950 - 1971	0.00	1951 - 1969	0.00
Increase	1971 - 2002	0.35	1969 - 1999	0.39

Source: Figure 4.

Table 4: Estimates of γ_0 and γ_1 of Eq. 2 (σ)

Females	γ_0	γ_1		Males	γ_0	γ_1
Mean	0.075*	0.297*		Mean	0.111*	0.169*
Sd	0.012	0.018		Sd	0.014	0.019

Note: * denotes significance at the 5% level.