Heights across the last 2000 years in England

Gregori Galofré-Vilà[1,2], Andrew Hinde[3] and Aravinda Guntupalli[4]

1- Department of Sociology and Mansfield College, University of Oxford

2- Dondena Centre for Research on Social Dynamics and Public Policy, University of Bocconi.

3- Southampton Statistical Sciences Research Institute, University of Southampton

4- School of Health, Wellbeing, and Social Care, The Open University

Abstract: This article uses a dataset of heights calculated from the femurs of skeletal remains to explore the development of stature in England across the last two millennia. We find that heights increased during the Roman period and then steadily fell during the 'Dark Ages' in the early medieval period. At the turn of the first millennium heights grew rapidly, but after 1200 they started to decline coinciding with the agricultural depression, the Great Famine and the Black Death. Then they recovered to reach a plateau which they maintained for almost 300 years, before falling on the eve of industrialisation. The data show that average heights in England in the early nineteenth century were comparable to those in Roman times, and that average heights reported between 1400 and 1700 were similar to those of the twentieth century. The article also discusses the association of heights across time with some potential determinants and correlates (real wages, inequality, food supply, climate change and expectation of life), showing that in the long run heights change with these variables, and that in certain periods, notably the thirteenth and fourteenth centuries, the associations are observable over the shorter run as well. We also examine potential biases surrounding the use of skeletal remains.

Acknowledgements: We should like to thank Susan Wolcott and a reviewer for valuable comments, Jane Humphries, Steve Broadberry and Laura Bonsall, who generously shared data with us, and Bernard Harris, Jane Humphries and John L. Brooke for their helpful comments on previous versions. The usual disclaimer applies.

Running head: Heights across 2000 years

JEL classifications: N01; N33; N53; O1; O13; O52

Key Words: Health; Height; England; Skeletal remains

1. Measuring wellbeing over the very long-run

Studies in recent years have continued a long tradition of attempts to measure living standards in Britain over the very long run using gross domestic product (GDP) estimates or real wages. Broadberry et al. (2015) have attempted to reconstruct GDP per head since the thirteenth century, revealing generally slow growth of *per head* income between 1270 and 1650 (0.19 per cent per year) with some periods of fast growth (such as that following the Black Death of 1348-1350), followed by a period of rapid growth between 1650 and 1870 (0.48 per cent per year). Others have attempted to estimate real wages from different occupational groups going back to the mid thirteenth century. In the early 1950s Phelps Brown and Hopkins (1956) looked at builders' wages in southern England from 1264 to 1954 and argued that there was a great rise and fall in the real income of wage-earners between 1300 and 1600 and that the level reached in 1450-1500 was not regained until after 1860. As these wage series focused solely on building craftsmen, they might not be representative of living standards of all working men.

Four decades later, Feinstein (1998) found a long plateau between the 1780s and the 1850s when the living standards of the average working-class family improved by less than 15 per cent. Adjusting manual workers' mean real earnings for unemployment, short-time working and seasonal unemployment, he argued that most British workers and their families experienced neither a deterioration nor a rapid improvement in living standards during these eight decades. Feinstein's series, focusing on blue-collar workers, reflected the evolution of wages below the average during the years of industrialisation, urbanisation and rapid population growth. Recently, Clark (2007) has revealed a picture of long-run stagnation in the hourly real wages of building craftsmen and laborers from 1250 until 1600, during which period economic changes were the result of demographic shifts; only after 1600 did technological change provide a long-run source of dynamism. More recently, Clark (2018) calculated a revised index of farm output which also illustrated less growth between 1270 and 1800 than the estimates of Broadberry et al. (2015). Allen (2001), like Phelps Brown and Hopkins, has argued that real wages did not improve massively between 1500 and 1850.

These real wage series, except for that of Feinstein to an extent, focused on workers' annual incomes that excluded information on the length of the working year. To correct this problem, Humphries and Weisdorf (2016) recently re-estimated historical real wages for unskilled male workers that were employed on annual contracts and argued that modern economic growth driven by an 'Industrious Revolution' began two centuries earlier (around 1600-1650) than previous estimates have suggested. Moreover, these new estimates correspond with the GDP per head estimated by Broadberry et al. (2015).

