Toddlers, teenagers & terminal heights: The determinants of adult male stature, Flanders 1800-76[1]

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Abstract

Does adult stature capture conditions at birth or at some other stage in the growth cycle? Anthropometrics is lauded as a method for capturing net nutritional status over all the growing years. However, it is frequently assumed that conditions at birth were most influential. Was this true for historical populations? This paper examines the heights of Belgian men born between 1800-76 to tease apart which moments of growth were most sensitive to disruption and reflected in final heights. It exploits two proximate crises in 1846-49 and 1853-56 as shocks that permit age effects to be revealed. These are affirmed through a study of food prices and death rates. Both approaches suggest a shift of the critical moment away from the first few years of life and towards the adolescent growth spurt as the most influential on terminal stature. Furthermore, just as height is accumulated over the growing years, conditions influencing growth need to be understood cumulatively. Economic conditions at the time of birth were not explanatory, but their collective effects from ages 11 to 18 years were strongly influential. Then, both health and nutrition mattered, in shifting degrees. Teenagers, not toddlers, should be our guides to the past.

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It is an axiom of anthropometrics that adult stature is the product of growth from conception to maturity. Yet, in practice, when analysing differences in adult stature most explanatory weight is attributed to conditions around birth. Interpretations of trends in adult height rely heavily upon the assumption that these early-life conditions drive change. Height data are organised by birth cohorts and associations made to other proxy measures of living conditions, for example mortality rates, prices or GDP per capita, and it has become the norm in the economics and economic history literature to anchor these using the year of birth. This is valid if conditions around birth do determine adult stature, or if they can be used to proxy living conditions across the entire growth period. Often, one year is *not* like the next. History is full of wars and epidemics, good harvests and bad. In terms of adult stature, was it better to be born in a famine, or 5, 10 or 15 years earlier? There are two periods of rapid development when we expect humans to be most sensitive to environmental conditions: the first 1000 days when half adult height is achieved, and adolescence when growth rates again rise steeply and peak before slowing down and ceasing altogether (maturity), today around 19 years in well-nourished populations but in the past as late as 25 years of age. It is not clear that birth year is a sufficient guide to such a protracted growth process. We do not even know if early shocks to stature persisted into adulthood. The question posed here is, what does mature stature capture? Growing children were always affected by their environments; we examine the ages at which conditions registered an enduring effect on the adult heights of Flanders' men.

There are legitimate reasons for focusing on the first 1000 days. Barker's pioneering research showed that foetal and very early-life experiences heavily influence later-life mortality: the so-called foetal origins hypothesis.[2] A nutritional shortfall during pregnancy and the first two years

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[2] Barker and Osmond, 'Infant mortality'; Barker 'Maternal nutrition'.

after birth affects the development of the vital organs and may trigger epigenetic and other effects with adverse consequences for lifetime health, leaving the individual scarred for (their likely shorter) life. A vast economics literature examines the long-term effects of growing up during adverse conditions. Although not without criticism, there is ample evidence that the disease environment, nutritional intake and sanitary conditions during childhood are associated with later-life cognitive ability, educational attainment, socioeconomic status, and the development of chronic diseases in old age.[3] Among others, Van den Berg, Lindeboom and Portrait showed that economic conditions at birth have a significant impact on later-life mortality.[4]

Two main explanations link early-life conditions and later-life effects, and both relate to height. One focusses on the shortage of food and deprived nutritional status, while the other emphasizes the importance of the disease environment. Human growth is influenced by both. Height is not only determined by genetics, but also by net nutrition during growth.[5] Net nutrition incorporates both nutritional availability and the health and disease environment since it is the outcome of food intake less nutritional demand made by diseases as well as physical activities. Undernutrition stunts. It slows the tempo of growth. In the absence of improved conditions, the individual is likely to be shorter than would otherwise have been the case. Consequently, stature appeals as a measure of early-life conditions and shocks. Today, child height-for-age (HAZ) performance is very widely used to diagnose need, and change in HAZ is deployed to

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[3] Cognitive ability: see Case and Paxson, 'Stature and status'; Guven and Lee, 'Height, aging and cognitive abilities'; educational attainment: see Parman, 'Childhood health and human capital'; socio-economic status: see Almond and Currie, 'Killing me softly'; old age: see Bengtsson and Broström, 'Do conditions in early life affect old-age mortality'; Barker and Osmond, 'Infant mortality'; Lindeboom, Portrait and van den Berg, 'Long-run effects on longevity'.
[4] Van den Berg, Lindeboom and Portrait, 'Economic conditions early in life', p. 300.
[5] See, e.g., Deaton and Arora, 'Life at the top'; Floud et al., *The changing body*; Inwood and Roberts, 'Longitudinal studies of human growth'.

evaluate policy interventions (for example, see the recent Unicef, *The State of Food Security and Nutrition in the World* September 2017).

What is less certain is the degree to which such early stunting persists into adulthood. For Sart in East Belgium, Alter, Neven and Oris found that every additional centimetre of adult height reduced the later-life risk of dying by six per cent, a result that held for military conscripts born 1815-28 but not 1829-60: they implicated conditions in mid-life in mediating associations for the later cohort.[6] There is likely a distinction between accumulated insults versus acute but temporary crises. Early-life conditions can be so adverse that infants die, their sufferings unrecorded by adult heights. Indeed, selection out might happen at any stage, and if the cause of death is sensitive to nutrition (as many infectious diseases are) it is possible this would favour the survival of taller individuals. There is considerable debate over selection versus scarring.[7] For China, Meng and Qian did find an important scarring effect of in-utero exposure to the 1959-61 famine and Gørgens et al. confirmed that early-childhood exposure to this crisis resulted in significantly shorter survivors.[8] Chen and Zou demonstrated that children born right before the famine were more than 3 cm shorter as a result of the crisis.[9] Likewise, Dercon and Porter showed that early-life exposure during the 1984 famine in Ethiopia reduced attained height by about 5 cm.[10] In a longitudinal study of Filipino children, de Cao found diseases in the second year of life stunted, while for historic Sweden Öberg found little evidence of any effect of exposure to disease in early life on height.[11]

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[6] Alter, Neven and Oris, 'Height, wealth and longevity', pp.28-30.
[7] See, e.g., Deaton, A., 'Height, health, and development'; Hatton, T.J., 'Infant mortality and the health of survivors'; Hatton, T.J., 'How have Europeans grown so tall?'.
[8] Meng and Qian, 'The long term consequences'; Gørgens et al., 'Stunting and selection effects'.
[9] Chen and Zou, 'The long-term health and economic consequences'.
[10] Dercon and Porter, 'Live aid revisited'.
[11] De Cao, 'The height production function'; Öberg, 'The direct effect of exposure to disease'.

Puberty is the second critical period for height formation. The growth velocity during puberty is lower than in early life but may last longer and is still important for adult stature. Current studies are identifying 'nutrition and disease around the time of birth, and in adolescence, as being crucial to physical development', at both the individual and population levels.[12] In a recent study of women in late 20th century sub-Saharan Africa, Moradi found conditions around birth, late childhood and puberty were all influential on final attained heights.[13] Pre-puberty features. In addition to infancy, de Cao identified conditions in the run up to puberty were formative, particularly ages 8 and 11 years, preparing the body for rapid adolescent growth.[14] A similar result was also made in a clever study exploiting the different ages of siblings migrating into Sweden, finding the period around age 9 years especially influential.[15] When Jacobs and Tassenaar explored lagged correlations between real wages, nutrition and heights of Dutch conscripts in the 19th century, they found the period of the adolescent growth spurt most pronounced, a lesser effect for early childhood, and no significant birth year effect.[16]

Critically, adolescent growth is a chance for catch up.[17] If growth is disrupted through a health or nutritional insult ('growth faltering') recovery can occur if environmental conditions improve before growth ends.[18] Barker et al. observed that when undernutrition in early development is followed by a period of better nutrition during childhood, individuals may experience accelerated growth. This might itself impose a health penalty in later life and can be

[12] Akachi and Canning, 'The height of women', p.408.
[13] Moradi, 'Nutritional status and economic development in sub-Saharan Africa'.
[14] De Cao, 'The height production function'.
[15] Van den Berg et.al., 'Critical periods'.
[16] Jacobs and Tassenaar, 'Height, income and nutrition', p.191.
[17] Boersma and Wit, 'Catch-up growth', Prader, Tanner and Von Harnack, 'Catch-up growth following illness or starvation'; Tanner, Growth as target-seeking function'.
[18] Some insults are irreparable, for example, those imposed on the foetus by alcohol and tobacco; Steckel, 'Stature and the standard of living', fn5 p.1911

part of the explanation of the relationship between early-life effects and old-age mortality.[19] Catch-up can be achieved by increased velocity especially around the adolescent growth spurt, or by deferring the adolescent growth spurt and growing for longer, potentially into the mid and later 20s for men. Historical populations exhibit much variation in the timing of the onset of puberty which equates to opportunities for extending growth. In medical literature, the pubertal growth spurt is commonly defined as the age of peak height velocity (PHV) after the age of 10. For Danish boys born between 1930 and 1969, or British boys today, the PHV is observed at age 14 years, whereas the age span 15-16 is typical among historical populations.[20] In Bach's choir in eighteenth-century Leipzig, boys' voices did not break until 16½ to 17 years; the growth spurt then occurs about one year after puberty has started.[21] The association between shorter stature, and later peak growth, is elegantly depicted in Table 4 of Floud and Wachter's analysis of Marine Society and other boys.[22] The evidence suggests that in the nineteenth century the pubertal growth spurt occurred later than today.[23]

Modern longitudinal studies on Gambia, Senegal, and Tanzania have found significant recovery over an extended adolescent growth phase, especially for girls, leading them to argue that puberty should be seen as 'an additional critical window' for policy interventions aimed at improving heights.[24] Significantly, early anthropometric studies observed catch-up. Steckel demonstrated how malnourished slave children made rapid gains during puberty when entering work earned them calories, observing that 'most of the absolute difference between slave heights and modern standards was made up during the late adolescent and postadolescent

[19] Barker, et al., 'Fetal origins of adult disease'.
[20] Tanner, *Growth at adolescence*; Tanner, *Foetus into man.*
[21] Daw, 'Age of boys' puberty': Tanner, et al., 'The adolescent growth spurt'.
[22] Floud and Wachter, 'Poverty and physical stature', p.443.
[23] Controversially, Schneider argues that the spurt was not even present until the 1910s. Schneider, 'Health, gender and the household'.
[24] Prentice et.al., 'Critical windows', Coly et.al., 'Preschool stunting', Hirvonen, 'Measuring catch-up'.

period'.[25] Komlos found similar outcomes among free African Americans.[26] Baten suggested that 'the anthropometric impact of insults during the early years might well be dwarfed by strong but temporary growth retardations or increases', requiring investigations to be alert to conditions just prior to measurement of individuals who were still growing.[27] Such effects may not have been temporary. In an important recent contribution, Beekink and Kok exploit two height measurements for the same men at ages 19 and 25 years for a small sample of militia in The Netherlands, whom they linked to their families of origin.[28] Even at this late stage, they found men capable of on-going growth of around five centimetres, with the shortest/slowest growers gaining most (their Table 2). Childhood determinants of growth visible at age 19 were weakened by age 25, suggesting ongoing growth made final height less sensitive to early-life conditions.

