Stunting and obesity in childhood
A reassessment using longitudinal data from South Africa

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Summary

Background: A series of cross-sectional studies have found a relationship between stunting and obesity in childhood. Because height appears in both the numerator of indices of stunting and the denominator of indices of obesity, random errors made by fieldworkers measuring heights can produce negative bias in estimates of this relationship.

Methods: With longitudinal data, height can be instrumented with its lagged value in a two-stage probit regression model, purging the estimated association between the probability of being obese or underweight and the height-for-age z-score of this errors-in-variables bias. Such a model is fitted to a cohort of 1110 primary-school-age children measured in 1993 to 2004 in a panel study in KwaZulu-Natal, South Africa. The study also collected detailed data on households' demographic and socioeconomic characteristics.

Results: Risk factors for stunting, wasting and obesity differed in this population. Stunting was not associated with childhood obesity in either the cross-sectional or two-stage models. In the cross-sectional analysis, however, random measurement errors masked a negative association between children's height-for-age and their probability of being underweight or wasted that emerged in the two-stage instrumental variable models. This association was further amplified, rather than attenuated, by controlling for children's household income, racial group, residence, and mother's education.

Conclusions: The validity of the findings of earlier cross-sectional studies of the association between stunting and obesity in childhood is dependent on the precision with which they measured height. Random measurement error can also mask an association between being stunted and underweight in cross-sectional studies.

Keywords: anthropometry, children, body height, body mass index, obesity, outcome measurement errors, econometric models, longitudinal studies, South Africa

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Introduction

Anthropometric indices based on children's heights and weights are used both to monitor the growth of individuals and to investigate children's health and health inequalities at the population level.[1] Stunting (low height-for-age), being underweight, and obesity in childhood are all indicators of sub-optimal physical and mental development and predispose children to poorer health, lower earnings, and higher mortality later in life.[2]

In an analysis of national surveys of Russia, Brazil, South Africa and China, Popkin *et al.* found that stunting was associated with being overweight among children in all four countries.[3] Because stunting remains common in less developed countries, this suggests that, as such countries become more affluent and activity patterns in them less energy-intensive, the prevalence of obesity in their populations may grow massively.

Subsequent research has produced similar findings for other populations,[4-7] although the relationship may differ between pre-school-age, primary-school-age and post-pubertal children.[8] One longitudinal study found that stunting in early childhood was associated with lower body mass indices (BMI) in late adolescence[9] and others that growth at different ages in childhood has varying implications for adult body composition.[10-12] Several studies of children in South Africa have produced contradictory findings.[13-15] Related research has suggested mechanisms operating during the developmental process that might explain the association.[16-19]

The cross-sectional evidence for the existence of this association is open to question because errors in measured heights that leave the estimated means of the two anthropometric indicators unbiased can produce negative bias in estimates of the indicators' correlation.[20] This bias is an artefact of the appearance of height in both the numerator of the index of stunting and the denominator of the index measuring obesity. Children whose heights are underestimated tend to be classified wrongly as obese and may not be classified as underweight when they are.

Popkin *et al.* discount this possibility on the grounds that a J-shaped relationship exists between obesity and stunting, with the risk of obesity being concentrated among the most stunted part of the population.[3] However, a proportion of children classified as severely stunted may merely have had their height underestimated because more children will lie just inside any cut point on the tail of the height distribution than just outside it, leading random measurement errors to inflate the apparent number of children in the distribution's tails.

This paper investigates the implications of this bias using longitudinal data on children from KwaZulu-Natal, South Africa. The determinants of stunting and being underweight and obese are compared before examining the link between stunting and BMI using methods comparable with those used by earlier cross-sectional studies.[3-7, 13-15] The data are then reanalysed

using lagged height as an instrumental variable (IV) with which to eliminate bias resulting from random errors in the measurement of height.