All these attempts to measure changes in living standards are limited by the fact that GDP does not value non-market activities, such as health and welfare, unless they are reflected in prices; and wages (when adjusted for changes in the cost of living) ignore fundamental elements of human well-being such as health. In addition, income and wages have different meanings in different periods which can impart a bias to long-run comparisons using traditional methods of measuring welfare.[1]

A widely available measure of health is life expectancy. In parallel with the above studies, other historians have searched for an accurate depiction of mortality trends. Based on burials and baptisms recorded in 404 Anglican parish registers, Wrigley and Schofield (1989) provided estimates of changes in mortality rates from the sixteenth to the nineteenth centuries. While this is probably one of the longest and clearest accounts of health in Britain, only a minority of parishes have data extending back to 1538 and many parishes have gaps in the series, especially around the time of the English Civil War (1642–1651) and the Commonwealth period. Another approach to measuring well-being has been to calculate the amount of food available in England and Wales (calories per head available for human consumption), with some estimates going back to the mid-thirteenth century (for a comparative review of the different estimates see Harris et al. 2015). However, estimates produced by different authors are substantively different both in level and trend and more research needs to be done to establish the reasons for the differences.

Finally, over the last 30 years anthropometric historians have studied well-being through changes in heights (for a systematic review of the literature see Galofré-Vilà 2017). Although the main causes of variation in individual height may be genetic, it has long been recognised that variations in the mean heights of different groups of people owe much to economic, social and environmental circumstances. There is a strong tradition of analysing heights using data from institutional populations, such as military recruits or convicts. However, these data tend only to be available from the eighteenth century onwards. For example, in England, the heights recorded from the Royal Marines and the British Army analysed by Floud et al. (1990) begin in the 1740s. We know very little about changes in heights for earlier periods.

In this article, we attempt to describe trends in the well-being of the English population over the last two millennia by estimating the average height of the English using data from skeletal remains. We also seek factors associated with changes in heights over time. Our purposes in doing this are, first, to try to examine very long run trends in welfare using a new source of data which is comparable over centuries and which

[1] See Steckel, Sciulli and Rose (2002) for a critique of the use of income and wages to measure well-being.

reflects a wide range of influences on well-being, especially in infancy and childhood; and, second, to compare the evolution in well-being revealed by the height data with trends revealed by other welfare-related series. By doing this we hope to contribute to the recent literature measuring welfare in England over the long run.

Our approach is inspired by the pioneering efforts of Steckel and his colleagues in North America and more recently in Europe.[2] We have assembled the details of a large group of individual skeletal remains for which we have reconstructed heights using information from the length of the long bones. In section 2 we describe the data. In sections 3 and 4 we discuss their representativeness and in section 5 we explain how we estimate body heights. Following this, in sections 6 and 7 we present the results for the development of mean heights over the last 2000 years and the factors associated with the trends. Section 8 compares our results with those of Steckel and his colleagues. Section 9 concludes.

2. Sources of evidence

To reconstruct the heights of people who lived in England over the last two millennia we collected individual bioarchaeological data from a range of archaeological excavations conducted during the last 30 years amounting to 4,746 individuals. Our first source is a set of archaeological excavations carried out in London and curated in the Museum of London, which report statistics on 2,762 skeletons. We then collected 613 observations from excavations conducted at Barton-upon-Humber, 581 observations for the Roman period housed at the English Heritage's Centre for Archaeology in Portsmouth and Winchester Museums; and 790 observations pertaining to different periods and places from a collection of previous studies made by Schweich (Table 1).[3]

The English Heritage data include the remains of 271 persons found in Ancaster, Lincolnshire. Ancaster was a small market town settlement established in the first century AD, with evidence of small-scale metalwork, pottery and masonry industries. A further 68 skeletons are from Baldock, Hertfordshire, one of the few Roman towns that developed from an earlier settlement (during the late Iron Age). Baldock was situated at the junction of several major roads and occupied mostly by traders and small peasant farmers. The remaining 310 skeletons are from Winchester, which at that time was probably a trading post, where several trade routes converged linking the east of

[2] In 1988 a group of scholars started to pool, classify and study data pertaining to stature, dental health, degenerative joint disease or trauma to create a 'health index' over the very long-run. These efforts led to Steckel and Rose (2002), which used data for 3,049 persons spanning 7,000 years. More recently, Steckel (2004; 2010), has moved on to study health in Europe during the last 2000 years.