Just as adolescent catch-up provides a route to improving final stature, conversely, challenges to growth during puberty and approaching maturity are more likely to be enduring. For children growing up during the Nigerian civil war, Akresh et al. showed that those groups most heavily involved by warfare had significantly lower adult average statures: particularly exposure to the conflict during adolescence (ages 13-16 years) was damaging, more than exposure in early childhood.[29] An insult received in adolescence might come too late to ever be redeemed. Some processes are set in play that, once triggered, cannot be reversed: puberty proceeds, growth plates fuse, and opportunities for gains diminish. Relatedly, it is worth considering the prodigious calorie requirements of boys during this phase of peak adolescent growth. They

[25] Steckel, 'A peculiar population', p.734.
[26] Komlos, 'Towards an anthropometric history of African-Americans'.
[27] Baten, 'Heights and real wages in the 18th and 19th centuries: An international overview', p.66.
[28] Beekink and Kok, 'Temporary and lasting effects'.
[29] Akresh, et al., 'War and stature'.

exceed that of similarly aged girls by up to 900 kcal/day, even surpassing the consumption of adult men. This makes teenage boys particularly sensitive to the economic and health climate of the time, be it good or bad. Boys' bodies thus respond more noticeably to the prospects before them. This may contribute to the observation that female stature is more robust to adversity: male stature has more opportunity to respond.

Either process – catch-up, or late insult – has the capacity to disrupt the link between early life and final height. Establishing which age group was most vulnerable to prevailing conditions has implications for what adult stature measures, its relations to early life, and association with health and longevity. It is therefore a fundamental question for anthropometric historians. Which boys grew up to be shorter men? Were the toddlers born during the worst days of a crisis marked for life by these bad experiences in early childhood, or was it the teenagers?

We view this problem of what adult stature captures by offering a novel approach that organises final height by different ages with varied exposure to economic and health conditions. Height data are collected from the local prison of Bruges, the capital and largest city of West Flanders. Although biased to the lower social classes, the height of prisoners is a suitable source to study, since this specific group is likely to be vulnerable to changes in environmental conditions. The paper deploys three approaches. First, we exploit a shift in conditions by looking at two well-defined crises in Flanders, 1846-49 and 1853-56, to investigate which was the most critical age of crisis exposure capable of exerting a persistent effect detectable in adult male heights.[30] Second, we generalise away from shocks and instead utilise annual variations in prices and mortality rates to disentangle the more generalised connections between macroeconomic

[30] One of the authors is currently writing a second paper on the stature of Flanders' women and girls.

conditions and heights. Finally, if adult stature is less clearly understood as the product of early-life conditions, then what does explain final heights? We argue that stature, as a cumulative measure of growth, is best understood using cumulative measures of health and welfare. This is similar to Moradi's approach of shifting GDP per capita to correspond to five-year birth cohorts, and Brinkman, Drukker and Slot's earlier work predicting height using lagged per capita income, weighted by velocity of growth at different ages.[31] Unlike the latter, who recognized the 'awkward problem' posed by shifts in the tempo of growth, we do not assume the timing of the growth profile, nor the rate at which each year of growth contributed to final stature.[32] Instead, we use our earlier empirical findings to guide us. For Bruges' boys, we propose height was a function of an adolescent algorithm summing conditions from ages 11 to 18 years.

This article consists of six sections. The next section discusses the crises of 1846-49 and 1853-56 in Flanders. The second section presents the data together with an assessment of their representativeness, limitations and corrections. Section III offers a long-term height trend for men in Flanders. It examines the evidence of stunting during the crises of the 1840s and 1850s, paying attention to years of exposure, and identifying cohort effects. Section IV further test which ages were most sensitive to prevailing conditions by examining age-specific relationships between stature, prices and mortality. We expand on this in the fifth section to consider the general effects of cumulative experiences of nutrition and health on growth and adult stature. Some general conclusions are assembled in section VI.

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[31] Moradi, 'Nutritional status and economic development in sub-Saharan Africa', Brinkman, Drukker and Slot, 'Height and income'.
[32] Brinkman, Drukker and Slot, 'Height and income', p.258.

I

In the mid-nineteenth century, Flanders was struck by crises due to structural economic vulnerability in combination with troubles in the food supply. Unlike the south of Belgium where industrialisation rapidly took off in the early nineteenth century, the economy in the northern part, Flanders, was ailing. Flemish agriculture was dominated by a system of proto-industrialisation in which farming was combined with activities in the textile industry. The importance of this textile industry for the Flemish economy dates back to early medieval times and remained of prime importance during the first half of the nineteenth century. More than half of the labour force was involved in the production process, mainly as part-time spinners and weavers in the rural linen industry. These activities formed a supplementary income for the small farms. Around 1820 the production of linen reached a peak, but the signs of a structural crisis were already apparent. After 1815, the Flemish linen industry had a difficult time due to diminishing export possibilities. In France, a domestic linen industry was established aided by a protectionist economic policy. Moreover, the fierce competition with mechanised British cotton put Flanders in a difficult position.[33] Already in 1837, the Flemish linen industry was in deep crisis, spreading also towards the important lace industry in the urban centre of Bruges.[34]

On top of the structural economic difficulties came a series of harvest failures. Problems started during the cold winter of 1844-1845 when the turnip and wheat yields were lower than normal. When harvests did not meet expectations, usually some more potatoes were planted for next summer to compensate. When the fungus *phytophthora infestans* emerged in the fields during the summer of 1845 those large potato plantations were destroyed. In comparison with other

[33] Vandenbroeke, ‘De proto-industriële ontwikkeling van België’.
[34] Sabbe, *De Belgische vlasnijverheid*, p. 483.

countries in continental Europe, the Belgian potato fields were affected very early by the disease, resulting in a dramatic impact on the harvest. Between 85 to 95% of the yield of 1845 was lost, and in subsequent years the potato crop returned only about half normal quantities. During the summer of 1846, a large part of the rye harvest was also affected by the blight, resulting in a loss of over 31 million kilograms in West Flanders. This was a major misfortune considering the small farmers were sowing rye mainly for personal use. The combined loss of potato and bread grains was estimated by Jacquemyns to add up to 66% of nutritional availability.[35] Since both bread grains and potatoes were affected, little substitution between food products was possible. The good grain harvest in 1847 and the reasonable returns in subsequent years were, according to Vanhaute, barely sufficient to avoid a general famine in Flanders.[36] The collapse of living standards for broad segments of the Flemish population lead to increasing poverty, mendicancy, vagabondage and theft. In West Flanders, the proportion of the rural population that relied on poor relief was about 35%, together with East Flanders the highest number in Belgium.[37] It was claimed that some peasants deliberately chose to be incarcerated to avoid starvation and some rural authorities officially gave permission for begging one day in the week.[38] Other peasants opted for emigration from the impoverished villages.[39] Furthermore, in 1846, a typhus epidemic struck Flanders. This infectious and highly contagious disease was not uncommon in the region, but weakened from near famine, the population was vulnerable and the numbers affected between 1846 and 1848 were extremely high. In West Flanders, more than 23,000 infections were counted, significantly pushing up

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[35] Jacquemyns, *Histoire de La crise économique ces Flandres*, p. 258-9.
[36] Vanhaute, ’So worthy an example to Ireland’, p. 131.
[37] Van Molle, *Katholieken en landbouw*, p. 24.
[38] Devogelaere, *De slechte jaren 1840-1850*, p. 136.
[39] Deschacht and Winter, ‘Rural crisis and rural exodus?’.

mortality. The outbreak of typhus was followed almost immediately in 1848-1849 by a cholera epidemic spreading from the port of Antwerp.[40]

After 1849, available nutrition and the disease environment in Flanders seemed to recover to pre-crisis levels. However, a new crisis was not far away. Grain prices between 1853 and 1856 rose towards levels exceeding those in 1847. Up to now, this second food crisis within the same decade has received much less attention and its causes are less well understood.[41] Although no important harvest failures occurred between 1853 and 1856, the yields were still below average and prices soared.[42] Rather than the national harvest, it was the international situation that caused the high prices. Grain yields outside Belgium were also meagre. More importantly the ports of the Baltic and Black Sea were closed for cereal export towards Western Europe due to the Crimean War.[43] Again, this period of crisis was accompanied by rising mortality due to disease outbreak. In 1854, a new cholera epidemic struck Flanders and smallpox made many victims during those years as well.[44]

Figure 1 shows prices for the most important cereals and potatoes on the market of Bruges as well as the crude death rate in the city over the long nineteenth century. A clear increase of food prices can be observed in 1846-47 and in 1853-56. High death rates were recorded in 1846-49 due to the outbreak of typhus and cholera. The immediate effect of the crisis was a population decline in Bruges and in the region under study. Between 1853 and 1855, cholera and smallpox caused the number of deaths in the city to again exceed the number of births. The combination

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[40] Devos, *Allemaal beestjes*, p. 113.
[41] Delfosse, '*La politique agricole de l'Etat Belge*; Ronsijn, 'Mediated and unmediated market dependence'.
[42] Delfosse, 'Etat, crises alimentaires et modernisation de l'agriculture', p. 71.
[43] Ronsijn, 'Mediated and unmediated market dependence': Paping, *Voor een handvol stuivers*, p. 49.
[44] Devos, *Allemaal beestjes,* p. 128.

of prices and mortality leads to the conclusion that ongoing hardship in Flanders was felt most severely between 1846-49 and again between 1853-56.

