IIIS Discussion Paper

No.429/ May 2013

A Tall Story: Characteristics, Causes, and Consequences of Stature Loss

Alan Fernihough
Mark E. McGovern



IIIS Discussion Paper No. 429

A Tall Story: Characteristics, Causes, and Consequences of Stature Loss

Alan Fernihough
Mark E. McGovern

May 2013

Disclaimer
Any opinions expressed here are those of the author(s) and not those of the IIIS.
All works posted here are owned and copyrighted by the author(s).
Papers may only be downloaded for personal use only.

A Tall Story: Characteristics, Causes, and Consequences of Stature Loss

Alan Fernihough* Mark E. McGovern†

May 2013

Abstract

Height is widely used as an objective measure of health status. It is commonly used in the large body of research evaluating welfare trends in historic populations and the long-run impacts of childhood environment. However, few research papers have examined the extent, causes or consequences of stature loss in aging populations. This is surprising, as many studies rely on the assumption that height is fixed in late adolescence. Using repeated observations on objectively measured data from the English Longitudinal Study of Ageing (ELSA), we document that stature loss is an important phenomenon among older individuals, and demonstrate how the use of unadjusted height will dramatically overstate health improvements for younger birth cohorts in cross sectional data. We show that there is an absence of consistent predictors of stature loss at the individual level. However, we exploit the panel element of the ELSA survey to show how deteriorating health and stature loss occur in tandem. While our analysis details the inherent bias of height measurements in older populations, we do not find that significant differences arise from the use of unadjusted height as an input in typical empirical health production function models.

JEL Classification: *I10, I12, J11*

Keywords: *Height, Stature Loss, Early Life Conditions, Health, Ageing*

*Institute for International Integration Studies, Trinity College Dublin. Email: alan.fernihough@gmail.com.

†Harvard Center for Population and Development Studies. Email: mcgovern@hsph.harvard.edu.

1 Introduction

Until relatively recently, good quality data on the health of individuals was rarely collected in nationally representative surveys. Even if current health status was available, researchers interested in well-being across the life course, such as the long run effects of childhood environment, were severely limited in their ability to quantify these effects. Assessing the welfare of historical populations is similarly problematic due to the lack of data.

To address this issue, researchers have routinely used height as an indicator for both population health and early life conditions. Apart from the advantage that it is often available when other indicators are not, it also has several other useful properties. It is relatively easy to measure, it has an objective scale, and it is generally assumed to be fixed in late adolescence. Hence, it is seen as a useful proxy for childhood nutritional status and disease environment, and a potential complement to other indicators of health and welfare such as life expectancy and GDP.

Given that height is regularly substituted as a measure for health status or early-life conditions, understanding the relationship between the height and health of individuals or societies is of obvious importance. Not surprisingly, a large literature exploring this relationship exists, including numerous articles in the most prominent economics journals. However, one aspect of the height-health nexus has been somewhat overlooked: stature loss associated with aging.

This paper illustrates how height loss amongst older cohorts represents an important phenomenon. To the best of our knowledge this paper is the first to document the relationship between age and reductions in stature using longitudinal data on measured height in a large-scale nationally representative sample. We use predictions from a linear regression model estimated on the same individuals over time from the ELSA survey to determine the magnitude of stature loss over the life course. This analysis suggests that the height of both men and women falls by as much as 2 cm to 4 cm on average across

the adult life course. We test whether age-related stature loss amongst the population is random, or whether it is predicted by either current or early-life environment.

To examine the determinants of stature loss, we estimate a series of empirical models. Firstly, we model changes in height on a number of time-invariant, or fixed, variables and find little consistent evidence linking stature loss to adverse conditions in adulthood or early-life. Secondly, we exploit the panel nature of the ELSA dataset and analyze how stature loss is affected by changes in health status (measured using either grip strength or peak respiratory flow). Thus, we are effectively estimating a fixed effects regression model that accounts for unobserved heterogeneity by controlling for all time-invariant factors. Our results show how deteriorating health status contributes to stature loss for both males and females. These results are robust to a number of model specifications, changes in survey wave, and placebo regressions wherein we model earlier stature loss as a function of later health changes.

The body of evidence we present clearly illustrates how stature loss is of a nontrivial magnitude, and also how it is correlated with deterioration in health. The implication of these findings is that the naïve inclusion of unadjusted height as an additional explanatory variable could lead to biased results in the context of regression modeling as it is correlated with health shocks. Given that height is frequently used in this way, our findings may have important implications for the economics literature on the subject. We investigate the extent of this possible bias by estimating a number of health production functions wherein stature is included as an input. To measure the consequences of using unadjusted height, we compare the coefficients produced via the inclusion of unadjusted height with those resulting from a standardized measure of stature that is not known to change over the life course: demispan. Despite the relatively large changes in height, the results in this section do not support the hypothesis that using unadjusted height will lead to substantially biased coefficients in similar applications. This pattern is also observed when we use unadjusted height from earlier waves.

2 Existing Research

The relationship between height and economic welfare is a popular research topic. A summary of the growth in this literature is provided by Steckel (2009), who listed 325 studies on stature published between 1995 and 2009. This literature has led to the re-consideration of living standards during the Industrial Revolution (Voth, 2003), and the status of the Native Americans (Steckel and Prince, 2001). Data have often been gathered from innovative sources, such as prison and army records (Mokyr and Ó Gráda, 1996) and skeletons (Steckel, 2005). Easterlin (2000) used height to document improvements in living conditions over time, as did Cutler et al. (2006). Similarly, Fogel (2004a; 2004b) linked nutritional gains to economic growth via height, and stature has also been used to compare sub-groups of individuals (Subramanian et al., 2011 and Bodenhorn et al., 2012).

At the individual level, height has been shown to be related to childhood disease environment in developed countries (Alderman et al., 2011; Bozzoli et al., 2009), including historical populations (Peracchi and Arcaleni, 2011; Young et al., 2008), although the relationship is not as clear for developing nations (Akachi and Canning, 2010; Deaton, 2007). The economics literature has noted the association between height and a number of adult outcomes, including cognitive ability, labor market status, and health (Case and Paxson, 2008; Deaton and Arora, 2009; Denny, 2010), and at least part of this relationship is believed to be due to the aforementioned association with early environment (Case and Paxson, 2010). Interestingly, Mankiw and Weinzierl (2010) have argued that the above properties encapsulated by human height should be used as an efficient alternative to income based tax policy.

Many of the papers discussed in Steckel (2009) use self-reported height, which has the potential to be affected by various types of measurement error (Engstrom et al., 2003; Rowland, 1990). Depending on the application, the issue is most serious when the reporting bias is systematically correlated with some characteristic of the individual. Using objectively measured height does not solve this issue if stature loss occurs. To

the best of our knowledge there are very few papers in the economics literature which identify the consequences of this potential measurement error in height. This issue of potential bias is raised, but not investigated in Leon et al. (1995) and Case and Paxson (2008). Mokyr and Ó Gráda (1996) adjust for the age profile in prison records, while more recently Huang et al. (2013) examined this issue with Chinese data.[1]

Clearly, all of these papers rely on the assumption that height correctly captures human welfare. For both the anthropometric and early life conditions literature, this requires the assumption that height is fixed in early adulthood. For the former this is the case because cohort comparisons are generally based on cross sectional comparisons, and it is not possible to distinguish the effects of age and cohort without longitudinal data. For the latter, if height changes during adulthood then this could induce spurious findings. For example, individuals may have low height, not because of early environmental effects, but due to some other factor such as age, adult health or adult socioeconomic status. This is particularly important if shrinking itself is a function of early environment, or the outcome of interest is also a function of stature loss.