Methods

The KwaZulu-Natal Income Dynamics Study (KIDS) is a panel of households in the eponymous province of South Africa on which data were obtained in 1993, 1998, and 2004.[21-22] Baseline data were collected from a clustered probability sample of all households but only Indian and African clusters were re-interviewed because of the low response rate and unusual characteristics of the few White and Coloured clusters. Households that moved to other parts of South Africa were retained in the panel. Interviews were also conducted in 2004 in next-generation households that had split off from the parental households and in the current households of children who had been fostered out. The 2004 wave obtained data on 1377 households containing members of 841 of the 1354 African and Indian households contacted in 1993. Each wave of fieldwork collected information on the demographic characteristics and activities of each household member and on the household's dwelling, other assets and economic status, including details of its income and expenditure.

In 1993, fieldworkers were instructed to measure the heights and weights of all children residing in the households aged <6 years. Height-for-age z-scores are available for 77% of them and weight-for-height z-scores for 75% (Table 1). Most of the missing data are for infants or one-year-old children. In 1998 and 2004 anthropometric data were collected on children aged 6+ months and <12 years and their completeness rises to 88% for height-for-age and 89% for weight-for-height/BMI in 1998 and 91% for both indicators in 2004. Fieldworkers were instructed to measure children's heights and weights twice and to take a third measurement if the first two were discrepant. They also sought to confirm the children's exact ages against birth certificates and other documents.

This design means that many of the children who were primary-school age in 1998 and 2004 have been measured more than once. One can construct a cohort from the data of 570 children measured in 1993 and 1998 and aged 5-11 in 1998 and 540 children measured in 1998 and 2004 and aged 5-11 in 2004.

Children's heights and weights were assessed against the 2000 CDC reference standards for children in good health.[23] Children were classified as underweight if their BMI was >1SD below the median BMI of healthy children of the same age and as severely underweight (wasted) if their BMI was >2SD below the median. They were defined as overweight if they had a BMI >1SD above the same median and as obese if their BMI was >2SD above it. About 4% of the

measures (see Table 1 for details) were dropped from the analysis because their vales were implausible, specifically height-for-age z-scores of <-6 or >6, height-for-age z-scores of <-3.1 combined with a weight-for-height z-score of >3.1, and weight-for-height and BMI z-scores of <-4 or >6.[24]

Biases analogous to that considered here have been addressed in other contexts, notably studies of the impact on hours worked of hourly pay rates, which many survey respondents estimate by dividing their total pay by their hours.[25-26] One strategy that can be applied to longitudinal data is to use a lagged indicator of height as an instrument to resolve this errors-in-variables problem. Errors in measures of a child's height taken several years apart by different fieldworkers are unlikely to be associated. Thus, assuming that errors in measured height are also uncorrelated with children's true heights (i.e. the measurement of height is unbiased), the earlier measure of height can be used to make a prediction of the later one that is purged of random measurement error.[27]

Specifically, the probabilities that children were overweight, obese, underweight, and wasted were modelled using probit regression. The simple probit model is

$$y_{it} = \beta x_{it} + \gamma z_{it} + \varepsilon_{it}$$

whereas the two-stage IV regression model takes the form

$$y_{it} = \beta_1 x^*_{it} + \gamma_1 z_{it} + \varepsilon_{1it}$$
$$x_{it} = \beta_2 x_{it-1} + \gamma_2 z_{it} + \varepsilon_{2it}$$

where y_{it} is a binary indicator of whether ith child has an unhealthy BMI z-score in year t; x_{it} is the child's height-for-age z-score at time t, z_{it} is a vector of other predictors which have associated vectors of coefficients γ, γ_1 and γ_2, and x^*_{it} is the linear predictor from the first-stage equation.

The model was fitted to the data from the 1998 and 2004 waves of KIDS using children's height-for-age z-scores in 1993 and 1998 respectively as instruments. The association between ε_{1it} and ε_{2it}, ϱ, provides the basis for the Wald test of the exogeneity of x_{it}. The smaller the value of ϱ the less likely it is that the simple probit model is biased.