Figure 1 here

II

There is now quite a tradition of using information on prisoners in the anthropometric literature.[45] For the Belgian prisons, height data are generally available from 1832 onwards when new registers were introduced after Belgian independence. This article uses prison data from the prison of Bruges, the capital and largest city of West Flanders. Located in 'het Pandreitje', the prison dates back to the eighteenth century. It became the central institution for the detention of men and women convicted under correctional law under the 'Code pénal' of 1810 that distinguished police, correctional and criminal punishments. Convicts under more serious criminal sentences were housed in two central institutions. Sentences of police punishments were never longer than a couple of days, while correctional sentences could be up to five years of imprisonment; criminal sentences were from five years up to life. The vast majority of police and correctional sentences in Bruges did not exceed the length of one month. The revised 'Code pénal' of 1867 did little to alter this situation.[46]

Prison officials recorded all new entries in the penal house chronologically in inscription registers, measuring the height of each convict in centimetres. A sample of entries at the prison

[45] See, e.g., Baten and Murray, 'Heights of men and women'; Carson, 'Health during industrialisation'; de Beer, 'Physical stature and biological standards'; Horrell, Meredith and Oxley, 'Measuring misery'; Inwood, et al., 'Growing incomes, growing people'. For Belgium: Depauw, 'Tall farmers and tiny weavers'.
[46] Sentences of the police court could not be more than seven days from then onwards. Monballyu, *Zes eeuwen strafrecht*, pp. 141-3.

between 1832 and 1902 was collected. The surname and first name of the individual, information on incarceration date, sex, age, occupation, birthplace, place of residence, conviction and height were entered in the database.[47] Four clusters of five years were sampled in full. All male convicts entering the institution in 1832-36, 1854-58, 1876-80 and 1898-1902 were selected. In this manner, continuous birth cohorts could be reconstructed between 1800 and 1875. No entries at the prison for 1847-48 were sampled since the number of correctional court cases doubled during those crisis years and may have changed the nature of those incarcerated, leading to selection bias.[48] During the sampled years, no such shifts in criminality rates can be observed. Subsequent robustness checks found no significant effects arising independently from decade of incarceration.[49] In total, 17,569 individual entries at the prison of Bruges were collected. The following concentrates on male prisoners born between 1800 and 1876, who entered prison aged 26 years up to and including 50 years. The lower boundary excludes individuals that were still growing and the higher boundary those that had shrunk appreciably.[50]

Recidivism rates in nineteenth-century prisons were often high.[51] Since most sentences were limited to a few days of imprisonment, repeated incarceration of individuals over a short time period was common. Double-counting is undesirable, as it can apportion undue weight to certain individuals and potentially introduce bias, for example, if recidivists are shorter.[52]

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[47] The source furthermore includes a lot of information on the criminal career of the prisoners, including the court of conviction, release date and transfers to other prisons.
[48] Bodenhorn, Guinnane and Mroz, 'Sample-Selection Biases'.
[49] We deployed a series of strategies to test whether period of incarceration influenced outcomes and found no statistically notable effects: (1) Regression of height on interacted incarceration/birth decades; (2) t-tests of height between incarceration decades for each birth decade; (3) regression controlling for age and birthyear with dummies for incarceration decades. We also ran our main results (1) systematically dropping each incarceration decade, and (2) decade by decade; again, the results persisted.
[50] A slight shrinkage already starts between age 30 and 40 and is known to be already about 0.5 to 1.0 cm around the age of 50, see: Sorkin, Muller and Andres, 'Longitudinal change in height of men and women'.
[51] Fyson and Fenchel, 'Prison registers', p. 172.
[52] Inwood and Maxwell-Stewart, 'Prison and the history of the family'.

Therefore, based on the recorded place of birth and the estimated birth year, a linkage of entries for individuals with the same name was conducted. More than 50 per cent of these observations belonged to a recidivist.[53] For each positive match, only one observation was considered. The recorded information on the inscription date that was the closest to the individuals 35th birthday was kept.[54] This left a core sample of 5,505 unique adult male prisoners. Appendix Table A1 gives the distribution of these men by year of birth, and their annual average stature.

The height distribution of the sample is generally bell-shaped, with the mean equalling the median, but not the mode: clearly the data suffer from some rounding on heights ending on 0 or 5, as can be seen in Figure 2. Heaping is particularly apparent for 160, 165 and 170 cm. Heaping can be a problem capable of distorting results.[55] This is a common feature of height data but is not usually perceived as a problem if there is no reason to presuppose there is an underlying bias upwards or downwards.[56] For instance, Mokyr and O'Grada claim that height heaping does not bias their estimates, but only reduces the precision.[57] A sensitivity test was performed to control for the effect of heaping on the Bruges prison data by weighting down the cases with rounded values, indicating little deviation to the presented results. It was thus concluded that heaping offered no systematic threat to the validity of the data.

Figure 2 here

[53] If recidivist are counted more than once when calculating average stature, the results are biased. See: Depauw, 'Selectivity of recidivism'.
[54] Since only observations of prisoners aged between 26 and 50 are taken into account, the entry closed to the 35th birthday is chosen for prisoners with multiple records. I expect that both height and occupational information is then most informative.
[55] Preece and Baines, 'A new family of mathematical models'; Wright and Bray, 'A mixture model for rounded data'; Wang, *Statistical methods for heaped data.*
[56] Komlos, 'How to (and how not to)'.
[57] Mokyr and O'Grada, 'Height and health in the United Kingdom', p. 149.

Prison records are one of the few sources containing information on adult stature for the nineteenth century, but they pose recognised problems of selectivity.[58] Naturally, the prison population is far from a representative sample of the society. Not all sections of society are equally likely to be involved in criminal activities and not all individuals are equally likely to get caught and sentenced for those activities. The distribution of the crimes committed by the prisoners confirms that most of the prisoners were convicted for small offenses. For England, Nicholas argued that transported British convicts were predominantly “ordinary working-class men and women who stole”.[59] The Belgian prisoners in this sample were mainly convicted for petty theft (21.7%), but most notably for hitting, minor assaults, battery and other kinds of violence (42.6%).

Were these, perhaps, ordinary working-class men who lashed out? Occupations clustered as expected around the lower socio-economic ranks. Compared to the census of 1846, farmers and agricultural workers were underrepresented in the Belgian prisons. A large share of the men was described in the prison registers simply as day labourer (*journalier*) or ordinary worker (*ouvrier*). We classified the occupations of the prisoners according to HISCO, and divided them into social groups based on the historical class scheme HISCLASS.[60] We use the abbreviated scheme with five classes: elite (HISCLASS 1-2), lower middle class (HISCLASS 3-6), self-employed farmers and fishermen (HISCLASS 8), skilled workers (HISCLASS 7 and 9) and unskilled workers and farm workers (HISCLASS 10-13). The distribution is given in Figure 3, showing the socio-economic structure of the sample over time. No clear shifting pattern can be observed. The prisoners were described largely as skilled and unskilled workers, becoming

[58] Bodenhorn, et al. ‘Problems of sample-selection bias’.
[59] Nicholas, *Convict workers.*
[60] van Leeuwen en Maas, *Hisclass.*

somewhat more skilled over the nineteenth century, possibly also reflecting more accurate descriptions of the professions. There are grounds for believing this likely reflected their family backgrounds.[61] Thus, the prison sample is not representative for the total population of Flanders, but a very specific group of individuals mostly drawn from the working classes of society. This group is however likely to be vulnerable to economic crisis and is therefore a suitable sample for studying crisis effects on height.

Figure 3 here

III

The existence of two proximate crises in 1846-49 and 1853-56 means the Flemish prison data can be used to examine three concerns: (1) the impact of being born during a crisis; (2) the consequences of reaching puberty during a crisis; and (3) the more complicated interaction of living through two consecutive crises during the growing years (defined as conception to age 25 years). Only a small proportion of offenders experienced a single crisis: those achieving adulthood before 1853 (born 1821-27), and those conceived after 1849 (born 1851-57). All those born between (1828-50) experienced a double-insult. From this it is possible to tease apart the age of greatest vulnerability.

The first step is to reconstruct the terminal height trend of Bruges prisoners born between 1800 and 1875, to observe if there is any evidence of stunting and if so, which birth years were most

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[61] Their own socioeconomic status is often used as a proxy for the socioeconomic status of the family during the growth period and is based on the assumption of a limited social mobility. See, e.g., Komlos *Nutrition and economic development.*Studies have shown that the occupation of conscripts in the nineteenth century matches the socioeconomic status of their fathers rather well; Lantzsch and Schuster, 'Socioeconomic status and physical stature', p. 53.

affected. Adult height has here been defined as the stature of men who had completed growth, but had not begun to shrink, and so includes those aged 26-50 years inclusive. Their average stature was 167 cm with a standard deviation of 6.2 cm. This makes these criminal men a little taller than the younger (immature) military conscripts (164.7 cm at age 20 years), born 1780-1880, from the more industrial Walloon areas of east Belgium studied by Alter, Neven and Oris.[62] This suggests a population well below modern expectations for the well-nourished but in keeping with many contemporary societies. Among prisoners, rates of stunting (defined as height-for-age z-score at or below -2) were highest among those of unknown occupation (25%), followed by unskilled and skilled workers at 18%, with farmers fairing comparably well at just 8%.

Figure 4 presents the height trend for Bruges men by year of birth. Do we observe a period of height deprivation associated with either the crisis of the mid-1840s or the mid-1850s? Mean male height from the prison of Bruges was about 167.5 cm around 1800 and also 75 years later. In between, the average height was lower with two notable periods of downturn. A first period of height depression is observed for prisoners born in 1814-15. A second and deeper fall occurred among Bruges prisoners born in the 1830s when average height drops from about 167 cm to 165.5 cm. The percentage stunted (22%) was up on the previous decade (19%), which was in turn worse than the start of the century (16%). Translated to living standards, the height trend indicates a substantial decrease in wellbeing during the first half of the nineteenth century very much in line with the historiography of 'Poor Flanders' and its ailing economy. For those born later in the 1840s onwards, life seems to have become better, increasing in line with per

[62] Alter, Neven and Oris, 'Stature in transition', p.236.

capita GDP.[63] And yet, there were two major crises in the later 1840s and mid-1850s, strongly reducing the nutritional availability for growing boys. As shown in section I, the most severe impact of the subsistence crises was felt between 1846 and 1849 and between 1853 and 1856. The crises represent clearly defined shifts in living conditions. The first crisis included one year where all three crops – wheat, rye and potato – were priced at more than two standard deviations above the norm. The second crisis can be seen as more severe in that there were two successive years (1854 and 1855) with such similarly high food prices with wheat racking up a third year in 1856. Meanwhile, stature seems comparatively robust during the crises of the 1840s and 50s measured by birth year.