There is some existing evidence that height declines with age in the anthropometric literature, but this evidence generally comes from surveys with relatively small samples which are not nationally representative. The data requirements to establish stature loss are quite burdensome, as rigorously testing the existence of shrinking ideally requires longitudinal data with height measured repeatedly, and objectively, not just self-reported. Using data from Western Australia, Chandler and Bock (1992) found evidence of stature loss after the age of 40. Cline et al. (1989) also found evidence of stature loss after the age of 40. Their analysis suggested that up to 55% of the difference between birth cohorts can be attributed to age effects. They find that the cumulative effect does not become significant until age 60. Galloway et al. (1990) found that stature loss is related to maximum height, and bone density, although they rely on self-reports for estimating maximum height. A related study highlighted the fact that individuals

[1]For a discussion of the consequences of measurement error in relation to BMI, see Madden (2013) and O'Neill and Sweetman (2012).

are not aware of stature loss (Galloway, 1988).

The consequences of stature loss have been noted to some extent in the clinical and anthropometric literatures, but not in economics (with one notable exception). The proposed solution has been to use arm or leg length to substitute for measured or reported height (Raxter et al., 2006; Sethi et al., 1995; Webb et al., 2008; Whitley et al., 2012). Recently Hirani and Mindell (2008), and Hirani et al. (2010) developed a correction procedure using arm length. Maurer (2010) instrumented for height using limb length. However, this may not be valid if shrinkage is correlated with maximum height (a feature we have confirmed in these data). The one exception to the absence of evidence on stature loss in the economics literature is Huang et al. (2013). These authors used data from the Chinese Health and Retirement Longitudinal Study (CHARLS) and estimated the extent of stature loss in this population, the association between stature loss and socioeconomic variables, and how this impacts on estimates of the effects of height and various adult outcomes. It is not clear whether their results are generalizable from the specific Chinese context to more developed countries, especially given the type of environments faced by the individuals in their data, which are not necessarily comparable to those faced by individuals in Western societies. In addition, as they only have a single cross-section of data, they rely on estimating pre-shrinkage height by predicting the relationship between limb length and height in a separate sample.

The main contribution of this paper is that we focus on nationally representative data which contains multiple observations for each individual over time. Therefore, we are able to directly measure stature loss using objective measured height across four waves and 10 years. We are also able to determine the relevance of limb length by comparing results where we substitute demispan (arm length) measurement for height. We establish that there is surprisingly little consistent association between shrinking and time invariant individual characteristics. However, as we have longitudinal data, we are able to demonstrate that the extent of height loss is predicted by deterioration in health. In the final section we discuss the implications of shrinking for the existing economics literature.

3 Data

3.1 Sample

The English Longitudinal Study of Ageing (ELSA) is a nationally representative panel of individuals aged over 50 in England.[2] The first round of data recruitment (Wave 0) occurred separately in 1998, 2000, and 2001 from the Health Survey for England (HSE).[3] Respondents were re-interviewed in 2002–2003 for the first wave. The second wave took place in 2004–2005, the third wave in 2006–2007, and Wave 4 in 2008-2009. Detailed health exams (which included nurse measured height) were conducted in Wave 0, Wave 2, and Wave 4. As well as providing demographic and socioeconomic information in each round, Wave 3 additionally included a retrospective life history wave, which has been shown to be an effective measure of early life conditions (Smith, 2009).

The sample size for analysis is presented in Table 1. Firstly, we focus on estimating actual stature loss as the difference in measured height between Wave 0 and Wave 2, giving a total of 6,981 observations with valid height. Of these individuals 5,168 are also present in Wave 3 to answer the module on childhood conditions. We also measure height loss between Wave 0 and Wave 4, which results in a sample of 4,625. Finally, in Wave 0 demispan measurement was taken from individuals aged 65 and over who also have height data, giving 4,654 observations. Because not all of these individuals were re-contacted for Wave 2, this represents a separate analysis sample. In all of our analysis we consider males and females separately. We are able to exploit differences in the length of time since the first interview to determine age effects when estimating stature loss between Wave 0 and Wave 2, as individuals in Wave 0 were recruited from different years of the HSE.

[2]ELSA is publically available from the UK data service `http://discover.ukdataservice.ac.uk/catalogue?sn=5050` (Marmot et al., 2012).

[3]See Mindell et al., 2012.

Table 1: Analysis Sample

	Men	Women	Total
Measured Height in Wave 0 and Wave 2	3,135	3,846	6,981
Measured Height in Wave 0 and Wave 2 and Childhood Variables in Wave 3	2,303	2,865	5,168
Measured Height in Wave 0, Wave 2 and Wave 4	2,051	2,574	4,625
Demispan Sample (65+ in W0)	2,098	2,556	4,654

Table 2: Variables For Regression Models

Sample With Measured Height in W0 and W2				
	Mean	Median	SD	N
Year of Birth	1935.69	1939	66.48	6981
Age Wave 0	60.98	60	9.46	6981
Age Wave 2	66.09	65	9.54	6981
Age Wave 4	67.84	68	13.31	5309
HSE Start Year 1998	0.44	0	0.5	6981
HSE Start Year 1999	0.17	0	0.38	6981
HSE Start Year 2001	0.39	0	0.49	6981
Male	0.45	0	0.5	6981
Excellent Childhood Health	0.33	0	0.47	5168
Left School Before 16	0.55	1	0.5	6981
Has a Degree	0.12	0	0.33	6981
5 Quantiles of Equivalised Household Income (W0)	3.15	3	1.4	6101
Bedrooms in Childhood Residence	2.93	3	0.91	4981
Number of Facilities in Childhood Residence	2.86	4	1.44	4994
Grip Strength W2	29.51	28	11.39	6862
Grip Strength W4	28.15	26	11.32	4677
Peak Flow W2	339.35	325	137.92	6303
Peak Flow W4	320.85	310	142.31	4379
Measured Height in Wave 0 (CM)	165.89	166	9.33	6981
Measured Height in Wave 2 (CM)	165.3	165	9.52	6981
Measured Height in Wave 4 (CM)	165.02	165	9.68	4625
Height Difference W0–W2	-0.59	-1	1.73	6981
Height Difference W0–W4	-1.19	-1	2.58	4625
Self Rated Health W2 (1=Excellent, 5=Poor)	2.76	3	1.09	6975
Self Rated Health W4 (1=Excellent, 5=Poor)	2.81	3	1.06	5204
Sample With Measured Demispan (65+ in W0)				
	Mean	Median	SD	N
Self Rated Health W0 (1=Excellent, 5=Poor)	2.27	2	0.97	4653
Demispan (cm)	76.81	77	5.31	4654

Table 2 gives descriptive statistics for variables in the regression models presented in Section 4 and Section 5 for the sample with measured height in Waves 0 and Wave 2, and the demispan sample. Initial baseline (Wave 0) measurements were taken under the auspices of the Health Survey for England. Demispan was recorded by nurses from individuals aged 65 years or over who were able to straighten their arms, while height was recorded during the main interview. The survey manual (HSE 1999) defines the demispan measurement as the distance between the sternal notch and the finger roots with arm out-stretched laterally. The measurement occurs by using a modified tape measure which hooks onto the gap between middle and ring fingers and then extends to measure the distance to the middle of the respondent's back.[4] For measuring height in the HSE interviewers were provided with a portable stadiometer, a device which consists of a sliding bar on a height scale which rests on top of the respondent's head.[5] Height was recorded without shoes, and to the nearest even millimetre.