[3] Sites with few observations (< 30) or where the date of birth of the sample could not be ascertained to within 150 years were not subjected to further analysis.

England with ports on the south coast (Mattingly 2006). The preserved bones pertain to a heterogeneous population, including craftsmen, traders and farmers along with those underemployed and seasonally employed (Bonsall 2013).

For the Saxon period (or the early medieval period) skeletal remains are in short supply (the Museum of London has records for less than 50 individuals dating from this period). Yet for a few places data are available and are used in the present study although not much is known about the origin populations. Raunds (101 skeletons), was a domestic settlement established early in the sixth century and Eccles (65 skeletons), was established soon after the destruction of a nearby Roman villa in the fifth century.

The Museum of London data include 1,820 medieval skeletons and 942 skeletons from the post-medieval period. Of the medieval skeletons, 636 come from the East Smithfield Black Death cemetery, which was the first Black Death cemetery established in London and which was in use between 1348 and 1350. This cemetery was a mass grave and information is not available on socio-economic status or occupation. The Museum of London has pointed out that the dental enamel hypoplasia was relatively high in this cemetery, suggesting that young adults were exposed to the Great Famine during early childhood.[4]

Merton Priory (676 skeletons) was a monastic cemetery (90 per cent of the remains were of males) but also included lay individuals, suggesting an integrated community. Individuals were buried in the medieval style (in east-west alignment) although prone burials were also found. The 309 skeletal remains found in St. Mary Graces were divided into two areas, the Abbey buildings and the Churchyard cemetery. Monks and important lay people were buried within the Abbey’s church and chapels, but the cemetery itself was used for the general population. A high prevalence of hypoplasia was also found there. St. Saviour monastic cemetery (199 skeletons) was founded in the year 1082 for monks of the Cluniac order and became a Benedictine Abbey in 1399 with a predominantly male buried population (Lawrence 1984). The 37 skeletons from Towton are from persons who died on 29 March 1461 in the Battle of Towton (the bloodiest battle ever fought on English soil) during the Wars of the Roses between the Houses of York and Lancaster.

Burial practice during the post-medieval period was more diverse than in earlier periods due to the impact of the Reformation. Intramural burial became the preferred option (for those who could afford it) and inhumation was still the dominant mode of disposal with cremation beginning to emerge again (Roberts & Cox 2003). St. Thomas’ Hospital was

[4] Dental enamel hypoplasia is a condition characterised by pits or other abnormalities in tooth enamel, which are thought to be a legacy of exposure to fever, illness or malnutrition in childhood. DeWitte (2014), suggests that people with hypoplasia and suffering poor nutrition were more vulnerable to the Black Death.

one of only three hospitals to survive the dissolution of the monasteries. The skeletal remains are from mass graves associated with the hospital, believed to be either pauper or epidemic graves (193 skeletons). The high number of general infectious diseases (e.g. syphilis) show the nature of the hospital, which provided some sort of refuge for the poor and sick. Farringdon St. Bride's lower churchyard (551 skeletons) was established as a result of the overcrowding of St. Bride's Church; it contained persons from low socio-economic backgrounds and most likely included individuals from Bridewell workhouse and Fleet prison, which were located nearby. Chelsea Old Church (198 skeletons), was a high-status cemetery on the outskirts of London, with the majority of those buried being adults who lived at least to 50-60 years of age.