Figure 4 here

In fact, both crises are visible in Figure 4, considering year of birth alone does not capture growth. It is necessary to think about crisis exposure across all the growing years from conception to age 25 when maturity was reached. The dotted line in Figure 4 charts the number of good years of growth: that is, a maximum of 26, minus years exposed to either of the two crises while young enough to be affected. Stature clearly reached its nadir in 1838. Conventionally, we would infer that conditions around birth must have been very poor for stature to fall so precipitously. In reality, observable conditions were benign. Wheat price was spot on average, rye and potatoes were a shade cheaper, mortality normal. What connects 1838 with the two crises is a simple fact: babies born in 1838 turned 8 years old in 1846 and 15 years old in 1853. These boys thus spent four growing years during the first crisis and – worse yet –

[63] GDP from The Maddison-Project, http://www.ggdc.net/maddison/maddison-project/home.htm, 2013 version; based Buyst, ‘Towards estimates of long term growth’; Bolt and. van Zanden ‘The Maddison Project’. For the Flemish case, see: Segers, *Economische groei en levensstandaard.*

they entered their (probably delayed) adolescent growth spurt during the second crisis. Others experienced the same eight years of crisis punctuated by three more benign years – those born in 1846 and reaching 10 years in 1856, through to those aged 15 and completing growth at age 25 years – and we might expect that all were to some extent scarred by it. What our analysis alerts us to is not the effect of just one poor birth year, but of accumulated distress felt most acutely across the pre- and adolescent growth phase, by this measure around ages 8 to 18 years.

This intuitive interpretation deserves more rigorous investigation. First, a test of means confirms that the crises stunted, and the effect was larger the greater the number of crisis years to which an individual was exposed. This can be seen in Table 1, which gives adult height by five categories: those reaching adulthood before either crisis, those who during their growing years were exposed to the first crisis only, to both crises, to the second crisis alone, and men conceived and born after the second crisis had ended. In absolute terms, even the greatest differences are small – half a centimetre to just over one centimetre - but they are significant and meaningful when comparing this many adults. Those exposed to both crises were the shortest at 166.4 cm, around five standard deviations below men free from any crisis exposure (born at the start and end of our period). The doubly-insulted were also significantly shorter than those exposed only to the first crisis (t=-3) or the second and worse crisis (t=-1.8).

Table 1 here

Can we get closer to confirming which part of the growth cycle was most vulnerable? Typically, we present terminal height by birth year, because birth cohorts share a particular set of circumstances. Human growth, however, is a long process. Perhaps year of birth is not as influential on stature as many assume. A way of thinking about influences on growth is to break away from a narrow focus on birth year, and consider how conditions pertaining at different ages influenced final height. What about health conditions and food availability at conception, at age 5 years, 10 years, 15 years, etc.? Nothing stops us from also arranging terminal height by age one year (birthyear+1), or age two (birthyear+2), etc. We can use this information about grown men to reveal which moment of human development was most influential upon final stature. If the basic living conditions that shape height are fairly constant across time, birthyear proxies all other growing years. Our approach requires conditions at birth to be different from those pertaining at puberty. Thus, we need to exploit variability. First, we explore the two shocks of 1846-49 and 1853-56. Second, in Section IV, we consider more general variations in prices and mortality.

Table 2 takes nine slices from the data at decades from 1816-76, with the addition of 1849 (the last year of the first crisis) and 1853 (the first year of the second crisis). This represents those who had completed growth before either crisis (1816); those exposed to the first crisis alone (1826); the bulk exposed to both crises (1836, 1846, 1849); exposed only to the second crisis (1853, 1856); and those born after these two crises had ended (1866, itself a bad cholera year, and 1876). Note, these are not heights-for-age, nor age at measurement. Each regression arranges individual adult male height, by the age that adult was in the given year. The same men can thus appear repeatedly across the regressions, at different ages. Included are a small number of men from the eighteenth century in order to have full age ranges in each of the regressions. Occupational skill levels are included to control for any sample irregularities. They indicate a fairly consistent story in which the elite class and farmers were the tallest, followed by the lower middle class who were significantly taller than skilled workers, unskilled workers, and those whose occupations were unknown. For 1826, the F-test is insignificant meaning all coefficients might jointly be zero; the other years all have meaningful results, in varying directions. Ages have been grouped into four-year classes. In all regressions, the reference category is adult men of the lower middle class. Shading indicates significant results, dark for negative effects, and light for positive relationships.

Table 2 here

The first observation of note is that in 1816, 1866 and 1876, age coefficients were typically significant and positive, showing that comparatively better times had arrived for boys who were still growing compared to their adult contemporaries (the reference group), even in 1866 when a cholera outbreak hit. This was particularly notable at the end of the period, when adult heights were depressed as a result of the crises, and economic growth was increasing.[64]

The second outstanding feature is the significant negative effect of the crises and the way the affected cohorts move through the years. Most remarkable is the mild effect on babies and infants to age two years during the actual crises of the 1840s and 1850s (1856 notwithstanding[65]). This is not to say that babies and toddlers were unaffected at the time, but that any stunting then experienced was largely compensated before final heights were attained. There was an exception to this. Noted earlier, babies and infants born in the benign year of 1836 did register considerable disadvantage. Being born in 1836 was not particularly hazardous, but subsequently living through two crises around puberty clearly was. They compared unfavourably with older children aged 7 to 10 years in 1836 who, a decade later, had largely cleared puberty when misfortune hit: those boys experienced just the one crisis and were not permanently stunted by it.

[64] Segers, 'Nutrition and living standards'.
[65] Babies and infants in 1856 were stunted at the 10% level of significance, but this may result from bad years in 1866-67 when mortality, and prices, again soared.

Through the lens of adult stature, we see boys of all ages suffering during the two crises, but not consistently. That the culmination of three years of severe conditions in 1856 did not consistently stunt across all ages tends to point in the direction of puberty. It was ages 11 to 18 that appear most frequently as being vulnerable. There was considerable (and statistically significant) stunting among boys as they approached, experienced, and emerged from the adolescent growth spurt. It was not birth but the later stages of growth that registered permanent, large, negative effects on terminal stature.

IV

Progressing from a focus on crisis years, it is instead possible to exploit variations in annual series of prices and the crude death rate to examine more precisely the ages most vulnerable to local conditions and most likely to depress or, indeed, bolster adult height. As noted earlier, whether mortality depressed stature through scarring or boosted it through selection is unclear. Either way, a high crude death rate signals poor health conditions, and potentially the loss of family members responsible for welfare through earning, spending and caring. Food prices are less equivocal and should have a negative effect on stature. Prices of wheat, rye and potato would be high when supply was short, and low when abundant. Estimates of the average food basket suggest that 70 per cent of the daily caloric intake came from these primary foodstuffs, with butter, meat and beer contributing much of the remainder.[66] The prices of rye, wheat and potato dominated the household budget and can be used to estimate the quantity and quality of the nutrition in a given year. Substitution within the diet was possible, but prices of these crops were not independent of each other. Wheat price correlated strongly with rye (r = 0.9),

[66] Segers, ‘Nutrition and living standards,’ p. 161; Bekaert, ‘Caloric consumption’, p. 635.

moderately with potatoes (r = 0.6) (but not with the crude death rate, though this did relate to potato (r = -0.3) and rye (r = -0.2)). Substitution was likely to favour one crop in particular. The lower the income, the more likely the consumption of the cheapest calories: potatoes, particularly in Flanders.[67] Bekaert estimated that 1000 calories of potato cost 5 Belgian cents, compared with a 1000 calories from bread made with rye at 7 cents, and from wheat at 9 cents.[68] Potatoes could also be grown on small local plots, allowing self-provisioning. The potato seems critical as a reserve crop, which is why the potato famine was so devastating. Notably, explaining adult height with a more representative basket of goods for those years where information existed for butter and meat slightly reduced the predictive power of the following model, because the basket had proportionally less potato.

The analysis of two proximate crises in 1846-49 and 1853-56 as shocks disrupting human growth shows evidence of stunting for children growing up during crisis. Viewing price and demographic indicators as continuous variables helps pinpoint critical growth to puberty. The shifting of the critical moment in growth away from the first few years of life and towards the adolescent growth spurt makes sense. Notably, when we make this adjustment, we find more powerful relationships emerge between height and some expected influences.

For each individual we compute 32 year variables: approximately the year in which someone was conceived, born, turned one year old, two years old, through to 30 years old. This captures all the possible years of male human growth and a bit more. Up to age 26, it is the same group of men at every age: numbers then diminish as 26 year olds in our study had yet to reach 27 or above, 27 years olds had yet to reach 28 or above, etc. (Later, in the regression analysis, we

[67] Bekaert, ‘Caloric consumption in Belgium’, p.635.
[68] Ibid.

exclude age categories 27-30 years to preserve sample size.) For each year, we attribute the price of wheat, rye, potatoes, and the crude death rate (CDR). Table 3 demonstrates the independent correlations between annual average adult male height with the environmental conditions prevailing at different ages. The same relationships prevailed, albeit with smaller coefficients, at the individual level. It is most revealing.

Table 3 here

The first two rows in Table 3 consider terminal height for those conceived or born in the year these prices and death rate pertained. There was no remotely significant effect. This meant these factors experienced around birth – health conditions, prices and the supply of foodstuffs – which unequivocally influence other aspects of longer term health, exercised no detectable persistent influence over adult stature. This appears a disheartening finding for those who believe anthropometrics offer a useful measure of human welfare, if you believe that terminal height was pre-eminently affected by conditions at birth – but not if puberty was driving developments.

The subsequent rows then consider the effect of prices and mortality in a given year upon males at different ages – different moments in the growth cycle. The same factors that failed to diminish or enhance the final height of the infants exposed to them, all possessed significant relationships to the welfare of boys at certain later ages, so much so that they subsequently registered in final attained stature.

Stature was permanently depressed by high prices and mortality levels experienced at specific ages. Significant results were all negative with the sole exception of mortality at age 3. Otherwise, the crude death rate stunted, significantly so between the ages of 15 and 19 years. (At the individual level, a negative relationship pertained with mortality from age 5 years.) Potatoes – as noted, in many ways the reserve crop, relied upon in times of hardship – were very important. High potato prices had an adverse effect on boys from 12 years old, with rye and wheat exerting a depressing influence from age 14. This points towards conditions during adolescent growth, when the prospect of catch-up growth was greatest, exerting a more powerful influence over final stature than conditions in early life.