For Wave 2 and Wave 4, all core members of the survey who had completed the previous interview in person were eligible for a nurse visit, where height was recorded. A similar procedure to the HSE was used for recording height.[6] Where the nurse was unable to measure standing height the respondent was asked to estimate their own height.[7] If the nurse believed that this guess was more than 2 cm off, the measure was recorded as unreliable. The nurse was unable to measure height in relatively few cases (for example, less than 5% of individuals in Wave 2).

Attrition is a feature of these data, and we carefully consider the consequences of attrition for our results throughout the analysis. Firstly, we are using height differences generated by subtracting measured height in Wave 0 with measured height in Wave 2 and Wave 4. Tracing and comparing the birth cohort height trajectories (using levels) over multiple waves would be problematic, and is therefore avoided. Secondly, we use the fact that we have multiple waves of data to perform sensitivity analyses. Our ex-

[4] http://www.esds.ac.uk/doc/4365%5Cmrdoc%5Cpdf%5Ca4365iab.pdf#page=157

[5] http://www.esds.ac.uk/doc/4365%5Cmrdoc%5Cpdf%5Ca4365iab.pdf#page=78

[6] http://www.esds.ac.uk/doc/5050%5Cmrdoc%5Cpdf%5C5050_Wave_2_Documentation.pdf#page=905

[7] An example of this might be if a respondent was in a wheelchair.

pectation is that some common element generating attrition exists. If attrition is biasing our results, then we would expect to see a difference in the analysis where we use the height difference between Wave 0 and Wave 2 and Wave 0 and Wave 4 as the outcome. Thirdly, if a degree of attrition bias does exist, our prior is that this bias is attenuating because smaller, less healthy individuals are more likely to leave the sample. If anything, the model results presented in the following are therefore likely to understate the relationship between height, stature loss, and health.

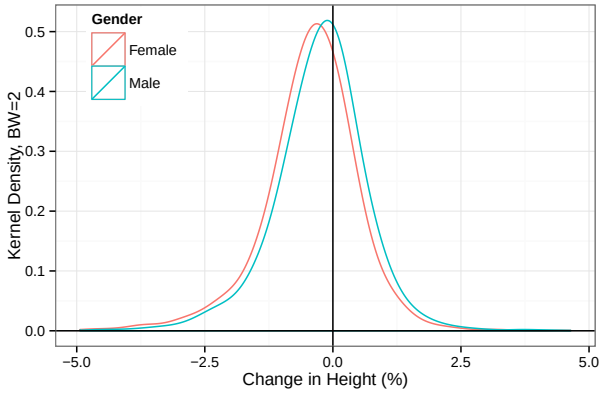
3.2 Stature Loss

We present initial evidence on the extent of stature loss based on the actual observed change in measured height across waves. All of our analysis concerns the change in height for the same individual, and not estimated using separate cohorts or samples. As outlined in Table 2, on average respondents lost 0.6 cm between Wave 0 and Wave 2, compared to the overall mean of 166 cm. Consistently, the mean loss from Wave 0 to Wave 4 was twice this. Interpreting the raw descriptive statistics is complicated by the fact that baseline height was collected in three different years depending on the initial HSE year, but on average this translates into a loss of 0.1 cm per year. In all our analyses we consider men and women separately, as previous research has established that women are more likely to be affected by stature loss (Huang et al., 2013). This is confirmed in our data.

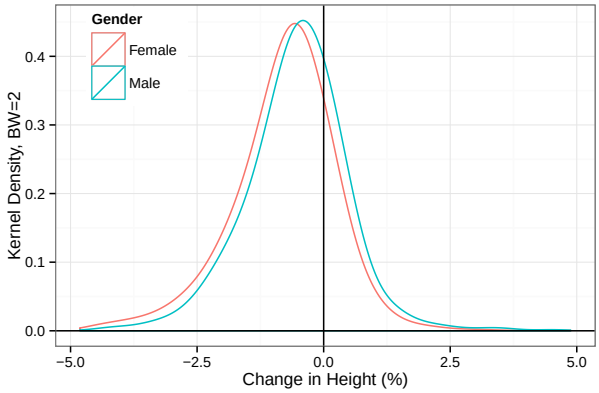
Figure 1 presents kernel density estimation plots of the percentage change in height. Panel (a) displays the difference between Wave 0 and Wave 2. Both men and women exhibit distributions where the mean is negative, and this is particularly evident for women. Panel (b) shows the corresponding density plot for the change in heights between Wave 0 and Wave 4. The stature loss is even more pronounced over this longer time period. We focus on the percentage change rather than the absolute change in order to capture the fact that the rate of shrinking is greater for taller individuals (which is also confirmed in the data).

Figure 1: Changes in Height Between Waves.

(a) Waves 0 and 2



(b) Waves 0 and 4



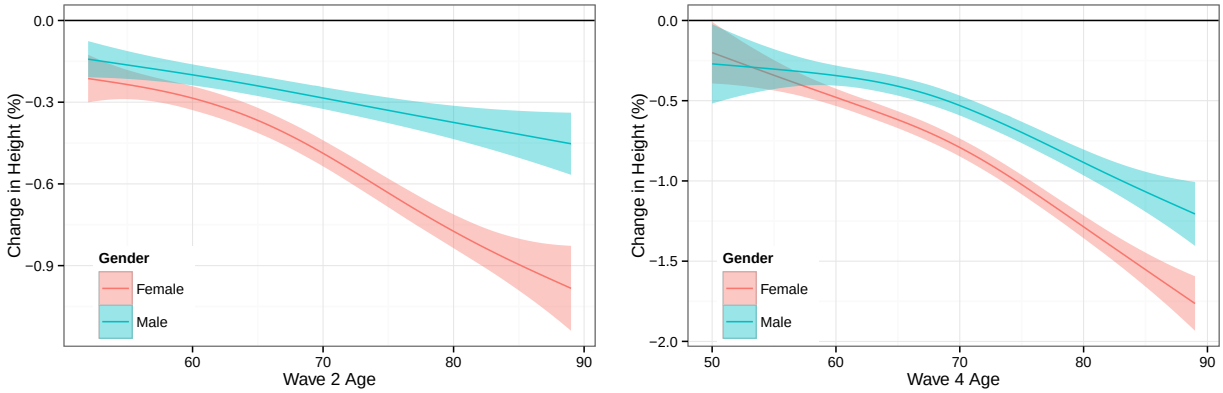
Source: ELSA Sample.

While the mean of each height distribution in Figure 1 is evidently less than zero, a considerable portion of individuals appear to increase in height. We see two reasons for this. Firstly, it is well established in the biology literature that height varies quite considerably over the day (Tillmann and Clayton, 2001). Secondly, we cannot rule out the existence of other forms of randomly distributed measurement error. Therefore, our measure of stature loss contains a certain degree of noise. However, it is worth emphasizing that we use changes in height as a dependent variable in the following analyses, and consequently our estimated models remain unbiased, although we face a loss in precision (the asymptotic variance will be larger).

Figure 2 plots the relationship between stature loss and age using semi-parametric generalized additive models. In panel (a), for individuals under 60, the loss is less than a third of a percentage point. However, for those aged over 60 the loss is up to a percentage point for both men and women. Panel (b) demonstrates the equivalent change between Wave 0 and Wave 4. The effect is much larger for both men and women, with the average loss in stature over the time period approaching 2 percentage points for the oldest women. On the basis of these results there is evidence that stature loss is most important after the age of 60.

Figure 2: Age Related Changes in Height Between Waves.

(a) Waves 0 and 2 (b) Waves 0 and 4



Source: ELSA Sample. +/- 1 SD Shaded.