The remains from Fishergate (224 skeletons) are mostly from the lay population of York; later on this was also the burial ground for members of the nobility and the higher ecclesiastical community (Schweich 2005). The Cistercian monastery of St. Mary Stratford Langthorne was founded in 1135 and quickly acquired great wealth to became one of the most important Cistercian houses in England. The remains found in Langthorne (158 skeletons) are mainly from a high-status monastic site (Schweich 2005). St. Peter's Church at Barton-upon-Humber (613 skeletons) is situated in a small market town serving local needs inhabited by a stable and predominantly indigenous population (Waldron 2007). The 137 remains from St. Martin's churchyard in Birmingham are associated with family graves of low and middle socio-economic status. Those buried there suffered from diseases associated with air pollution and overcrowding of the Industrial Revolution.

3. Reconstructing stature from the length of the long bones

There are many difficulties in interpreting bioarchaeological data as the kind of information that can be derived from a bone is limited and not always unequivocal (Bass 1971). Given the difficulties in analysing the data, the initial collection of 4,746 observations was narrowed down to 921 individuals for reasons that we now describe (Table 1).

[Take in Table 1]

The first issue is to determine the sex of the remains. We only considered the remains that were successfully classified by archaeologists as male or female and, since most of the classified remains were males, our analysis was confined to males, leaving us with 2,217 valid observations. Female and unclassified cases amounted to 1,030 and 1,499 respectively. We removed female data because the morphology of male and female bodies is different, and girls are more resistant to adverse conditions than boys (Tanner 1962). Another problem was to estimate the age at death of the remains. Following the classification made by the Museum of London, the aggregated age of death data provided by various archaeological groups was classified from previous categories of sub-adults (1-5, 12-17 years), adults (18-34, 18-45, 25-34, 35-49 or 18-49 years) and old adults (above 50 years) into sub-adults (0-17 years), adults (18-49 years) and old adults (above 50 years). From this classification, only males that had probably achieved their mature heights and who died as adults have been considered (those aged between 18 and 49 years). We excluded those considered as 'old adults' (aged 50 years and over) because of the possibility of shrinkage. Young and old bones are also more difficult to sex and less likely to survive (Bass 1971; Steckel & Rose 2002). This left 2,070 observations.

In forensic anthropology, there are two main methods for reconstructing stature from bone measurements: the mathematical and the anatomical. The mathematical method takes advantage of the high linear correlation between the length of the long bones and stature while the anatomical one reconstructs stature by summing the measurements of the skeletal elements that contribute to height, adding a correction factor for soft tissue. Since the anatomical method can rarely be applied to incomplete skeletal remains, which account for the vast majority, we use the mathematical method.

The idea behind this method is that the size of some bones that are often well preserved, such as the femur, has a high correlation with stature and this correlation can be estimated with an equation. Different equations are available, and we used those of Trotter and Gleser (1952). Although the use of mathematical equations may imply a loss of accuracy in the reconstructed height, and the use of equations between individuals with different genetic potential may also increase the error, this method is still the best way – and in many applications the only way – to reconstruct individual height from ancient samples. Since we only reconstruct the height of adult male populations there is no need to adjust the equations for gender and no need to use different equations for children and older individuals. We use the femur because this bone does not greatly change in proportions between maturity and death (most of shrinking from the age of around 50 years is due to the compression of intervertebral disks), and it responds to nutritional stress or benefits more quickly than other bones (Steckel & Rose 2002). Unfortunately, both right and left femurs were not well preserved in many skeletons: we had 921 skeletons with well-preserved right femurs and only 761 with well-preserved left femurs and almost all individuals with information on the left femur reported the details of the right femur. Accordingly, we used the right femur for our study. The baseline estimation of stature from the femur length is obtained with: 2.38 times the femur length plus 61.41 cm (with an error of 3.27 cm).