Catch-up growth was impossible at the other end of the cycle. What Table 3 also reveals are the detrimental effects of adverse conditions late in the growth cycle, among those in their 20s. For an insult to prolong growth by delaying maturity, it must kick in prior to the changes that trigger the adolescent spurt. Then, the spurt is delayed, maturity deferred, and growth lingers on as late as the mid-20s. If injury is added to insult, and conditions are not propitious in this late phase of delayed growth, the last chance for those small incremental gains in stature are lost. Here it is apparent that high food prices – more than mortality – retained the power to stunt well into adulthood.[69]

Regression analysis offers a simultaneous solution, guiding us closer to the years that were most influential on final height. We compute z-scores for each indicator so that the results are easy to compare as all are measured in standard deviations.[70] Averages and standard deviations for our series are based on the long nineteenth century (1802/3-1914). We compute the average value of each indicator over four-year age groups, averaging crop prices because of the problem of autocorrelation. We have consistent series for all three crops from 1803, and as our analysis incorporates year of conception, this means we focus on birth years from 1804-1876. In the regression analysis reported in Table 4, adult stature is predicted using the mean age-specific

[69] The anomalous result at age 30 years may arise from age heaping, and the inadvertent inclusion of younger men in this category.
[70] This yields identical results to computing a geometric mean.

value of crops and mortality expressed as z-scores, for all adult men aged 26-50 years, born between 1804-1876.[71]

Table 4 here

An informative pattern emerges. No significant relationship was recorded between stature and conditions prevailing between conception and birth. Between ages three to six years, a somewhat anomalous significant *positive* relationship existed between mortality and stature.[72] Powerfully, the largest effects were negative, were driven by both mortality and nutrition, and they were felt at ages 11 through 18 years, especially 15 through 18 years. This meant bad times inflated prices and mortality and left boys to become shorter men, while boys gained during good times and their adult selves were taller. From this analysis, we conclude that adult heights of Flemish men were most profoundly shaped by the quality of their adolescent growth spurt.

V

If pubertal growth is key to understanding Flemish heights, and if height really is a good measure of net nutritional status, then we would expect to see the height trend explained, at least in part, by what was happening to food prices and death rates. Figure 5 illustrates the now familiar series for adult male heights of prisoners over 1800-76. Alongside it are the four other series: the z-scores for the prices of wheat, rye, potato and the crude death rate – not for a single year, but averaged over the key years of adolescent growth, from ages 11 to 18 inclusive. Because we expect negative relationships (high prices and mortality should stunt; low prices

[71] Note, data starts in 1802 for wheat and rye, and in 1803 for potatoes and CDR. For completeness, subsequent computations of averages cover those born in the years 1804-76 (conceived from 1803).

[72] One way to look at this puzzling trend is the possibility that high prices reduced the chance of having younger siblings. Indeed, the coefficient on CDR for this age group is also positive and significant.

and mortality should promote growth) we run the axis for z-scores in reverse order to make the associations more apparent.

Figure 5 here

The importance of health and nutrition for human growth is clear once viewed through this adolescent lens. The series for adolescent exposure intertwine around the shape drawn by adult stature. Unlike relationships in year of birth, each of these indicators accumulated across ages 11 to 18 years correlates with height at an aggregate annual level: wheat = -0.45, rye = -0.42, potato = -0.43, and CDR=-0.34, all at $p < 0.003$. This is also true for the individual-level data, although with smaller coefficients as would be expected. Because the three crops are highly correlated, they cannot be entered into a regression independently. Instead, an annual average of z-scores for the three crops is used, $Z_{prices} = \frac{1}{3}\left(Z_{wheat} + Z_{rye} + Z_{potato}\right)$, again summing across ages 11 to 18. A standard deviation increase in prices reduced stature by three-quarters of a centimetre (t=-5.6, p=0.000) and CDR by over one-half of a centimetre (t=-4.7, p=0.000), with an $R^2 = 0.386$. Conversely, reductions in prices and mortality boosted stature by equivalent amounts. The same results were found at the individual level. The effects of nutrition and health appear additive. Both prices and CDR had negative effects unconditional on the level of the other factor. Interacting the two and adding this to the regression yielded a negative but insignificant coefficient.

Figure 5 also highlights the shifting interplay between the four different measures: in the first half of the century low prices help compensate for high mortality in producing stature; in the third quarter, improvements in mortality do more of the work. Together, we see the joint importance of nutrition and health for physical development over the key pubertal growth window. Our final Figure 6 simplifies the account by offering a composite measure – the adolescent algorithm – in which our cumulative pubertal measures of CDR, and of prices, each account for fifty percent:

$$Adolescent\ Algorithm_{birthyear} = \sum_{ages=11}^{18} \frac{(Z_{prices} + Z_{CDR})}{2}$$

The adolescent algorithm starts to resemble a moving average of heights. Such a series is also included. It is a five-year case-weighted centred moving average of adult male stature, based on the earlier figures. The fit is tight. Food and death at ages 11 to 18 predicts an impressive three-quarters of the variation in stature for this smoothed series of height for Flanders' men.

Figure 6 here

For these Belgian men, the relationship between adult stature, health and nutrition is best understood through a focus on adolescence. The value of summing our measures across the growing years can be seen in Table 5. This compares results when examining height, health and nutrition by three levels: (1) year of birth, (2) all 26 growing years, and (3) more narrowly by ages 11 to 18. Height is measured variously at the annual level (e.g. average heights and index for each year 1804-76), as a smoothed annual series, and at the level of individual prisoners. The correlation of our composite measure of prices and mortality with adult stature varies considerably, and always in the same way. There is no relationship by year of birth (the coefficient is positive but insignificant). There is a moderate and as predicted negative association when considering all the growing years (conception to 25 years). Focusing on the pubertal growth window strengthens the correlation further. The regression results at all levels emphasise this. Averaging the composite index of prices and mortality across the growing years explains 18 per cent of annual variation in annual adult stature. Limiting coverage to the adolescent algorithm and thus conditions pertaining between the ages of 11 through to 18 years reduces the coefficient since there is more underlying variability, but doubles the explanatory power of the model to 39 per cent. As noted above, 75 per cent of variation in the smoothed series is explained by changes in the adolescent algorithm. The individual data likewise affirms the efficacy of using cumulative measures of economic and health variables for predicting stature.

Table 5 here

Finally, if catch-up really was driving adult height and weakening the connection with earlier environmental conditions, then men who had yet to complete their growth should exhibit stronger associations. They did. The final rows in Table 5 consider prisoners aged 18-25 years, so in their final growth phase. Their heights register stronger, negative effects from their accumulated experience of prices and mortality rates. Perversely – or perhaps hinting at selection – adverse conditions in year of birth finally register a statistically significant effect: very tiny, but positive.

VI

Nineteenth-century Flanders witnessed fortunes swing and notable shocks. Structural economic troubles combined with a deep agricultural depression put living standards under severe pressure in West Flanders, with the most acute impact felt between 1846-49 and between 1853-56. The reconstruction of the adult height trend for prisoners in Bruges clearly shows that some form of permanent stunting was inflicted, but on the whole not for babies conceived and born and growing during the most severe crisis years. More generally, both food prices and mortality indicators in the prisoners' year of birth failed to show any persistent negative effect on attained height. Conditions pertaining at birth were insufficient to capture the whole growth story. Indeed, they appear marginal to final male height, even misleading.

Flemish boys teach us that adolescence mattered most in shaping their adult stature. Our argument is predicated on three stylised facts. One, height accrues over all the growing years. Two, boys are good at catch-up, so puberty matters. Three, nutrition and health are both important for growth. By examining terminal heights through shocks, and against measures of prices and mortality prevailing at different ages, this article suggests a different way of reading trends in height that is more alert to cohort effects, to adolescent growth, and to the cumulative and shifting influences of both health and nutrition. Strong negative effects were found for food prices from age 12 and for the crude death rate from age 15 onwards. Adult height is a cumulative measure of net nutrition and we have argued that its determinants are likewise best understood cumulatively. For boys, the most appropriate guide is to sum measures of health and nutrition across the long pubertal growth window, and here we have focused on ages 11 to 18. This adolescent algorithm brings heights, health and nutrition into much greater accord.

This leaves the question, why were conditions around puberty more influential than those around birth? Three factors are implicated. One is mortality: infants might be so severely affected by hardship that they die and consequently are never recorded by adult stature. Yet, among survivors to adulthood, we do not detect additional scarring in this study. Two other factors pertain to adolescence. Second, we posit a great facility of boys for catch-up growth. Boys grow for longer than girls and this offers a protracted opportunity for restoring lost height. The cost of the pubertal growth spurt is high, demanding many calories, but if conditions are propitious and resources forthcoming (perhaps a good harvest, or entering paid work) then gains can be considerable. The third factor is the flip-side. Costly adolescence growth offers opportunities, but there is also an equivalent elevated risk around peak growth velocity and afterwards, making this phase susceptible to challenges. The earlier an insult was experienced (e.g. in infancy), the greater the chance of recovery; height lost in later growth cannot readily be salvaged. Late insults and gains both register in more permanent ways creating a moment with the capacity to fracture the connection between birth, childhood, and final attained height. All this cautions against expecting strong relationships between male adult height, conditions in utero and at birth, and later-life health outcomes, especially when conditions were volatile. We conclude that height is only a good proxy for boys' early-life conditions if those conditions mirror what was happening during adolescence (which, of course, they often do).

There are clearly many enduring consequences of deprivation experienced in utero, infancy and early childhood. Whether adult stature is one of them depends upon the subsequent opportunities for growth, both good and bad. The ability of boys to grow fast in adolescence and into their mid-20s reduces the certainty that adult stature will reflect environmental conditions at birth, or indeed at any one precise moment in time. This behoves us to think cumulatively, and directs us to the second, adolescent growth phase, when past fortunes might be consolidated, insults restored, or new injuries amassed. It was teens, not toddlers, whose stature responded in indelible ways to prevailing conditions to shape height trends in nineteenth-century Flanders.