4 Comparing Cohorts in the Presence of Stature Loss

As outlined in the introduction, a common means of comparing the welfare of populations has been to evaluate their heights, particularly, but not exclusively, in the absence of any other health related data. However, these comparisons almost always involve the use of a single cross section, or occasionally repeated cross sections, and to the best of our knowledge few studies have adjusted their data to take account of stature loss.

Given our findings in the previous section, ignoring this problem has the potential to provide very misleading results. The worst case scenario involves using a single cross section of data, comparing the height of the elderly to the height of the young, and ascribing any difference to birth cohort effects. Figure 2 shows that there are substantial age effects. In what follows, we use the observed change in measured height for each individual. This allows us to separate out the cohort and age effects, and demonstrate the extent of the bias that stature loss causes in these comparisons.

We correct the birth cohort height trajectory with the following procedure. Firstly,

we fit the following linear regression models:

$$\frac{(\mathbf{h}_{it} - \mathbf{h}_{i0})}{\mathbf{h}_{i0}} = \alpha + \beta \mathbf{age}_{it} + (\mathbf{year}_{it} - \mathbf{year}_{i0})\gamma + \boldsymbol{\varepsilon}_{it}, \qquad t \in \{2, 4\} \tag{1}$$

separately for both men and women, where t indicates the terminal wave, the dependent variable represents the percentage change for individual i's height between waves, and the regressors are age in terminal wave and the difference in years between waves (as a categorical variable). Eq. (1) is a simple representation of how stature change is related to both age and time. In the following section, we add explanatory variables. While we have adopted a basic linear functional form in eq. (1), we also estimated this relationship via nonparametric regression, and found that the results were almost identical.[8] As discussed above, we use the percentage change in height as we find that stature loss is positively correlated with initial height, indicating that taller individuals have the capacity to shrink more.

The coefficient estimates of eq. (1) are listed in Table 3 and Table 4 (included in Section 5). We use these estimates to correct for age related height loss by predicting the percentage height change for each individual depending on their age, and then calculating the cumulative height loss by projecting these in reverse until the individual's age in the initial wave is 50.[9]

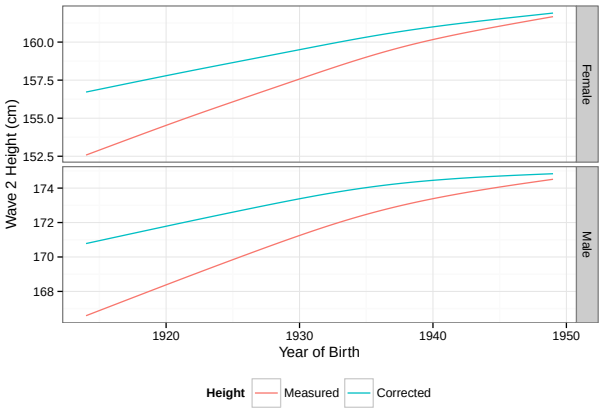
Panel (a) in Figure 3 gives results of this analysis based on our aforementioned correction procedure for Waves 0 and Wave 2. This graphic demonstrates the magnitude of the bias which arises from ignoring the effects of stature loss when comparing populations on the basis of height. In a single cross section, the researcher would conclude that the female cohort born around 1940 was approximately 5.4 cm taller than the female cohort born around 1920. In reality, once the fact that those born in the 1920s are older in the data and stature loss is accounted for, the difference is closer to 1 cm. For men, this difference is also evident. For example, the difference in raw height between those born

[8] These results are available upon request.

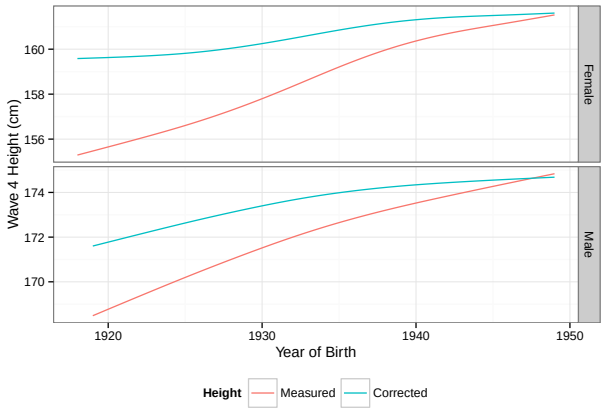
[9] For example, a male is aged 52 and 170 cm tall in Wave 2. From our estimates this, male will have a corrected height of 170 cm + 170 cm$\times$0.037% $\approx$ 170.06 cm at age 52, 170.06 cm + 170.06 cm $\times$ 0.036% $\approx$ 170.12 cm at age 51, and 170.12 cm + 170.12 cm $\times$ 0.034% $\approx$ 170.18 cm at age 50.

Figure 3: Measured and Corrected Heights Comparison.

(a) Waves 0 and 2



(b) Waves 0 and 4



Source: ELSA Sample.

in the 1920 and those born in the 1940 is approximately 5 cm in the data, but is 2.6 cm when adjusted for age effects. This difference is somewhat smaller for males, reflecting the fact that females are more prone to age-related stature loss. We also find similar results when we estimate the model using changes in height between Wave 0 and Wave 4, as displayed in panel (b).[10] This analysis demonstrates that cohort comparisons on the basis of height data which is not adjusted for age structure can provide highly misleading results. In particular, the use of unadjusted height will dramatically understate the welfare of the older population. In the following, section we consider the implications of stature loss for the existing economics literature.

5 Characteristics and Consequences of Stature Loss

Thus far we have presented evidence that clearly shows how stature loss affects older populations. In this section, we further our analysis by exploring whether there is individual-level heterogeneity in terms of predictors of stature change.

[10]We note that the levels appear to be different, as those in panel (b) are taller than those in panel (a). The source of this discrepancy is likely to be due to attrition bias. Nevertheless, our result—that leaving stature uncorrected overstates differences in height—remains intact.

Table 3: Modeling Percentage Changes in Height Between Waves: Male Sample

	Waves 0 to 2					Waves 0 to 4				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
(Intercept)	0.532***	0.517***	0.491***	0.479***	0.519**	1.224***	1.147***	1.145***	1.292***	1.165***
	(0.123)	(0.146)	(0.149)	(0.176)	(0.210)	(0.223)	(0.232)	(0.234)	(0.261)	(0.302)
Age W2	−0.009***	−0.009***	−0.009***	−0.008***	−0.009***					
	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)					
Age W4						−0.027***	−0.026***	−0.026***	−0.026***	−0.025***
						(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
4 Years Between Waves	−0.061	−0.035	−0.032	−0.051	−0.052					
	(0.051)	(0.059)	(0.059)	(0.060)	(0.064)					
5 Years Between Waves	−0.275***	−0.246***	−0.247***	−0.280***	−0.252***					
	(0.065)	(0.076)	(0.076)	(0.077)	(0.082)					
6 Years Between Waves	−0.282***	−0.306***	−0.305***	−0.324***	−0.315***					
	(0.044)	(0.050)	(0.050)	(0.052)	(0.054)					
7 Years Between Waves	−0.293***	−0.277***	−0.276***	−0.299***	−0.325***	0.246	0.281*	0.281*	0.267	0.240
	(0.055)	(0.065)	(0.065)	(0.066)	(0.070)	(0.158)	(0.162)	(0.162)	(0.165)	(0.173)
8 Years Between Waves						0.162	0.184	0.187	0.171	0.133
						(0.161)	(0.166)	(0.166)	(0.169)	(0.176)
9 Years Between Waves						−0.030	−0.016	−0.012	−0.021	−0.025
						(0.164)	(0.169)	(0.169)	(0.172)	(0.180)
10 Years Between Waves						−0.028	−0.011	−0.010	−0.012	−0.020
						(0.156)	(0.160)	(0.160)	(0.163)	(0.170)
11 Years Between Waves						−0.143	−0.127	−0.123	−0.136	−0.167
						(0.163)	(0.168)	(0.168)	(0.171)	(0.179)
Excellent Childhood Health		0.079**		0.084**	0.086**		0.062		0.068	0.074
		(0.039)		(0.040)	(0.042)		(0.045)		(0.046)	(0.049)
Excellent or Very Good Childhood Health			0.081**					0.040		
			(0.040)					(0.047)		
Facilities in Childhood Home				0.029**	0.026*				0.016	0.020
				(0.014)	(0.015)				(0.016)	(0.017)
# Bedrooms in Childhood Home				−0.041*	−0.035				−0.067***	−0.060**
				(0.021)	(0.022)				(0.025)	(0.027)
Left School Before 16					0.012					0.076
					(0.048)					(0.056)
Has a Degree					−0.006					−0.028
					(0.059)					(0.068)
Equivalised Income Quintile: 2					0.053					0.049
					(0.075)					(0.090)
Equivalised Income Quintile: 3					−0.014					0.038
					(0.075)					(0.091)
Equivalised Income Quintile: 4					−0.058					0.016
					(0.074)					(0.088)
Equivalised Income Quintile: 5					0.031					0.065
					(0.078)					(0.092)
R^2	0.028	0.033	0.033	0.038	0.040	0.067	0.071	0.070	0.074	0.070
Adj. R^2	0.026	0.031	0.031	0.034	0.033	0.065	0.067	0.067	0.069	0.062
Num. obs.	3098	2282	2282	2185	1949	2187	1963	1963	1890	1693