Results

The mean height-for-age of children in KIDS was about 1SD below that of the reference population (Figure 1). Children were on average shorter in 1993 than 1998 and in 1998 than 2004. In 1993 and 1998, but not 2004, children's heights dropped increasingly behind those of the reference population as they got older. The proportion of children aged 2-6 with a BMI z-score <-2 was nearly 12% in 1993, but lower in 1998, and down to the level found in well-nourished populations by 2004. The proportion of children with a BMI z-score >2 fell between

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1993 and 2004. For example, 14% of children aged 2-5 were obese in 1993 compared to 7% in 2004. The prevalence of obesity declined with age across childhood. The proportions of children who were merely overweight or underweight, as opposed to obese or wasted, were much higher. In 2004, for example, 9.6% of children aged 2-12 were underweight, while only 2.1% of them were wasted, and 19.0% of them were overweight but only 3.5% obese. The differentials and trends in these indicators (not shown) followed similar patterns to those for wasting and obesity.

The finding that the prevalence of both wasting and obesity fell across the waves of the study suggests that, at least in part, these trends may be an artefact of reduced errors in the measures of height and weight. This interpretation receives partial support for pre-school-age children from Figure 2. The 1993-98 increase in children's average height resulted from a general shift to the right of the distribution of heights. This change is probably real. In contrast, the 1998-2004 increase resulted largely from changes in the tails of the distribution, which narrowed. This pattern of change is less plausible. Similarly, at least some of the 1993-98 decrease in the prevalence of underweight was probably real, but much of the apparent 1998-2004 decrease in the proportions of children that were either underweight or overweight may have been an artefact of improvements in data quality.

Table 2 examines inequalities in children's heights-for-age using first a cross-sectional regression model (adjusting the standard errors for the existence of multiple measures on some children); second, a random intercept model that incorporates child-specific offsets to the z-scores that are distributed normally around the population average; and, third, a dynamic model which includes lagged height-for-age z-scores as an explanatory variable. This model was fitted to the 1155 pairs of observations that exist for successive waves.

Most of the results are robust to the exact specification of the regression model. Children's heights increased between 1993 and the later waves. They dropped back slightly against the reference standard among older children. The z-scores did not vary by sex. Children's height was positively associated with the *per capita* income of their household but Indian children were taller than African children even after allowing for this. No evidence exists that mothers' education affected their children's heights after controlling for income and race.

The final model shows that, while children's height was associated with their height 5-6 years earlier, the coefficient is small. This may mean that substantial catch-up growth occurred or merely reflect regression to the mean resulting from errors in the measurement of height. Including lagged height in the model attenuates, but does not eliminate, the effect of contemporary household income. Thus, the cross-sectional relationship between poverty and stunting results from both a shorter-term and longer-term history of faster child growth in

better-off households. Multiplying out the predictions from this model reveals that the substantial height advantage of young children born into households based in the metropolitan areas of Durban and Pietermaritzburg in 1993 had been completely eroded by about age 10.

Table 3 presents regressions on their height-for-age z-scores of the proportions of children aged 6-11 in 1998 or 2004 that were overweight or underweight. The relationship is not adjusted for the children's age and sex but doing so does not greatly affect the fit of the models (results not shown). Although an earlier measure of height is available for <50% of all children measured in either 1998 or 2004, the coefficients of models fitted to these two samples are similar, suggesting that children who were measured twice were fairly typical of all children.

Instrumenting, that is repeating the analysis using height-for-age z-scores predicted from their values in the previous wave of data, increases the coefficients on height-for-age in the two models predicting overweight and obesity and reduces the coefficients on height-for-age in the two models predicting the probability of being mildly and severely underweight. This is what one would expect if measurement error has created a spurious negative correlation between the two measures in the cross-sectional analysis. Figure 3 confirms that a clear association existed between children's lagged and current height-for-age z-scores in both 1998 and 2004, supporting use of the lagged z-score as an instrument.