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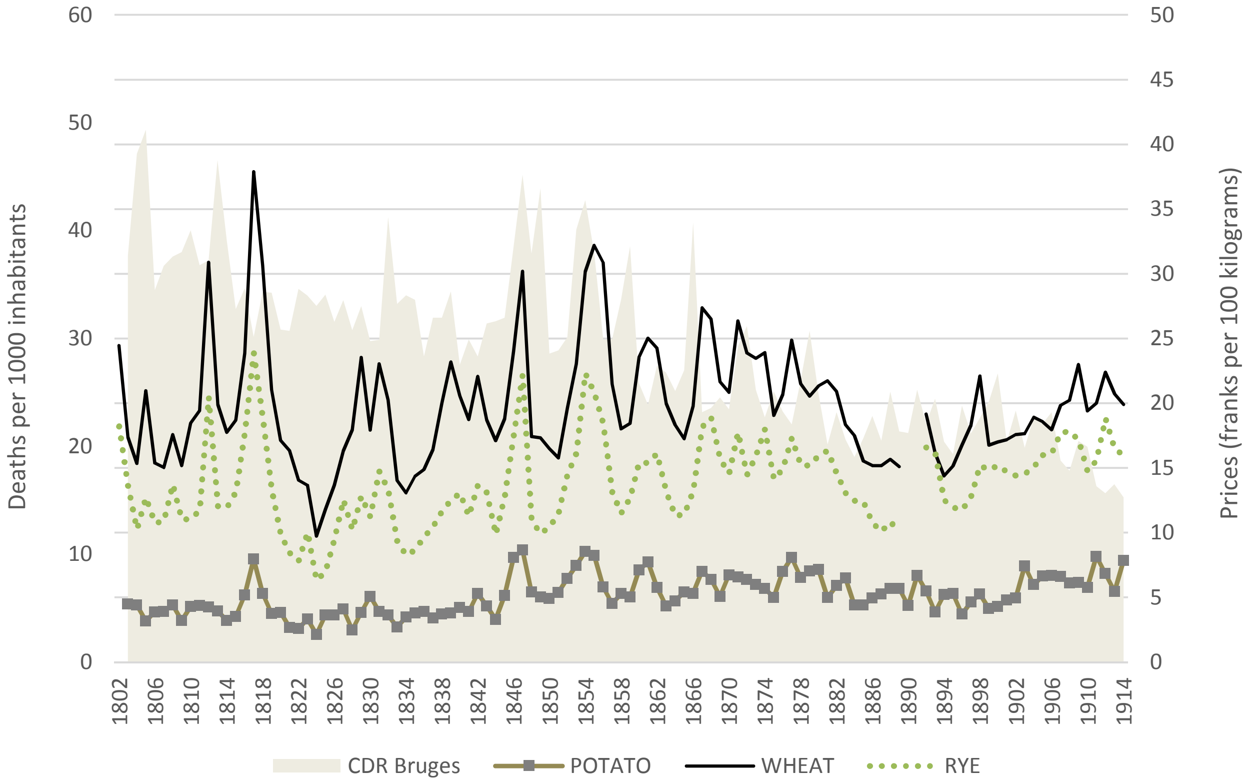
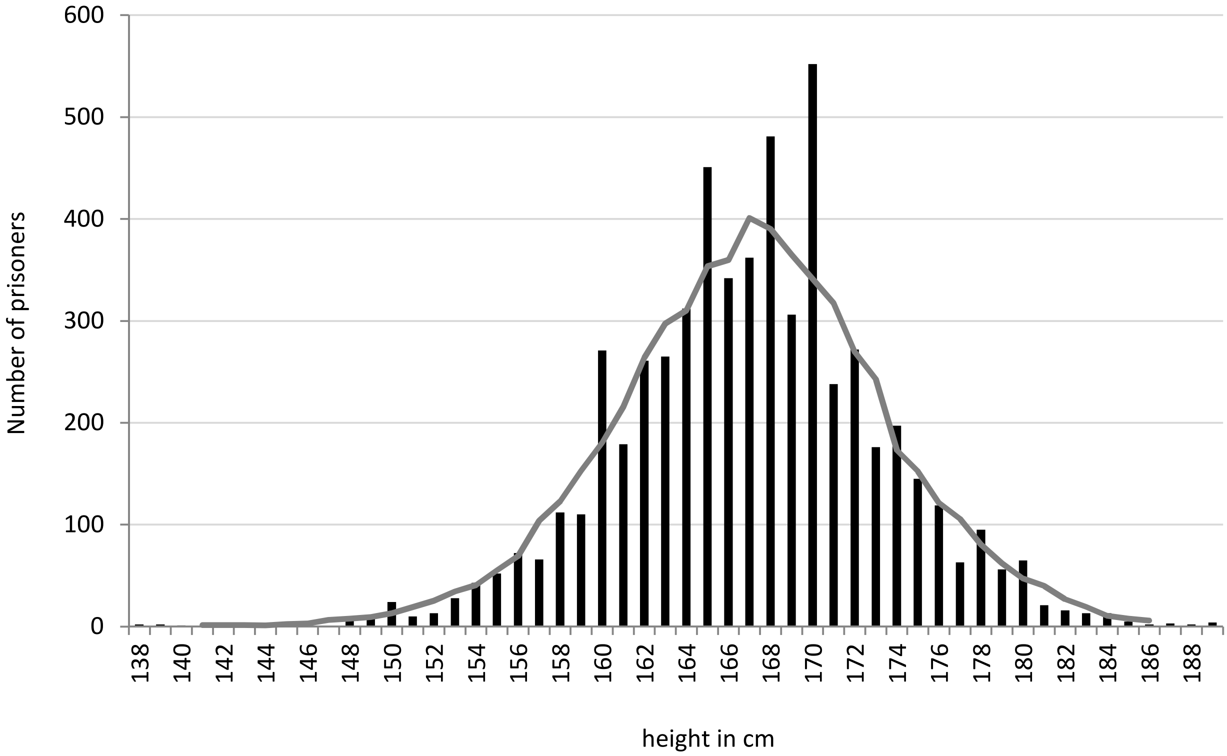
Figure 1. Food prices and crude death rate for Bruges, 1802-1914



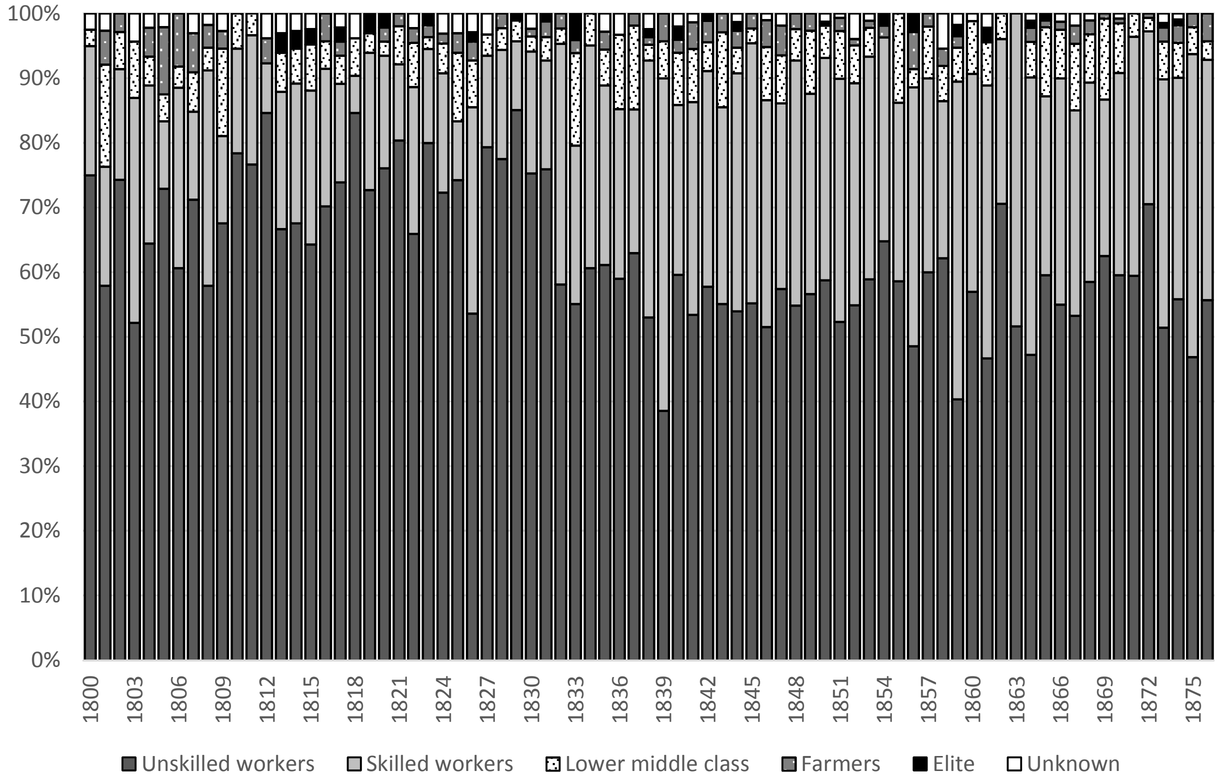
Source: Crops: Verlinden, C., Dokumenten voor de geschiedenis van prijzen en lonen in Vlaanderen in Brabant (XIIIe – XIXe eeuw), Deel IV, 1973 p.177-182 (wheat); Verlinden, C., Dokumenten voor de geschiedenis van prijzen en lonen in Vlaanderen in Brabant (XIIIe – XIXe eeuw), Deel IV, 1973 p.183-188 (rye); Verlinden, C., Dokumenten voor de geschiedenis van prijzen en lonen in Vlaanderen in Brabant (XIIIe – XIXe eeuw), Deel IV, 1973 p. 203-208 (potato). CDR: Van Haecke, L., Bruges-la-Morte. Differentieel mortaliteitsonderzoek voor de stad Brugge (2de helft 19de eeuw - 1ste helft 20ste eeuw), unpublished MA-thesis (Ghent University) 2004, p. 79; Sentrie, P., Een demografische schets van West-Vlaanderen, 1500-1850, unpublished MA-thesis (Ghent University) 2007, p. 106; De Vos, G. De voedingstoestanden te Brugge (1800-1860): een bijdrage tot de studie van de levensstandaard, unpublished MA-thesis (Ghent University) 1984, pp. 19-26; Death certificates Bruges, City Archives Bruges (www.archiefbankbrugge.be); LOKSTAT, Ghent University Quetelet Centre.