As a robustness check, we also have reconstructed stature from the tibia and from the tibia and femur (Trotter & Gleser 1952; 1958). The use of different bones gives very similar heights with a mean centred around 170 cm. The height reconstructed for the entire period using the right femur was 169.72 cm (standard deviation 5.53 cm), while the right tibia gave an estimate taller by 0.37 cm (standard deviation 5.26 cm). The difference between the mean height reconstructed from the left femur and that from the left tibia is 0.31 cm (with greater stature reported by the tibia and a standard deviation of 5.62 for the left femur and 5.20 for the left tibia). These results suggest that our estimates based on the right femur are robust. The observed height distribution is very close to a Normal distribution suggesting a good representativeness of all heights in the sample (Appendix Figure A1).

In Appendix Table A1, we also compare our height estimates from the different sources with those made by the original collectors of the data. They are very close in all cases, particularly when comparing our approximations with the estimates from the Museum of London. However, our estimates are somewhat lower than those of Schweich, who used equations different from ours to estimate heights from femur bones. The fact that different methods can produce different results highlights the value of the exercise attempted in this article of applying a consistent method of estimation through time and across space.

4. Selection bias

The exercise of reconstructing the stature from the length of the femur is subject to several potential sources of bias. First, we use the age of 18 years to distinguish those who have reached their adult heights from those who have not, yet we have no evidence that 18 years was the age in which men in the sample attained their mature heights. Even though in well-nourished populations a man might attain his mature age at 16-17 years, we do not know if this was the case in general, as poor nourishment can retard the growing period until the ages of 23-25 years. Unfortunately, since the ages reported by archaeologists are given by age groups (e.g., 18-34, 35-49 or simply 18-49 years) we cannot control for the age at which maximum height was attained and we had to assume that individuals classified as being 18-49 years were adults who had achieved their mature heights.[5]

[5] The age group 18-49 years includes some adolescent skeletons who may not have attained their full adult height. This may mean that we overestimate the impact of subsistence crises in our height series, to the extent that we include in our data individuals aged 18-25 years who, if they were affected by poor nutrition in early childhood, would probably not have attained their full adult height by 18 years. However, we anticipate that this effect is modest, and we are constrained by the age groups used in archaeological reports.

Second, while basing the study on individuals aged between 18-49 years selects most of the individuals who have attained mature height and who have not yet started to shrink, if height is inversely associated with life expectancy, we might ask to what extent the selection of individuals who died at relatively young ages (e.g., below 50 years) might distort the results? We think the extent of any distortion is likely to be small. Life expectancy in England was below 40 years during almost all the period with which we are dealing, so death within the age range 18-49 years was not unusual.[6] In effect, there are two selection effects operating: one through which we select into our sample those who have escaped infant and child mortality (and so who might be expected to be healthier than the average person born); and a second by which the healthiest individuals among the remaining sample members are selected out by survival to age 50 years. These two effects work in opposite directions which suggests that our results may well provide reasonable estimates of the 'average' well-being of the population. As the proportions of deaths in infancy and childhood and at ages 50 years and over probably did not change drastically over time before 1800, we think that the long-run trends we identify should be robust to the effects of selection. The most important exception to this was probably London in seventeenth and eighteenth centuries, where infant and child mortality rose to punishing levels, intensifying the positive selection of healthier-than-average persons into our sample (Razzell & Spence 2007). Finally, as Steckel and Rose (2002) argue, the inclusion of old adults (aged above 50 years) might introduce further selection effects as osteoporosis is more likely to be present in elderly individuals and bones affected by this disease are less likely to survive.

Third, we do not know in any good detail whose bones we are looking at. This problem has also been pointed out by other historians. For instance, Kunitz (1987, p. 270) believed that the "extent to which burials represent an unbiased sample of the social strata of a population living in a particular place at a particular time is generally unknown". All we know is the place that the deceased individuals were buried. In Section 2 we did mention the likely social class of several of our samples on the basis of the cemetery in which they were buried, and we find that in many cases there is a good degree of consistency between the heights derived from different samples in the same period (see Appendix Table A1).[7] Steckel (2013, p. 418) also argued that in general normally "more urban than rural sites are excavated (owing to more construction), excavations may be incomplete, seasonal migrations may obscure some burial sites, and

[6] Using the Model West life tables published in Coale et al. (1983), we find that with an expectation of life at birth of 20.4 years, 56% of deaths occurred between aged 18 and 49 years; the corresponding figure with an expectation of life at birth of 30.1 years was 44 per cent, and with an expectation of life at birth of 39.7 years it was 33 per cent.