Neither the simple nor the two-stage IV probit models indicate that stunting was a risk factor for being overweight or obese. In contrast, the IV models reveal that measurement error was masking an association between stunting and being underweight or wasted. The estimates of ϱ in this second pair of models suggest that it is unlikely ($p=0.002$) that the unadjusted height-for-age z-scores are exogenous. Instrumenting transforms a spurious positive relationship between unadjusted height and body mass into a negative one.

Table 4 expands the IV models to control for a range of demographic and socioeconomic determinants of BMI other than height. These models provide weak evidence that household income was associated with being overweight, together with weak evidence that, after controlling for income, Indian children were less likely to be overweight than Africans. No evidence exists that either urban residence or the educational achievements of their mothers influence whether children were overweight or obese. The proportion of children who were overweight or obese fell with age and may have diminished over time. Girls of primary-school age were more likely to be obese than boys ($p=0.052$). The determinants of the proportion of children that were underweight or wasted are not simply the inverse of those for being overweight. Poverty was not a risk factor but urban residence was. Moreover, having controlled for residence, Indian children were much more likely to be unhealthily thin than Africans.

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Adjusting for additional characteristics has little impact on the relationship between the proportions overweight or obese and height, which remains weakly positive, in contrast to the basic probit model. Moreover, adjusting for them does not attenuate the inverse association between being underweight or wasted and height. Instead, it unmasks an even stronger association than that estimated by the bivariate IV model.

Discussion

KIDS provides apparent evidence of improvements in the nutritional status of children in KwaZulu-Natal between 1993 and 2004. However, at least after 1998, these improvements may have been largely spurious: measurement error may have produced an overly pessimistic impression of the numbers of stunted, underweight and obese children in the first two waves of the study. Either way, the prevalence of being underweight in 2004 was low and childhood obesity has not emerged as a major problem in this province of South Africa. By contrast, stunting remains common. Even in 2004, by age 10 the average height of these children was about 1SD below that of children in well-nourished populations.

The determinants of stunting, wasting and obesity differ markedly in KwaZulu-Natal. A strong association existed between household poverty and primary-school-age children's heights. This reflects growth deficits both more than 5-6 years earlier and more recently. At least among younger children, urban residence also protected against stunting and Indian children were taller than African children from a similar socioeconomic background. In contrast, household incomes were unrelated to the probability that children were underweight. Moreover, urban residence and Indian ethnicity put children at risk of being underweight, rather than being protective. Thirdly, while poverty and being Indian were associated with reduced probabilities of being overweight, urban residence was unimportant. No evidence exists that the educational background of mothers affected their children's anthropometric outcomes in this population once one has adjusted for other determinants. Moreover, at the largely pre-pubertal ages examined here, the outcomes of the boys and girls were similar.

This analysis found no relationship between stunting and obesity in childhood. This finding matches those of previous research in KwaZulu-Natal but not of some studies conducted elsewhere in South Africa.[13-14] However, using IV methods to adjust for random errors in the measurement of height turned a *positive* association between height and being severely underweight into a strongly *negative* one. Short children were more likely than taller children of the same age to be underweight or wasted. Measurement error masks this association in a straightforward cross-sectional analysis. However, being tall was not associated with obesity,

although this association has been found in populations in which obesity is more common.[28] As controlling for household income, racial group, residence and mother's educational background strengthened rather than attenuated the association between being short and being underweight, it seems unlikely that it results from confounding with other socioeconomic determinants of these anthropometric indices.

These findings suggest that random measurement errors have the potential to cause considerable bias in cross-sectional analyses, throwing doubt on much of the evidence that stunting is a risk factor for obesity in childhood. Of course, they have no implications for longitudinal studies that examine the impact of stunting for obesity in adulthood. Moreover, the results are specific to KIDS, to primary-school-aged children, and to KwaZulu-Natal. According to the 2004 data, which seem more reliable than those collected in the earlier waves, childhood obesity remains uncommon in KwaZulu-Natal. Perhaps it is only when obesity becomes prevalent that an association between stunting and childhood obesity emerges. Moreover, detailed analyses of this association have suggested that stunting in childhood is linked to later obesity via fat deposition at puberty.[19, 29] KIDS only collected anthropometric data on children aged <12 and cannot be used to investigate whether stunting and obesity are linked in secondary-school-age children.