$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$

5.1 Stature Loss and Early Environment

Both Table 3 and Table 4 display our linear regression results when we model changes in height as a function of observable fixed characteristics. Columns (1) and (6) of both tables correspond to the regression model in eq. (1). The other columns display the results for additional regression models wherein we introduce additional variables that measure childhood conditions, education, and current income.

The results exhibited in Table 3 provide mixed evidence for the hypothesis that childhood conditions play an important role in stature loss for the male population. The self-reported measure of childhood health is positively correlated with stature change,

Table 4: Modeling Percentage Changes in Height Between Waves: Female Sample

	Waves 0 to 2					Waves 0 to 4				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
(Intercept)	1.148***	1.017***	1.020***	0.834***	0.881***	2.143***	2.090***	2.136***	2.080***	1.165***
	(0.108)	(0.129)	(0.129)	(0.153)	(0.183)	(0.206)	(0.219)	(0.219)	(0.247)	(0.302)
Age in Wave 2	−0.021***	−0.020***	−0.020***	−0.018***	−0.017***					
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)					
Age in Wave 4						−0.040***	−0.041***	−0.041***	−0.041***	−0.025***
						(0.002)	(0.002)	(0.002)	(0.002)	(0.003)
4 Years Between Waves	0.012	0.059	0.060	0.051	0.045					
	(0.047)	(0.053)	(0.053)	(0.054)	(0.058)					
5 Years Between Waves	−0.364***	−0.289***	−0.289***	−0.298***	−0.306***					
	(0.059)	(0.067)	(0.066)	(0.068)	(0.074)					
6 Years Between Waves	−0.297***	−0.260***	−0.260***	−0.268***	−0.297***					
	(0.039)	(0.044)	(0.044)	(0.045)	(0.048)					
7 Years Between Waves	−0.280***	−0.181***	−0.181***	−0.168***	−0.208***	−0.042	0.022	0.020	0.109	0.240
	(0.049)	(0.057)	(0.057)	(0.058)	(0.063)	(0.151)	(0.158)	(0.158)	(0.165)	(0.173)
8 Years Between Waves						−0.005	0.055	0.053	0.159	0.133
						(0.154)	(0.162)	(0.162)	(0.169)	(0.176)
9 Years Between Waves						−0.288*	−0.206	−0.212	−0.108	−0.025
						(0.156)	(0.163)	(0.163)	(0.170)	(0.180)
10 Years Between Waves						−0.283*	−0.223	−0.227	−0.120	−0.020
						(0.150)	(0.157)	(0.157)	(0.164)	(0.170)
11 Years Between Waves						−0.268*	−0.196	−0.200	−0.077	−0.167
						(0.156)	(0.163)	(0.163)	(0.171)	(0.179)
Excellent Childhood Health		−0.003		−0.007	0.003		0.049		0.042	0.074
		(0.036)		(0.037)	(0.040)		(0.042)		(0.043)	(0.049)
Excellent or Very Good Childhood Health			−0.007					−0.005		
			(0.035)					(0.041)		
Facilities in Childhood Home				0.018	0.019				−0.001	0.020
				(0.012)	(0.013)				(0.014)	(0.017)
# Bedrooms in Childhood Home				0.008	−0.008				−0.014	−0.060**
				(0.019)	(0.021)				(0.022)	(0.027)
Left School Before 16					0.000					0.076
					(0.041)					(0.056)
Has a Degree					0.039					−0.028
					(0.067)					(0.068)
Equivalised Income Quintile: 2					−0.063					0.049
					(0.060)					(0.090)
Equivalised Income Quintile: 3					−0.044					0.038
					(0.063)					(0.091)
Equivalised Income Quintile: 4					−0.098					0.016
					(0.062)					(0.088)
Equivalised Income Quintile: 5					−0.038					0.065
					(0.066)					(0.092)
R^2	0.074	0.063	0.063	0.061	0.061	0.130	0.134	0.133	0.135	0.070
Adj. R^2	0.072	0.061	0.061	0.059	0.056	0.128	0.131	0.131	0.131	0.062
Num. obs.	3765	2817	2817	2697	2355	2775	2481	2481	2373	1693

$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$. Standard errors and p-values in Models 1–9 adjusted for heteroscedasticity.

indicating that those with better childhood health—defining themselves either excellent, or very good and excellent—experienced a lower degree of stature loss. Columns (4), (5), (9), and (10) include further measures that account for childhood environment: facilities in the childhood home and number of bedrooms in this home. Household facilities also appear to be protective. This holds only for stature loss between Waves 0 and Wave 2. However, these results show the existence of a negative conditional relationship between the number of bedrooms in childhood home and stature change for Waves 0 to Wave 4. If we use number of bedrooms as an indicator of childhood family income, these results indicate that greater childhood family wealth is associated with stature loss. However, it is difficult to separate whether or not this variable is contaminated by urban-rural differences. Unfortunately the data do not contain information on the location of birth or childhood residence. In columns (5) and (10) we add further explanatory variables that measure educational attainment and income. Interestingly, these variables do not appear to predict stature loss.

Table 4 reports the results for women in an equivalent format to those displayed for men. To an even greater extent than for men, there is no consistent predictor of stature loss.