[7] It is also not clear that there were great differentials in mortality by social and economic status in England before the eighteenth century: see Razzell and Spence (2006).

the quality of preservation depends on the acidity level of the burial environment". Hence, our samples tend to be biased towards central urban settlements and London in particular. On the other hand, since we are dealing with a single country, and burial customs were unchanged for long periods, there is no need to compare different burial types within the same historical period, as would be necessary if one were to compare skeletal remains between different countries with different burial customs, for example, across Europe (Roberts & Cox 2003). We have calculated the proportions of our sample in different periods which come from London. There are variations, but they seem unrelated to the height series, and we do not see abrupt changes in mean heights at points where the proportion of the skeletons in our sample which were buried in London changes.

It has been argued that migration became important during the medieval period with the Germanic and Scandinavian influxes, and variations in height during this period could be due to migration rather than nutritional and environmental conditions. Yet, without more sophisticated techniques such as chemical analysis and carbon-14 dating to explore the genetics of the bones, this claim remains uncertain. As Roberts and Cox (2003, p. 195) argue, although "some may argue that the height increase may indicate the mixing of (taller) people from the continent. This cannot currently be proved". Moreover, recent research suggests that "most, if not all, of the invasion groups arriving in Britain, from the Romans to the Normans, were relatively small migrations" (Pattison 2008, pp. 2, 423). Regarding internal migration, little information can be drawn from the remains, but we note that the data may contain individuals who were buried some distance from their place of death (although possibly close to the place they were born or had lived most of their lives).

Since our sample is from deceased individuals in England, we avoid further composition effects and bias in aggregating data from distant areas and over time. Koepke and Baten's (2005) analysis of data from Europe, for example, includes very few observations in some centuries for the Mediterranean region, but much more data from eastern Europe and Scandinavia. For instance, Brooke (2014, p. 378) argues that most of Koepke and Baten's data comes "from thinly populated eastern Europe and Scandinavia, with the Mediterranean, France, Germany, and Britain barely represented at all." We therefore believe that the evidence collected allows us to say something about health in England (and particularly in Central and Southern England where most of our remains have been found).

5. Estimating trends in height over time

Associated with the problem of the very fragmentary information from the skeletal remains is the challenge of locating the remains in time. In general, most archaeological remains can only be dated to within a few decades, and often only to within a century (McGhee 1981).[8] Various ways forward have been proposed. One is to assign the remains to the different historical periods and report the mean height for long periods such as Roman, early-medieval, late-medieval and post-medieval (Roberts 2009; Roberts & Cox 2003). However, this approach only provides a very general illustration of the heights in England over the long run. A second has been to plot directly the reference periods reported by archaeologists against time, which implies an assumption of a constant stature for a long period. Thus Kunitz (1987) reported a constant height for the period between 43 and 407 AD of 171.1 cm for England; and de Beer (2004) implied that in the Netherlands the height of upper social class males remained constant from 1000 to 1600 at 174.0 cm.

A third option, proposed by Steckel (2010), is to group individuals born within a maximum period of 300 years and assume that burials are evenly distributed across the dates that deposits occurred, organising the results by centuries. Thus if, say, 225 individual skeletons were dated in the period 1425 to 1649 (225 years), he would assume that 75 of the deaths occurred between 1425 and 1499, 100 between 1500 and 1599, and 50 between 1600 and 1649. A modification of this approach has been applied by Koepke and Baten (2005, p. 67) who “used the average of the earliest and latest date … [although] the real date could have been both before and after the middle of a century”. In this case, for example, if archaeologists provided a dating range between 860 and 930 AD they would allocate the sample to the period between 800 and 899 (as the average is 895).