Although most research in low- and middle-income countries has used weight-for-age or the BMI to identify wasting and obesity in children, future cross-sectional research investigating stunting and obesity in childhood could avoid the bias discussed here by adopting waist circumference or related measures to measure obesity.[30] Moreover, it is likely that the measurement of height is more precise in small-scale studies conducted by specialist staff than in large general-purpose household surveys. If random errors in the measurement of children's heights are small, the bias resulting from such errors will be unimportant. Equally though, no obvious reason exists why the accuracy of the anthropometric measurements in KIDS should be worse than those made in other large-scale surveys such as studies in the Demographic and Health Surveys and the Living Standards Measurement Study programmes.

In conclusion, random errors in measured height produce an artefactual association between stunting and obesity and may mask an association between stunting and being underweight in cross-sectional data. In panel studies, one can sidestep this bias by means of a two-stage IV regression analysis that instruments height with a measure of it made on another occasion (or with several such measures). Analysis of KIDS suggests that sufficiently large random non-sampling errors in the measurement of height can occur in large-scale, general-purpose surveys to introduce substantial bias. This bias may reverse the direction of the

relationship between height and categorical measures based on the BMI. These findings do not necessarily invalidate those of earlier cross-sectional studies of this relationship; they do emphasize that the validity of these earlier results is conditional on the accuracy with which height was measured.

A National Income Dynamics Study was recently established in South Africa that has measured people of all ages.[31-32] The initial waves of data were collected in 2008 and 2010. Once these data have been released, it will be possible to apply IV methods to up-to-date data representing the whole population of South Africa, including children who have been through puberty.

KEY MESSAGES

- The relationship between stunting and obesity in childhood found by many cross-sectional studies could be an artefact of random errors in the measurement of height.

- In longitudinal studies, a lagged indicator of height can be used as an instrumental variable in a two-stage regression model to eliminate this bias.

- Applying the method to data from South Africa shows that, although bias masks the association in a cross-sectional analysis, short children were in reality more likely than taller children to be underweight.

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Table 1 Samples of children with anthropometric information, KwaZulu-Natal Income Dynamics Study

	Wave 1 - 1993	Wave 2 -1998	Wave 3- 2004
Ages of children measured	<6 years	6 mo – 12 yr	6 mo – 12 yr
Number of eligible children	1237	2001	2437
Children whose height was measured	1014	1867	2236
Plausible height-for-age z-score	954	1758	2215
Children whose weight was measured	1014	1868	2245
Plausible weight-for-age or BMI z-score	924	1775	2214

BMI = Body Mass Index

Table 2 Determinants of height-for-age z-scores, KwaZulu-Natal Income Dynamics Study

	In cross-section		Random effects		Dynamic model	
	Regression coefficient	p-value	Regression coefficient	p-value	Regression coefficient	p-value
Lagged height/age z-score					0.1000	<0.001
Wave 1998	0.2854	<0.001	0.2734	<0.001	..	..
2004	0.2435	<0.001	0.2396	<0.001	0.3456	<0.001
Girls	0.0292	0.485	0.0362	0.386	-0.0574	0.434
Exact age of child (years)	-0.0515	<0.001	-0.0517	<0.001	-0.1493	<0.001
Metropolitan residence	0.0735	0.362	0.0724	0.336	2.1676	<0.001
Age × Metropolitan residence					-0.2256	0.001
Indian	0.2935	0.002	0.2974	0.002	0.4698	0.004
Mother's education (none)						
Lower primary	0.0960	0.460	0.0984	0.419	0.1962	0.304
Upper primary	-0.2488	0.009	-0.2325	0.010	-0.1438	0.319
Partial secondary	-0.0154	0.860	0.0108	0.892	-0.0739	0.572
Matriculated and above	-0.0321	0.744	0.0029	0.976	-0.2671	0.096
ln(*per capita* expenditure)	0.1957	<0.001	0.1854	<0.001	0.1164	0.032
Constant term	-1.8418	<0.001	-1.8114	<0.001	-0.2849	0.370
Number of children	3745		3745		1064	
Number of observations	4918		4918		1155	
Random effect σ(i)			0.6438		0.7661	
% variation intra-child			22.4		45.3	