5.2 Changing Health Status and Stature Loss

The previous section tested for predictors of stature loss in terms of time invariant characteristics. In this section, we expand our analysis to examine the dynamic relationship connecting height and health status. To do this, we exploit the panel nature of our data and estimate the following linear regression model:

$$\Delta \mathbf{h}_{it} = \alpha + \Delta \mathbf{health}_{it}\beta + \Delta \mathbf{year}_{it}\boldsymbol{\gamma} + \boldsymbol{\varepsilon_i} \tag{2}$$

where changes in height ($\Delta \mathbf{h}_{it}$) are regressed on changes in health ($\Delta \mathbf{health}_{it}$) and the number of years between waves, which we model as a fixed effect. Since we are using

Table 5: Panel Regressions, Change in Height between Waves 2 and 4 (Z-Scores)

	Male Sample		Female Sample	
	(1)	(2)	(3)	(4)
(Intercept)	0.104^{*}	0.108^{*}	-0.040	-0.041
	(0.061)	(0.061)	(0.050)	(0.050)
Change in Peak Flow (Z-Score)	0.048^{**}		0.074^{***}	
	(0.021)		(0.025)	
Change in Grip Strength (Z-Score)		0.062^{***}		0.047^{*}
		(0.021)		(0.025)
4 Years between Waves 2 and 4	-0.076	-0.079	-0.003	-0.001
	(0.067)	(0.067)	(0.056)	(0.056)
5 Years between Waves 2 and 4	0.007	-0.006	0.056	0.063
	(0.117)	(0.117)	(0.096)	(0.096)
R^2	0.004	0.006	0.004	0.002
Adj. R^2	0.002	0.004	0.003	0.000
Num. obs.	1751	1751	2112	2112

$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$

a first differences approach, we can rule out the influence of fixed factors, or individual heterogeneity that does not change over time, which may simultaneously influence stature loss and changes in health status.

To model the effect of changing health status, we use two well-known indicators: peak flow and grip strength. Both are markers of worsening physical health. Since these health variables were not measured in the baseline interview, so we model changes between Waves 2 and Wave 4.

Our results are presented in Table 5. Once again, we split our sample based on gender. Overall, the coefficients reported in this table are consistent with the hypothesis that stature loss is a function of worsening health. Each of the coefficients on either peak flow or grip strength is positive, and all the two-sided t-tests have p-values, at most, below 0.1. Interestingly, none of the coefficients included to measure time between the surveys appears to be important in the model, as all of these coefficients are small in magnitude and have t-test p-values above any conventional statistical significance

Table 6: Placebo Panel Regressions, Change in between Height Waves 0 and 2 (Z-Scores)

	Male Sample		Female Sample	
	(1)	(2)	(3)	(4)
(Intercept)	0.298^{***}	0.296^{***}	0.091^{**}	0.091^{**}
	(0.053)	(0.053)	(0.044)	(0.044)
Change in Peak Flow (Z-Score)	0.007		-0.008	
	(0.021)		(0.025)	
Change in Grip Strength (Z-Score)		-0.010		0.008
		(0.021)		(0.024)
4 Years between Waves 0 and 2	-0.097	-0.095	0.091	0.091
	(0.078)	(0.078)	(0.066)	(0.066)
5 Years between Waves 0 and 2	-0.218^{**}	-0.217^{**}	-0.310^{***}	-0.309^{***}
	(0.104)	(0.104)	(0.082)	(0.082)
6 Years between Waves 0 and 2	-0.391^{***}	-0.390^{***}	-0.293^{***}	-0.294^{***}
	(0.067)	(0.067)	(0.055)	(0.055)
7 Years between Waves 0 and 2	-0.326^{***}	-0.325^{***}	-0.183^{***}	-0.182^{***}
	(0.085)	(0.085)	(0.070)	(0.070)
R^2	0.024	0.024	0.028	0.028
Adj. R^2	0.021	0.021	0.025	0.025
Num. obs.	1747	1747	2117	2117

$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$

level. This finding suggests that, conditional on the inclusion of health changes, time, or change in age, does not matter for height loss. In other words, stature loss is mediated through deteriorating health status (which obviously is a function of age) but age itself does not appear to have an independent effect on changes in height in this population.

To examine the robustness of our findings in Table 5, we conduct a placebo test. One concern with Table 5 is that a simultaneity exists between height and health differences, so that our results may simply reflect a path dependence between these two elements. Our placebo analysis represents an attempt to allay this concern by modeling height change between Wave 0 and Wave 2 as a function of later changes in health status. If a path dependence exists, then we would expect to find a relationship between previous stature loss and later health change. However, Table 6, which is presented in

an identical format to Table 5, does not support such a relationship. All of the health variable coefficients are insignificant. Furthermore, the time effect that was absent from Table 5 appears to be present in these models.

5.3 Consequence of Stature Loss For Health Production Function Estimation

In the previous sections we demonstrated how stature loss is both symptomatic of poor health, and can dramatically overstate birth cohort comparisons in cross-sectional data. In this section we extend this line of investigation, and analyze the importance of using a measure of stature that is not subject to change over the life course. We estimate the following prototypical health production function:

$$\mathbf{health}_i = \alpha + \mathbf{height}_i\beta + \mathbf{X}_i\gamma + \boldsymbol{\varepsilon_i} \tag{3}$$

where we measure health as a function of height and other factors ($\mathbf{X}_i$). As previously discussed, height is commonly used as a control variable to capture net nutrition in early life and genetic factors. Estimating eq. (3) is potentially problematic in cases where health status is correlated with unadjusted height, causing $\hat{\beta}$ to be greater than its true value.

Huang et al. (2013) used an adjusted measure of height, via a two-step procedure, whereby arm and leg lengths of a younger cohort are used to predict height an older cohort. The rationale underlining this methodology assumes that arm and leg length do not change over the life course of an individual, so in effect they are just substituting the unadjusted height for arm and leg lengths. We follow a similar methodology here, and use the demispan measurement that was collected in the baseline survey. Unlike Huang et al., we do not use a two-step procedure. Instead we include the demispan variable as a substitute for unadjusted height and standardize both measures into z-scores so that we can directly compare the coefficients. In our case there is no advantage to using the

Table 7: Health Production Functions, Linear Probability Models: Self-Rated Health is Excellent or Very Good.

	Male Sample				Female Sample			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(Intercept)	0.833***	0.859***	0.928***	0.931***	0.859***	0.890***	0.935***	0.950***
	(0.135)	(0.133)	(0.134)	(0.132)	(0.120)	(0.118)	(0.120)	(0.120)
Age W0	−0.003	−0.003*	−0.003	−0.003	−0.003**	−0.004**	−0.003**	−0.004**
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Height W0 (Z-Score)	0.032***		0.021*		0.041***		0.031***	
	(0.011)		(0.011)		(0.010)		(0.010)	
Demispan W0 (Z-Score)		0.031***		0.025**		0.040***		0.033***
		(0.011)		(0.011)		(0.010)		(0.010)
Has a Degree			0.080**	0.081**			0.142**	0.142***
			(0.039)	(0.039)			(0.056)	(0.044)
Left School Before 16			−0.159***	−0.161***			−0.129***	−0.131***
			(0.027)	(0.027)			(0.022)	(0.021)
R^2	0.007	0.007	0.036	0.037	0.011	0.011	0.031	0.032
Adj. R^2	0.006	0.006	0.035	0.035	0.010	0.010	0.029	0.030
Num. obs.	2097	2097	2094	2094	2556	2556	2554	2554
t-test of Height=Demispan P-value		0.899		0.710		0.928		0.830

$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$. Standard errors and p-values in Models 1–8 adjusted for heteroscedasticity.

Huang et al. method, and replicating it would only result in larger standard errors on the corrected height coefficient due to the addition of regression parameter uncertainty.

Table 7 details the health production function regression results. Once again, we stratify our results based on gender, and within this we perform two analyses. In the first case—columns (1) and (2), and columns (5) and (6)—we do not include any additional control variables. Column (1) shows the coefficient results when unadjusted height is included as a regressor, whereas column (2) includes demispan, instead of unadjusted height, as the regressor of interest. The format is identical for the female sample, shown in columns (5) and (6). Columns (3), (4), (7), and (8) show results for equivalent models that include control variables for educational attainment. Overall, the results in Table 7 show that the naïve use of non-stature adjusted height does not lead to substantial biases in empirical health production functions. Columns (2), (4), (6), and (8) all include p-values from t-tests examining if the height coefficient from the previous column is equal to the demispan coefficient. All of these tests fail to reject the null hypothesis that the two stature measures are equal.