Different methods have different implications and place the remains at different points in time, leading to different height estimates. For example, in the example cited from Koepke and Baten there is a high probability that some of the sample members died during the period 900-930, and thus are also allocated to the wrong century. The wider the range of dates for a set of skeletons, the greater the likely inaccuracy in dating. If archaeologists provide a period between 1050 and 1375 for a set of deaths, then Koepke and Baten would allocate all the deaths to the thirteenth century. This, they acknowledge, might explain some unexpected results from their analysis: for instance, they found that height increased during the Black Death in Central and North Europe: “A negative effect of the so-called crises of the fourteenth century (Hundred Years War,

[8] Clearly, some archaeological evidence can be more precisely dated on the basis of documentary evidence pertaining to specific events generating the evidence. But this would only apply to a minority of the skeletons analysed in this article.

Great Famine, and the plague) cannot be seen. A reason could be that the inadequate temporal resolution of our data" (Koepke 2008, p. 143).

In this article we propose a new method for representing the development of height across time. As already seen from the archaeological work, each skeleton can be given an earliest possible and a latest possible date of death, the difference between these dates forming a window within which the true date of death lies. We considered that windows greater than 150-200 years in length are difficult to analyse because, depending on the dating of the remains the same remains can be placed in three different centuries. Hence, we only considered remains that can be dated within a window equal to or narrower than 150 years in length (or 200 years in a few cases). The mean length of the window within which the skeletal remains can be dated in our sample is 84.7 years.

In our method, we first overlap different samples by the different periods in which people lived, to create a sequence of intervals within each of which the sample is the same, and between which samples differ. We estimate the mean height within each of these intervals as a weighted average of the mean heights of each of the samples contributing to that interval, where the weights are the relative sample sizes. For example, for the interval 1250-1299 we used the sample of St. Peter Church, Merton Priory, St. Saviour and Langthorne (with mean heights of 172.42 cm, 174.5 cm, 171.37 cm, and 171.12 cm respectively), with a weighted average height of 172.67 cm. From 1300 until 1330 we used the samples from Baldock, St. Saviour, Merton Priory, and Langthorne (with mean heights of 168.59 cm, 171.37 cm, 168.80 cm, and 171.12 cm respectively), and a weighted average height of 169.60 cm. Between 1330 and 1348 we used data from Baldock, Langthorne and Merton Priory (with mean heights of 168.59 cm, 171.12 cm, and 168.80 cm respectively) and a weighted average height of 169.42 cm. Finally, for the years 1348 and 1349 data are from Baldock, Langthorne, Merton Priory, and East Smithfield (with mean heights of 168.59 cm, 171.12 cm, 168.80 cm, and 167.64 cm respectively), and a weighted average height of 167.70 cm.

It will be convenient to be able to plot the weighted average height for each period as a point estimate. The deaths in each period can be regarded as occurring, on average, at the mid-point of that period. Adult heights, however, are mainly determined by nutrition and other conditions between aged 0-15 years. Supposing that the average age of death of those in our sample to be around 40 years, we present our tables and charts using the date of birth of the bodies, by subtracting 40 years from the average date of death.

Data on the time periods covered by each sample and mean heights we estimated for each sample are reported in Appendix Table A1. We can use this information to compute the amount of data we have for each of the intervals described in the previous paragraph. Because the intervals have different lengths, Appendix Figure A2 presents the amount of information as 'skeletons per year'. The data for the first millennium AD are very limited, and there are periods for which skeletal evidence is absent (for example 600 to 900). From the start of the second millennium the amount of data rises to a peak in the thirteenth and fourteenth centuries. There is then an abrupt fall to very low levels between 1400 and 1700 before the quantity of data increases in the eighteenth and early nineteenth centuries. The varying amount of data available should be taken into account when interpreting the results, which we now present.