Table 3 Bivariate probit regressions of the proportions of children with extreme body mass indices on their height-for-age z-scores, children aged 5 to 11 years, KwaZulu-Natal Income Dynamics Study, 1998 and 2004 waves

	Overweight (z>1)		Obese (z>2)		Underweight (z<-1)		Wasted (z<-2)	
	Regression coefficient	p-value	Regression coefficient	p-value	Regression coefficient	p-value	Regression coefficient	p-value
Simple probit (*N*=2480)	0.0284	0.236	0.0160	0.717	-0.0077	0.778	0.0846	0.034
Simple probit (*N*=1110)	-0.0019	0.959	-0.0414	0.554	-0.0158	0.681	0.0934	0.095
Two-stage probit (*N*=1110)	0.1743	0.250	0.1987	0.461	-0.3676	0.004	-0.4308	0.003
Rho	-0.2193		-0.2980		0.4398		0.6270	
Wald test of exogeneity	1.34	0.247	0.76	0.383	6.21	0.013	8.33	0.004

Table 4 Two-stage probit regression model of the proportions of children with extreme body mass indices instrumenting their height-for-age z-scores with their lagged values, children aged 5 to 11 years, KwaZulu-Natal Income Dynamics Study, 1998 and 2004 waves

|	Overweight ($z>1$)		Obese ($z>2$)		Underweight ($z<-1$)		Wasted ($z<-2$)	
	Regression coefficient	p-value	Regression coefficient	p-value	Regression coefficient	p-value	Regression coefficient	p-value
Height-for-age z-score	0.2360	0.169	0.1154	0.755	-0.5016	<0.001	-0.5720	<0.001
2004 vs 1998	-0.4982	<0.001	-0.3046	0.230	0.0579	0.609	-0.2606	0.183
Indian vs African	-0.3997	0.074	-0.1159	0.773	0.9567	<0.001	0.7203	0.001
ln(*per capita* expenditure)	0.1405	0.093	0.2351	0.182	-0.0094	0.900	0.0517	0.611
Urban vs rural	-0.0167	0.899	0.0273	0.914	0.3332	0.009	0.3577	0.033
Exact age in years	-0.0245	0.542	-0.0944	0.295	-0.8050	0.001	-0.6096	0.055
Age^2					0.0463	0.001	0.0313	0.090
Mother's schooling								
Lower primary	-0.3057	0.258	-11.613	0.481	0.2463	0.320	-0.6804	0.489
Upper primary	-0.1111	0.584	-0.2772	0.527	0.1969	0.319	0.0681	0.799
Partial secondary	0.0757	0.666	-0.1092	0.764	0.1341	0.458	0.0172	0.945