Tables 8 and 9 further our analysis into the potential biases introduced from using unadjusted height. These tables make use of the fact that our data is in longitudinal

Table 8: Health Production Functions, Linear Probability Models: Self-Rated Health is Excellent or Very Good, Male Sample

	Waves 0 and 2				Waves 0 and 4			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(Intercept)	0.906***	0.914***	0.866***	0.873***	0.841***	0.861***	0.777***	0.791***
	(0.067)	(0.067)	(0.067)	(0.067)	(0.091)	(0.089)	(0.090)	(0.089)
Age W2	−0.007***	−0.008***	−0.006***	−0.006***				
	(0.001)	(0.001)	(0.001)	(0.001)				
Age W4					−0.006***	−0.006***	−0.005***	−0.005***
					(0.001)	(0.001)	(0.001)	(0.001)
Height W0 (Z-Score)		0.032***		0.020**		0.024**		0.011
		(0.009)		(0.009)		(0.011)		(0.011)
Height W2 (Z-Score)	0.034***		0.022**					
	(0.009)		(0.009)					
Height W4 (Z-Score)					0.028**		0.016	
					(0.011)		(0.011)	
Has a Degree			0.099***	0.099***			0.094***	0.095***
			(0.026)	(0.026)			(0.029)	(0.030)
Left School Before 16			−0.098***	−0.098***			−0.104***	−0.105***
			(0.020)	(0.020)			(0.024)	(0.024)
R^2	0.028	0.027	0.048	0.048	0.016	0.016	0.039	0.038
Adj. R^2	0.027	0.027	0.047	0.046	0.016	0.015	0.037	0.036
Num. obs.	3093	3093	3093	3093	2187	2187	2187	2187
t-test of Later Height=Earlier Height P-value		0.830		0.819		0.707		0.660

$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$. Standard errors and p-values in Models 1–8 adjusted for heteroscedasticity.

Table 9: Health Production Functions, Linear Probability Models: Self-Rated Health is Excellent or Very Good, Female Sample

	Waves 0 and 2				Waves 0 and 4			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(Intercept)	0.845***	0.862***	0.836***	0.850***	0.910***	0.940***	0.840***	0.863***
	(0.061)	(0.060)	(0.061)	(0.060)	(0.076)	(0.075)	(0.076)	(0.074)
Age W2	−0.006***	−0.007***	−0.005***	−0.005***				
	(0.001)	(0.001)	(0.001)	(0.001)				
Age W4					−0.007***	−0.008***	−0.006***	−0.006***
					(0.001)	(0.001)	(0.001)	(0.001)
Height W0 (Z-Score)		0.017**		0.006		0.020**		0.006
		(0.008)		(0.008)		(0.009)		(0.010)
Height W2 (Z-Score)	0.022***		0.011					
	(0.008)		(0.009)					
Height W4 (Z-Score)					0.027***		0.014	
					(0.010)		(0.010)	
Has a Degree			0.069**	0.070**			0.123***	0.124***
			(0.030)	(0.030)			(0.032)	(0.032)
Left School Before 16			−0.126***	−0.128***			−0.138***	−0.140***
			(0.017)	(0.017)			(0.020)	(0.020)
R^2	0.019	0.019	0.039	0.038	0.025	0.024	0.055	0.054
Adj. R^2	0.019	0.018	0.038	0.037	0.025	0.023	0.054	0.053
Num. obs.	3764	3764	3764	3764	2774	2774	2774	2774
t-test of Later Height=Earlier Height P-value		0.531		0.506		0.439		0.392

$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$. Standard errors and p-values in Models 1–8 adjusted for heteroscedasticity.

form, so we have repeated height measurements. Table 8 presents the results obtained via the male only sample, and Table 9 is the equivalent table for the female sample. In all of these regressions we use unadjusted height, however we allow unadjusted height to vary based on the sample wave. For example, columns (1)–(4) in both tables display results obtained using a sample of individuals interviewed in both Wave 0 and Wave 2, whereas (5)–(8) shows individuals interviewed in Wave 0 and Wave 4.

The assumption underlining the analysis here is that height measured at Wave 0 is less subject to stature loss than the heights measured in the latter waves. Thus, stature loss should bias the latter wave height coefficients away from the null. The results reported in Tables 8 and 9, show that this occurs to a certain extent. The coefficients on height from Wave 2 and Wave 4 are typically greater than those from the first wave. Furthermore, the disparity between these is greater when the comparison is made between Wave 4 and Wave 0, as opposed to between Wave 2 and Wave 0, which we would expect as stature loss increases over time. However, as in Table 7, all of the p-values on t-tests examining the equality of the coefficients cannot reject the null hypothesis, at any conventional significance level. In summary, it appears that while the height coefficients in health production functions may be biased, the extent of this bias appears not to be substantial, although further research is required to establish whether our results generalize fully to other settings.

6 Conclusion

This paper documents the extent of stature loss in an elderly population. We find substantial amounts of shrinkage, which increases in age. Ignoring the life course trajectory associated with height will dramatically overstate cohort differences when viewed in terms of a cross section. At the same time, we find a lack of consistent predictors of stature loss in terms of fixed characteristics such as education, childhood environment, or adult household income. However, we demonstrate that height loss occurs in conjunction with health shocks. When we test for how this form of measurement error affects

the typical regression analysis involving height, we find that, qualitatively, results are not affected.

Our results have a number of consequences for the extensive economics literature on height. To the best of our knowledge, this paper is the first to provide evidence on the extent of stature loss in a nationally representative sample with longitudinal objective measurements. We are therefore able to validate the use of height in previous research, where concerns about shrinking have been raised, but not tested (Case and Paxson, 2008). While our results indicate no significant differences in the effects of adjusted and unadjusted height for health, future research should investigate further whether these findings hold in other contexts beyond the health production function regressions we present in this paper. Although our findings suggest that the consequences of stature loss for individual level analysis may not be too adverse, this is not that case at cohort level. We show that age structure must be accounted for when comparing height across groups.

Finally, we found no clear relationship between stature loss and measures of SES or childhood health. This is perhaps somewhat surprising, given the literature on the consequences of these variables for health. Instead, our results are more consistent with the view that shrinking is affected by health shocks, as opposed to the health stock of an individual. It will take further research to establish whether there are any causal determinants of stature loss.

Acknowledgments

The views expressed in this paper are those of the author(s) and not necessarily those of the Harvard Initiative for Global Health. The Program on the Global Demography of Aging receives funding from the National Institute on Aging, Grant No. 1 P30 AG024409-06.

Fernihough's postdoctoral research is funded by the European Research Council under the European Union's Seventh Framework Programme (FP7/2007-2013) / ERC grant agreement no. 249546.

References

[1] Yoko Akachi and David Canning. Health trends in Sub-Saharan Africa: Conflicting evidence from infant mortality rates and adult heights. *Economics and Human Biology*, 8(2):273–288, 2010.

[2] Harold Alderman, Michael Lokshin, and Sergiy Radyakin. Tall claims: Mortality selection and the height of children in India. *Economics & Human Biology*, 9(4):393–406, 2011.

[3] Howard Bodenhorn, Carolyn Moehling, and Gregory N. Price. Short criminals: Stature and crime in early America. *Journal of Law and Economics*, 55(2):393–419, 2012.

[4] Carlos Bozzoli, Angus Deaton, and Climent Quintana-Domeque. Adult height and childhood disease. *Demography*, 46(4):647–669, 2009.

[5] Anne Case and Christina Paxson. Stature and status: Height, ability, and labor market outcomes. *Journal of Political Economy*, 116(3):499–532, 2008.