Figure 2: Frequency distribution of male heights (in cm) in the prison of Bruges



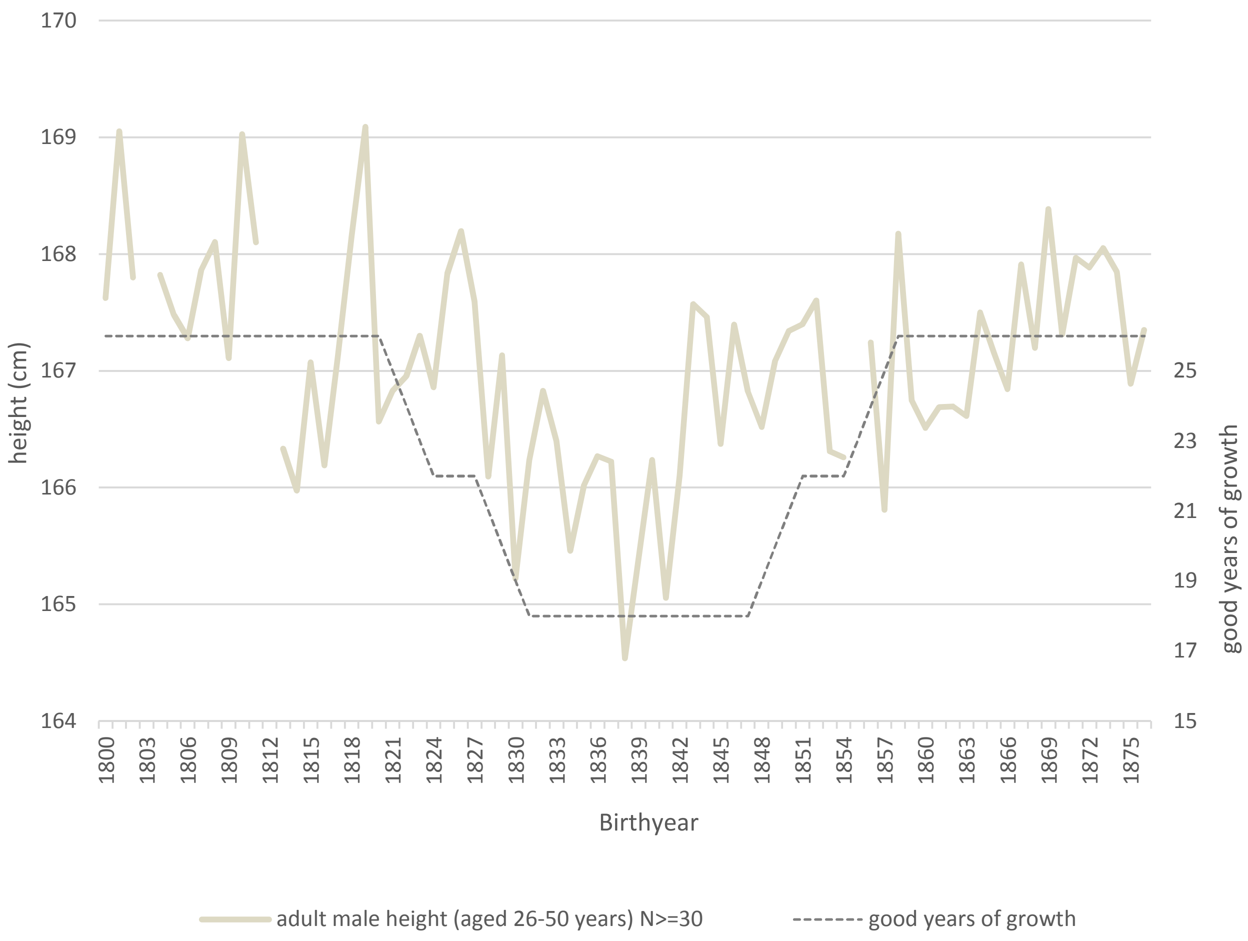
Source: Dataset of 5,505 adult male prisoners, aged 25-50 years, from Bruges. State Archives Bruges (RAB), Prison Archive Bruges (SI Brugge 1999), Enrolment registers (inschrijvingsrollen), 1354-1356, 1375-1378, 1387-1394 and 1418-1423.

Figure 3 HISCLASS of adult male prisoners arranged by year of birth



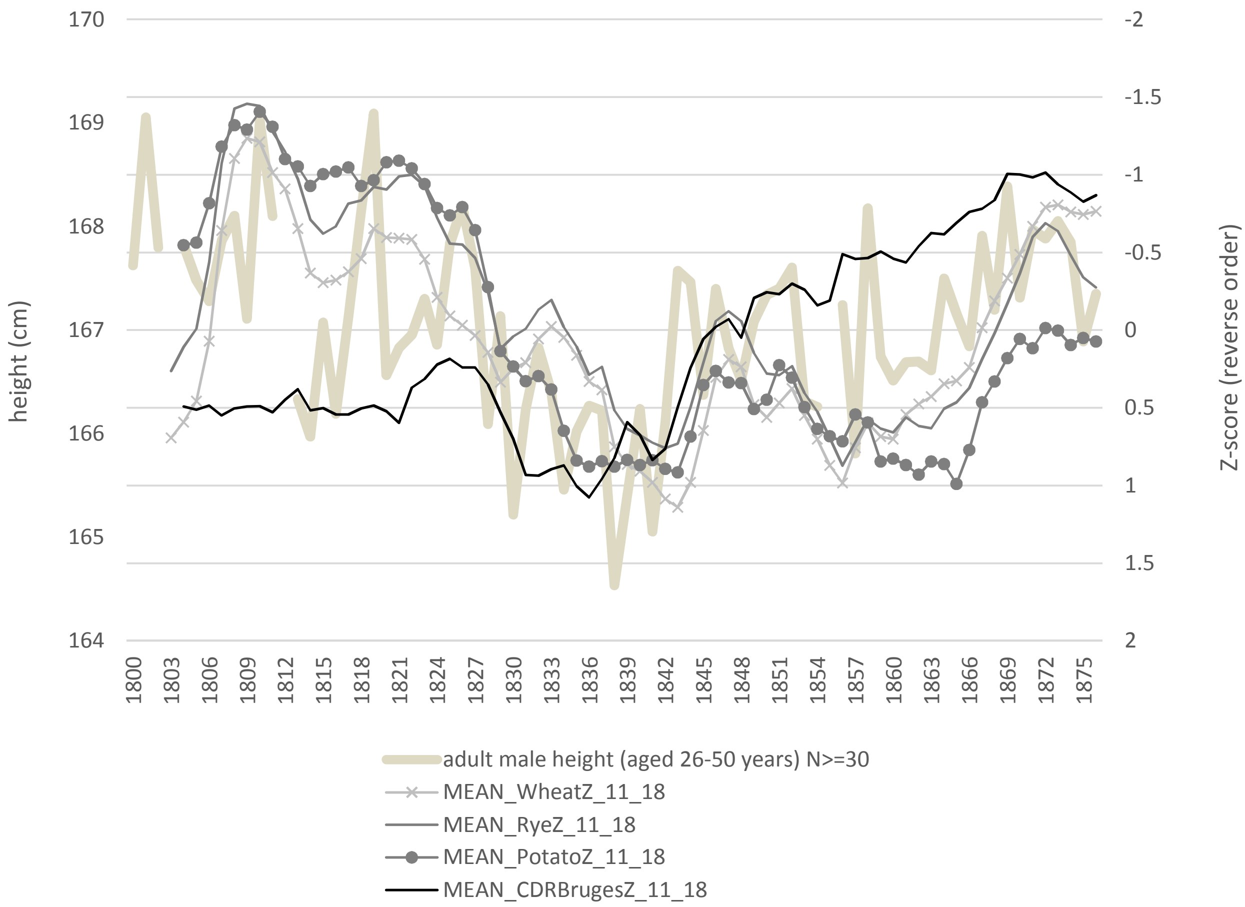
Source: Dataset of prisoners from Bruges, see Figure 2.

Figure 4: Average height of male prisoners (26-50 years) in Bruges by birth year, yearly average, 1800-1876.



Source: Dataset of prisoners from Bruges, see Figure 2.

Figure 5 Adult male height, prices and the crude death rate



Source: For prices and CDR see Figure 1. Dataset of prisoners from Bruges, see Figure 2.

Figure 6 Adult male stature (26-50 years) and the adolescent algorithm of health and nutrition in Bruges, 1800-76

Source: As for Figure 5

Table 1 Crisis exposure and adult male height (26-50 years)

		before either crisis (born 1800-20)	first crisis only 1846-49 (born 1821-27)	both crises (born 1828-50)	second crisis only 1853-56 (born 1851-57)	after crises (born 1858-76)
	mean adult height (cm)	167.55	167.43	166.41	166.93	167.46
	N of cases	1195	442	1940	509	1735
first crisis only (born 1821-27)	mean difference	**-0.12**				
	t-score	-0.35				
	significance	0.72				
both crises (born 1828-50)	mean difference	**-1.14**	**-1.02**			
	t-score	-4.93	-3.06			
	significance	0.00	0.00			
second crisis only (born 1851-57)	mean difference	**-0.62**	**-0.50**	**0.52**		
	t-score	-2.05	-1.28	1.83		
	significance	0.04	0.20	0.07		
after crises (born 1858-76)	mean difference	**-0.09**	**0.04**	**1.05**	**0.54**	
	t-score	-0.37	0.11	5.12	1.88	
	significance	0.71	0.91	0.00	0.06	

Source: Dataset of prisoners from Bruges, see Figure 2.

Table 2 Adult male height arranged by growing age in nine selected years

if born this year	completed growth before either crisis			exposed to first crisis			exposed to both crises									exposed to second crisis only						no crisis					
	1816			1826			1836			1846			1849			1853			1856			1866			1876		
	B	t	Sig.	B	t	Sig.	B	t	Sig.	B	t	Sig.	B	t	Sig.	B	t	Sig.	B	t	Sig.	B	t	Sig.	B	t	Sig.
adult height cm (ages 26-50 years)	168.57	164.03	0.00	168.69	228.55	0.00	168.31	238.12	0.00	168.60	287.65	0.00	168.81	315.16	0.00	168.87	348.29	0.00	169.46	329.99	0.00	167.52	349.26	0.00	167.41	420.78	0.00
AGES																											
conception to 2 years	0.38	0.47	0.64	0.13	0.25	0.80	-1.30	-2.26	0.02	-0.26	-0.60	0.55	-0.17	-0.45	0.65	-0.16	-0.41	0.68	-1.02	-1.92	0.05	1.56	3.96	0.00	1.09	2.74	0.01
3 to 6	1.63	1.93	0.05	-0.55	-0.96	0.34	-1.25	-2.20	0.03	-1.08	-2.41	0.02	0.01	0.01	0.99	-0.28	-0.81	0.42	-0.12	-0.34	0.73	0.90	1.96	0.05	1.56	5.08	0.00
7 to 10	1.35	1.76	0.08	0.06	0.09	0.93	0.00	0.01	1.00	-1.75	-3.64	0.00	-1.44	-3.35	0.00	-0.11	-0.27	0.79	-0.54	-1.42	0.15	1.08	2.10	0.04	1.37	4.05	0.00
11 to 14	1.47	1.80	0.07	-0.82	-1.27	0.20	0.03	0.05	0.96	-1.14	-2.25	0.02	-1.46	-3.20	0.00	-1.56	-3.89	0.00	-0.62	-1.49	0.14	1.12	2.57	0.01	0.80	2.07	0.04
15 to 18	2.62	3.14	0.00	0.61	0.99	0.32	0.35	0.56	0.58	-0.97	-2.22	0.03	-0.98	-2.05	0.04	-1.58	-3.67	0.00	-2.09	-5.01	0.00	1.33	3.78	0.00	0.62	1.43	0.15
19 to 22	1.97	2.13	0.03	0.04	0.07	0.95	-0.70	-1.10	0.27	0.43	0.93	0.35	-0.48	-1.17	0.24	-1.10	-2.44	0.01	-1.41	-3.09	0.00	1.20	3.01	0.00	0.11	0.22	0.83
23 to 26	0.33	0.33	0.74	0.62	0.95	0.34	0.61	0.87	0.38	-0.29	-0.54	0.59	0.43	0.92	0.36	-0.60	-1.57	0.12	-1.37	-3.06	0.00	0.37	0.91	0.36	0.99	3.15	0.00
27 to 50													*reference category*														
HISCLASS																											
Elite	-1.26	-0.38	0.70	1.73	0.74	0.46	3.90	2.05	0.04	1.62	1.01	0.31	1.55	1.00	0.32	2.32	1.57	0.12	2.11	1.42	0.16	0.79	0.50	0.62	1.47	0.98	0.33
Farmers	-0.88	-0.66	0.51	0.68	0.59	0.55	1.16	0.94	0.35	1.46	1.43	0.15	1.35	1.41	0.16	1.51	1.68	0.09	0.96	1.05	0.30	0.56	0.62	0.54	1.53	1.89	0.06
Lower middle class													*reference category*														
Skilled workers	-2.47	-2.67	0.01	-1.29	-1.70	0.09	-0.74	-1.07	0.28	-1.50	-2.59	0.01	-1.85	-3.46	0.00	-1.82	-3.68	0.00	-2.19	-4.30	0.00	-1.78	-3.77	0.00	-1.24	-2.97	0.00
Unskilled workers	-2.55	-2.99	0.00	-1.35	-1.95	0.05	-1.33	-2.09	0.04	-1.54	-2.82	0.00	-1.86	-3.69	0.00	-1.80	-3.84	0.00	-2.30	-4.74	0.00	-1.98	-4.32	0.00	-1.26	-3.14	0.00
Unknown	-1.83	-1.08	0.28	-0.63	-0.47	0.64	-0.94	-0.75	0.45	-2.26	-1.90	0.06	-3.06	-2.66	0.01	-2.87	-2.73	0.01	-3.90	-3.35	0.00	-3.92	-3.47	0.00	-2.76	-2.63	0.01
observations	1064			1637			1789			2512			2909			3304			2931			2961			3983		
Adjusted R^2	.016			.003			.013			.015			.017			.017			.024			.016			.014		
F	2.435	0.004		1.396	0.161		3.013	0.000		4.170	0.000		5.103	0.000		5.782	0.000		7.010	0.000		4.954	0.000		5.608	0.000	