Matriculated +	0.1735	0.423	0.0944	0.824	-0.0107	0.962	-0.1701	0.563
Girls vs boys	-0.0456	0.639	-0.4398	0.052	0.0874	0.351	-0.0055	0.964
Constant	-1.1210	0.018	-2.0622	0.039	1.6347	0.128	0.6110	0.664
Rho	-0.3007		-0.2234		0.5578		0.7153	
Wald test	2.03	0.154	0.26	0.609	9.2	0.002	9.93	0.002
N of children	1110		1110		1110		1110	
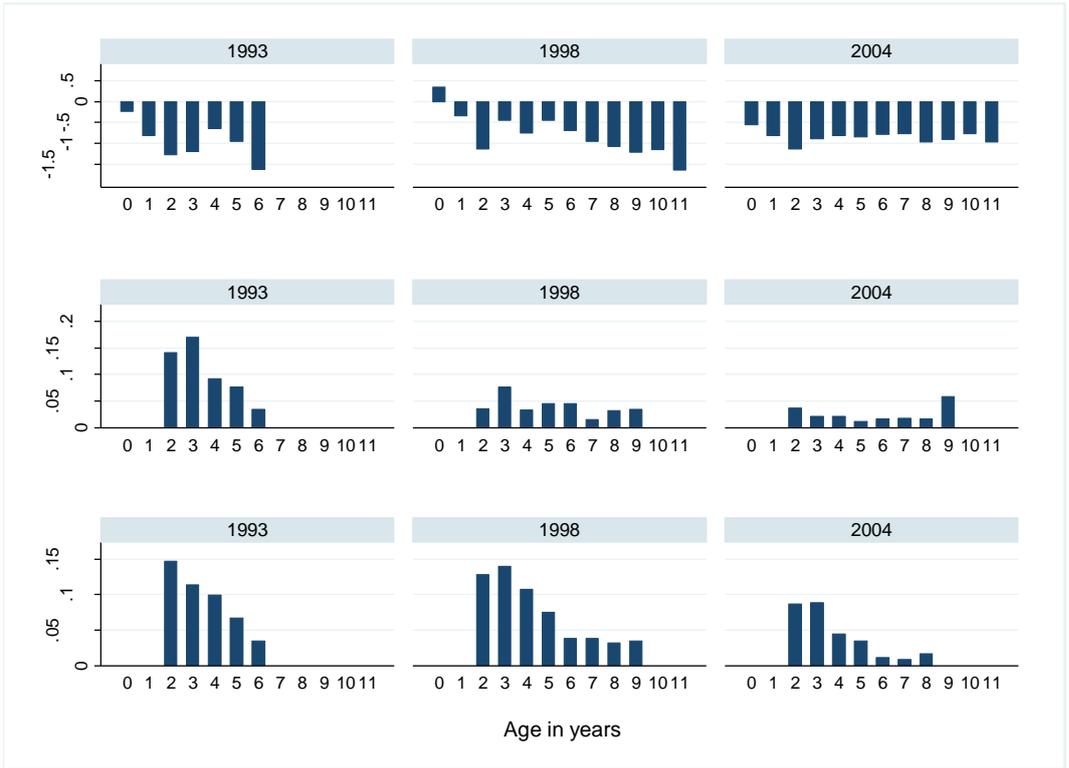
Figure 1 Mean height-for-age z-scores and proportions of children wasted and obese by age in years and wave, KwaZulu-Natal Income Dynamics Study
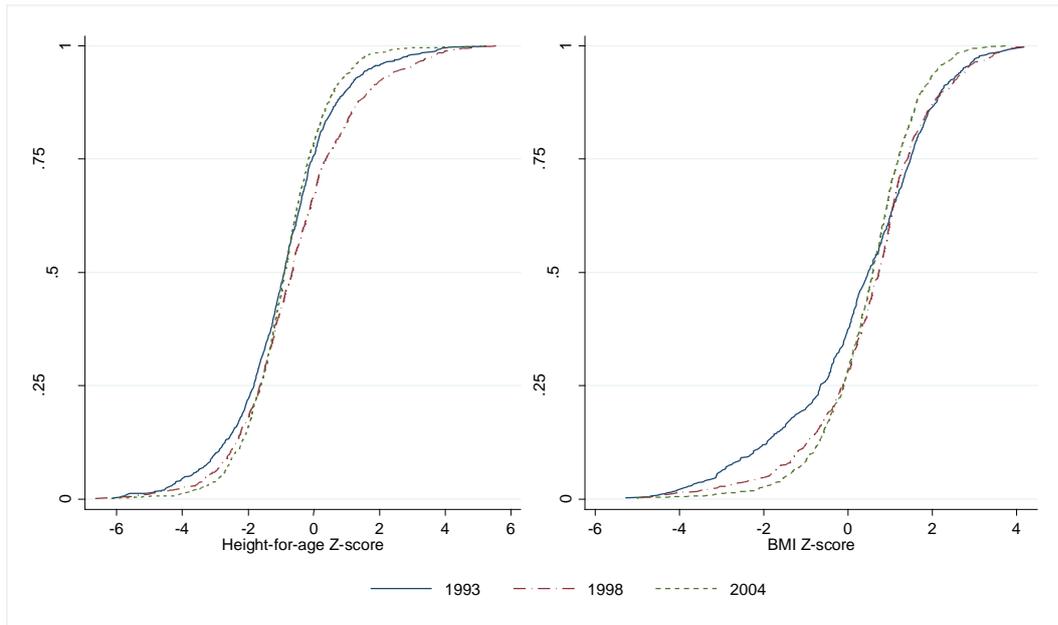
Figure 2 Cumulative distribution of height-for-age and body-mass-index *z*-scores by wave of fieldwork, children aged 6 months to 6 years, KwaZulu-Natal Income Dynamics Study
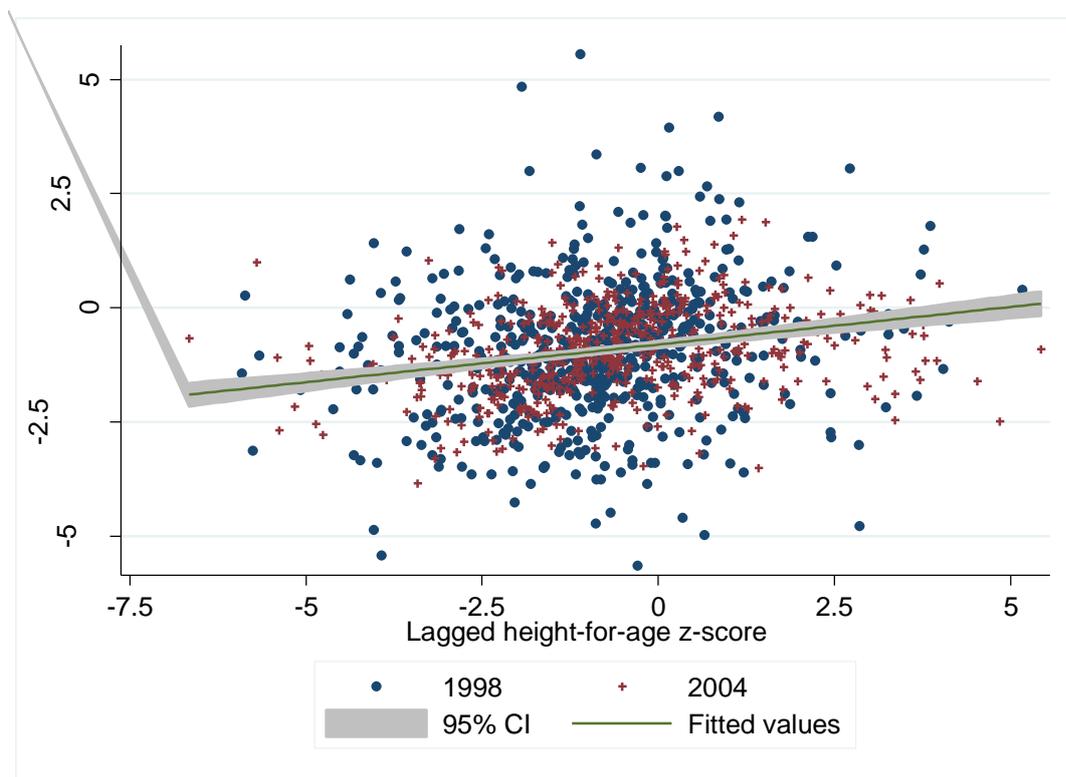
Figure 3 Relationship between children's height-for-age *z*-score and their height-for-age *z*-score in the previous wave of the study, KwaZulu-Natal Income Dynamics Study.