[6] Anne Case and Christina Paxson. Causes and consequences of early-life health. *Demography*, 47(1):S65–S85, 2010.

[7] Peggy J. Chandler and R. Darrell Bock. Age changes in adult stature: trend estimation from mixed longitudinal data. *Annals of Human Biology*, 18(5):433–440, 1991.

[8] Martha G. Cline, Keith E. Meredith, John T. Boyer, and Benjamin Burrows. Decline of height with age in adults in a general population sample: estimating maximum height and distinguishing birth cohort effects from actual loss of stature with aging. *Human biology*, 61(3):415–25, 1989.

[9] David Cutler, Angus Deaton, and Adriana Lleras-Muney. The determinants of mortality. *The Journal of Economic Perspectives*, 20(3):97–120, 2006.

[10] Angus Deaton. Height, health, and development. *Proceedings of the National Academy of Sciences*, 104(33):13232–13237, 2007.

[11] Angus Deaton and Raksha Arora. Life at the top: The benefits of height. *Economics & Human Biology*, 7(2):133–136, 2009.

[12] Kevin Denny. Height and well-being amongst older Europeans. *Geary Institute, University College Dublin Working Papers WP 201048*, 2010.

[13] Richard A. Easterlin. The worldwide standard of living since 1800. *The Journal of Economic Perspectives*, 14(1):7–26, 2000.

[14] Janet L. Engstrom, Susan A. Paterson, Anastasia Doherty, Mary Trabulsi, and Kara L. Speer. Accuracy of self-reported height and weight in women: An integrative review of the literature. *The Journal of Midwifery & Womens Health*, 48(5):338–345, 2003.

[15] Robert W. Fogel. *The Escape from Hunger and Premature Death, 1700–2100: Europe, America, and the Third World*. Cambridge University Press, 2004.

[16] Robert W. Fogel. Health, nutrition, and economic growth. *Economic Development and Cultural Change*, 52(3):643–658, 2004.

[17] Alison Galloway, William A. Stini, Sherry C. Fox, and Patricia Stein. Stature loss among an older United States population and its relation to bone mineral status. *American Journal of Physical Anthropology*, 83(4):467–476, 1990.

[18] Allison Galloway. Estimating actual height in the older individual. *Journal of Forensic Sciences*, 33(1):126, 1988.

[19] Vasant Hirani and Jennifer Mindell. A comparison of measured height and demi-span equivalent height in the assessment of body mass index among people aged 65 years and over in England. *Age and Ageing*, 37(3):311–317, 2008.

[20] Vasant Hirani, Faiza Tabassum, Maria Aresu, and Jennifer Mindell. Development of new demi-span equations from a nationally representative sample of adults to estimate maximal adult height. *The Journal of Nutrition*, 140(8):1475–1480, 2010.

[21] Wei Huang, Xiaoyan Lei, Geert Ridder, John Strauss, and Yaohui Zhao. Health, height, height shrinkage and ses at older ages: Evidence from China. *American Economic Journal: Applied Economics*, Forthcoming, 2013.

[22] David A. Leon, George Davey Smith, Martin Shipley, and David Strachan. Adult height and mortality in London: Early life, socioeconomic confounding, or shrinkage? *Journal of Epidemiology and Community Health (1979-)*, 49(1):5–9, 1995.

[23] David Madden. Self-reported and measured bmi in Ireland: Should we adjust the obesity thresholds? Working Papers 201301, School Of Economics, University College Dublin, February 2013.

[24] N. Gregory Mankiw and Matthew Weinzierl. The optimal taxation of height: A case study of utilitarian income redistribution. *American Economic Journal: Economic Policy*, 2(1):155–176, 2010.

[25] Michael Marmot, Zoe Oldfield, Sam Clemens, Margaret Blake, Andrew Phelps, James Nazroo, Andrew Steptoe, Nina Rogers, and James Banks. English longitudinal study of ageing: Wave 0 (1998, 1999 and 2001) and waves 1–5 (2002–2011) [computer file]. 18th edition. sn: 5050, 2013.

[26] Jürgen Maurer. Height, education and later-life cognition in Latin America and the Caribbean. *Economics & Human Biology*, 8(2):168–176, 2010.

[27] Jennifer Mindell, Jane P. Biddulph, Vasant Hirani, Emanuel Stamatakis, Rachel Craig, Susan Nunn, and Nicola Shelton. Cohort profile: The health survey for england. *International Journal of Epidemiology*, 2012.

[28] Joel Mokyr and Cormac Ó Gráda. Height and health in the United Kingdom 1815–1860: Evidence from the East India Company Army. *Explorations in Economic History*, 33(2):141–168, 1996.

[29] Donal O'Neill and Olive Sweetman. Estimating obesity rates in the presence of measurement error. IZA Discussion Papers 7288, Institute for the Study of Labor (IZA), March 2013.

[30] Franco Peracchi and Emilia Arcaleni. Early-life environment, height and BMI of young men in Italy. *Economics & Human Biology*, 9(3):251–264, 2011.

[31] Michelle H. Raxter, Benjamin M. Auerbach, and Christopher B. Ruff. Revision of the Fully technique for estimating statures. *American Journal of Physical Anthropology*, 130(3):374–384, 2006.

[32] Michael L. Rowland. Self-reported weight and height. *The American Journal of Clinical Nutrition*, 52(6):1125–1133, 1990.

[33] Harinder K. Sethi, L. S. Sidhu, and Pushpa Singal. Estimates of aging and secular changes using total arm length. *American Journal of Human Biology*, 7(3):363–368, 1995.

[34] James P. Smith. Reconstructing childhood health histories. *Demography*, 46(2):387–403, 2009.

[35] Richard H. Steckel. Young adult mortality following severe physiological stress in childhood: Skeletal evidence. *Economics & Human Biology*, 3(2):314–328, 2005.

[36] Richard H. Steckel. Heights and human welfare: Recent developments and new directions. *Explorations in Economic History*, 46(1):1–23, 2009.

[37] Richard H. Steckel and Joseph M. Prince. Tallest in the world: Native Americans of the Great Plains in the Nineteenth Century. *American Economic Review*, 91(1):287–294, 2001.

[38] S. V. Subramanian, Emre Özaltin, and Jocelyn E. Finlay. Height of nations: A socioeconomic analysis of cohort differences and patterns among women in 54 low- to middle-income countries. *PLoS ONE*, 6(4):e18962, 2011.

[39] Vallo Tillmann and Peter E. Clayton. Diurnal variation in height and the reliability of height measurements using stretched and unstretched techniques in the evaluation of short-term growth. *Annals of Human Biology*, 28(2):195–206, 2001.

[40] Hans-Joachim Voth. Living standards during the Industrial Revolution: An economist's guide. *The American Economic Review*, 93(2):221–226, 2003.

[41] Elizabeth Webb, Diana Kuh, Anne Peasey, Andrzej Pajak, Sofia Malyutina, Ruzena Kubinova, Roman Topor-Madry, D. Denisova, Nada Capkova, Michael Marmot, and Martin Bobak. Childhood socioeconomic circumstances and adult height and leg length in Central and Eastern Europe. *Journal of Epidemiology and Community Health*, 62(4):351–357, 2008.

[42] Elise Whitley, Richard M. Martin, George Davey Smith, Jeff M. P. Holly, and David Gunnell. The association of childhood height, leg length and other measures of skeletal growth with adult cardiovascular disease: the Boyd-Orr cohort. *Journal of Epidemiology and Community Health*, 66(1):18–23, 2012.



Institute for International Integration Studies
The Sutherland Centre, Trinity College Dublin, Dublin 2, Ireland