	significance
negative	0.05
positive	0.05

Source: Dataset of prisoners from Bruges, see Figure 2.

Table 3. Correlation of adult stature with food prices and mortality, 1804-76

Adult male height (26-50 years) by year in which …	Food prices						Mortality	
	POTATO		RYE		WHEAT		CDR	
	coefficient	significance	coefficient	significance	coefficient	significance	coefficient	significance
Conceived	.162	.178	.116	.335	.058	.634	-.014	.909
Born	.136	.259	.145	.225	.066	.579	-.006	.962
Aged 1	.035	.771	.075	.526	-.047	.692	.020	.869
Aged 2	.077	.520	.088	.455	.033	.781	.065	.588
Aged 3	.137	.243	.054	.646	.025	.833	.241	.038
Aged 4	.004	.973	.128	.276	.051	.665	.116	.327
Aged 5	-.056	.634	.028	.811	-.042	.725	-.013	.913
Aged 6	-.004	.974	.035	.769	-.006	.959	-.005	.968
Aged 7	-.018	.876	.100	.398	.030	.799	-.041	.730
Aged 8	-.096	.418	.056	.635	-.038	.746	-.055	.642
Aged 9	-.029	.807	.020	.868	.007	.951	-.171	.145
Aged 10	-.030	.803	.137	.246	.168	.152	-.116	.325
Aged 11	-.136	.249	.073	.539	.088	.455	-.166	.157
Aged 12	-.238	.041	-.050	.670	-.009	.943	-.146	.213
Aged 13	-.358	.002	-.185	.115	-.121	.305	-.167	.154
Aged 14	-.414	.000	-.333	.004	-.342	.003	-.154	.191
Aged 15	-.297	.010	-.307	.008	-.343	.003	-.208	.075
Aged 16	-.329	.004	-.245	.035	-.259	.026	-.255	.029
Aged 17	-.374	.001	-.306	.008	-.309	.007	-.251	.031
Aged 18	-.314	.006	-.293	.011	-.316	.006	-.288	.013
Aged 19	-.317	.006	-.243	.037	-.288	.013	-.223	.056
Aged 20	-.321	.005	-.224	.055	-.239	.040	-.057	.629
Aged 21	-.253	.029	-.152	.197	-.182	.120	-.049	.679
Aged 22	-.311	.007	-.219	.060	-.308	.008	.114	.332
Aged 23	-.405	.000	-.285	.014	-.363	.001	.011	.923
Aged 24	-.284	.014	-.268	.021	-.326	.005	-.017	.883
Aged 25	-.324	.005	-.267	.022	-.376	.001	-.122	.300
Aged 26	-.367	.001	-.299	.010	-.434	.000	.031	.790
Aged 27	-.174	.138	-.115	.331	-.197	.092	.118	.315
Aged 28	-.046	.697	.059	.615	.009	.942	.182	.121
Aged 29	-.161	.170	-.064	.589	-.066	.574	.174	.137
Aged 30	-.242	.038	-.144	.220	-.143	.226	.163	.167

	significance
negative	0.05
negative	0.10

	positive	0.05

Source: For prices and CDR see Figure 1.. Dataset of prisoners from Bruges, see Figure 2.

Table 4. Regression of adult stature on Z-scores for food prices and mortality, 1804-76

	B	t	Sig.
adult height cm (ages 26-50 years)	167.84	455.92	0.00
AVERAGE Z-SCORE for …			
CROPS during …			
conception to 2 years	-0.23	-1.09	0.28
3 to 6	-0.14	-0.64	0.52
7 to 10	0.01	0.03	0.98
11 to 14	-0.30	-1.75	0.08
15 to 18	-0.43	-2.21	0.03
19 to 22	-0.09	-0.51	0.61
23 to 26	-0.01	-0.04	0.97
CDR during …			
conception to 2 years	-0.01	-0.05	0.96
3 to 6	0.62	2.30	0.02
7 to 10	-0.08	-0.31	0.76
11 to 14	-0.47	-1.79	0.07
15 to 18	-0.70	-2.57	0.01
19 to 22	0.33	1.15	0.25
23 to 26	-0.45	-1.17	0.24
HISCLASS			
Elite	1.69	1.35	0.18
Farmers	1.50	2.19	0.03
Lower middle class		*reference*	
Skilled workers	-1.13	-3.00	0.00
Unskilled workers	-1.16	-3.20	0.00
Unknown	-1.64	-1.90	0.06
observations	5369		
Adjusted R^2	0.02		
F	5.20	0.00	
		significance	
	negative	0.05	
	negative	0.10	
	positive	0.05	

Source: For prices and CDR see Figure 1. Dataset of prisoners from Bruges, see Figure 2.

Table 5 Composite indexes of prices and CDR by adult male height (26-50 years), born 1804-76

Composite index (prices and CDR) measured by …	Correlations with adult height (annual averages)			Correlations with 5-year moving average of height		
	Pearson's correlation	p	N	Pearson's correlation	p	N
year of birth	0.09	0.455	71	0.13	0.298	71
average from conception to 25 years	-0.43	0.000	71	-0.61	0.000	71
average from 11 to 18 years	-0.63	0.000	71	-0.86	0.000	71
	Regression of adult height (annual averages)					
	Constant	B	t	p	N	(Adjusted) R^2
year of birth	166.98	0.14	0.75	0.455	71	0.00
average from conception to 25 years	167.13	-1.54	-3.98	0.000	71	0.18
average from 11 to 18 years	167.05	-1.38	-6.80	0.000	71	0.39
	Regression of 5-year moving average of height					
year of birth	167.00	0.13	1.05	0.298	71	0.02
average from conception to 25 years	167.16	-1.66	-6.38	0.000	71	0.37
average from 11 to 18 years	167.06	-1.39	-14.24	0.000	71	0.75
	Regression of adult height (individual prisoners 26-50 years)*					
year of birth	167.01	0.09	0.64	0.524	5369	0.00
average from conception to 25 years	167.16	-1.54	-5.00	0.000	5369	0.00
average from 11 to 18 years	167.04	-1.36	-6.97	0.000	5369	0.01
	Regression of adult height (individual prisoners 18-25 years)*					
year of birth	167.38	.059	3.63	0.000	3968	0.05
average from conception to 25 years	167.48	-2.37	-7.76	0.000	3968	0.06
average from 11 to 18 years	167.31	-2.34	-10.19	0.000	3968	0.07

* HISCLASS controls included

Source: For prices and CDR see Figure 1. Dataset of prisoners from Bruges, see Figure 2.

Table A1 Men incarcerated in Bruges Prison, aged 26-50 years, born 1800-76
Height and valid cases by birthyear

1800	167.63	40	1840	166.24	99
1801	169.05	38	1841	165.05	73
1802	167.80	35	1842	166.11	90
1803	168.04	23	1843	167.57	69
1804	167.82	45	1844	167.46	76
1805	167.48	48	1845	166.37	87
1806	167.28	61	1846	167.40	97
1807	167.86	66	1847	166.82	108
1808	168.11	57	1848	166.52	124
1809	167.11	37	1849	167.08	113
1810	169.03	37	1850	167.34	160
1811	168.10	30	1851	167.40	149
1812	167.58	26	1852	167.60	102
1813	166.33	33	1853	166.31	90
1814	165.97	37	1854	166.26	54
1815	167.07	42	1855	166.84	29
1816	166.19	47	1856	167.24	35
1817	167.13	46	1857	165.81	50
1818	168.15	52	1858	168.18	37
1819	169.09	33	1859	166.75	57
1820	166.57	46	1860	166.51	86
1821	166.83	51	1861	166.69	45
1822	166.95	44	1862	166.70	51
1823	167.30	55	1863	166.61	62
1824	166.86	65	1864	167.50	91
1825	167.83	66	1865	167.16	94
1826	168.20	69	1866	166.84	80
1827	167.59	92	1867	167.91	107
1828	166.09	89	1868	167.20	94
1829	167.13	94	1869	168.39	128
1830	165.22	85	1870	167.31	131
1831	166.23	83	1871	167.97	111
1832	166.83	43	1872	167.88	146
1833	166.40	49	1873	168.05	138
1834	165.46	61	1874	167.85	111
1835	166.02	72	1875	166.89	96
1836	166.27	61	1876	167.35	70
1837	166.22	54			
1838	164.54	83	1800-76	167.06	5505
1839	165.40	70	st.dev.	6.2	

Source: Dataset of 5,505 adult male prisoners, aged 25-50 years, from Bruges. State Archives Bruges (RAB), Prison Archive Bruges (SI Brugge 1999), Enrolment registers (inschrijvingsrollen), 1354-1356, 1375-1378, 1387-1394 and 1418-1423.