6. Long-term trends in stature

The height trend revealed by our data for England over the last two millennia is reported in Table 2 and Figure 1. Here we move beyond previous attempts by Roberts and Cox and Kunitz to discuss health over the very long run in England as we provide continuity in the height estimates rather than estimates for benchmark years or for different cemeteries separately. Still, our results are close to the height estimates in some benchmark years (available for some long historical periods) made by Roberts and Cox (2003). We find that height increased gradually during the Roman period with a mean height during this period of 168-169 cm. Roberts and Cox argue that during the Roman period mean stature was 169 cm (based on 1,296 individuals). After the Romans left the British Isles, heights started to decline in the 500s. Roberts and Cox find that, by the end of the early-medieval period, heights increased to 172 cm (based on 996 observations) while we find that in the twelfth century, stature reached 173 cm before it began to decline during the thirteenth century. According to Roberts and Cox, excavations of post-medieval sites indicate that the population was on average about 171 cm tall (based on 558 individuals). We find that mean height was about 172-173 cm from 1400 to a point in time after 1600. The low mean for the data point around 1420 is based almost entirely on a set of skeletons from the battle of Towton.[9]

Mean heights fell during the seventeenth century to 170 cm in the 1700s. The figure of 171 cm for this period reported by Roberts and Cox "almost entirely represents the middle classes who were better fed" and people from the working classes were found to be somewhat shorter at 169 cm, precisely the height estimates we present here (Roberts & Cox, pp. 391-392; See also Brickely et al. 1999; and Molleson & Cox 1993).

[9] Although we include the Towton data in Figure 1, we omit them in Figures 2-5 to ensure that the low heights from the Towton sample is not included in analysis. This sample is based on young men aged in their twenties. In that case they may all have been born during the 1430s. The 1430s are known to have been the harshest decade of the fifteenth century. The climate was unusually cold, and there is evidence of famine conditions in much of norther and western Europe. This was the only decade in the fifteenth century in which such conditions prevailed (see e.g., Camenisch et al. 2016). Therefore, we think that the short stature of these men may actually confirm the sensitivity of the height measure to well-being in infancy.

[Take in Table 2 and Figure 1]

Despite the consistency between our estimates and the data from Roberts and Cox for some benchmark periods, we also find that there is a low degree of agreement between Koepke's heights for North Eastern and Central Europe and our data for England (Figure 2). While there is some synchrony between stature in England and North-Eastern Europe, with the onset of the second millennium they clearly diverge. Indeed, taking the data for North Eastern Europe over the last 2000 years, except for the data for the fifteenth century, heights were almost stagnant with a mean value of 169.57 cm and a standard deviation close to 1 cm (Koepke 2016). Given the low convergence between sources and lack of variation in Koepke's data, in the next section we describe our height data for England in detail and then in Section 8 we compare it with Steckel's health index at the European level based on a range of health characteristics, apart from stature.

[Take in Figure 2]

7. Heights across the last 2000 years in England

Let us consider the English story in more detail. During the Roman period heights slowly increased. This was a time when important towns and *villas* were developed. Urban centres provided shelter and work. As the concentration of people increased in towns and cities, the Romans prioritised the need for clean supplies of water and a sewage disposal system (Roberts & Cox 2003). Bowman (1994, p. 110) has argued that "the Roman water systems were effective in enabling people to live in densely populated towns while avoiding a lot of water-related diseases". New agricultural techniques were also used, for instance crop rotation enabled people to graze their stock and manure the land at the same time. Trade increased, while diet also changed, with an increase in beef and pork consumption. Thus, even though contact with a continental empire and the opening up of new trade routes might have helped the spread of some diseases, Roberts and Cox (2003, p. 220) contend that, overall, during the Roman period "either people are living healthy lives and are well fed, or that their bodies are very efficient at adapting to the circumstances in which these populations found themselves".

In 410 Roman control over the British Isles essentially ended. While heights did not immediately deteriorate after the departure of the Romans, they did fall from about 600 onwards. This is consistent with the argument, advanced by Cameron (1993, p. 5) and others, that the "Anglo-Saxon population could not have been particularly healthy. The conditions of life and diet help to establish a background for many of their illnesses". According to Roberts and Cox (2003, p. 176), there was a "decline in urban settlement and … many Roman towns were abandoned as flourishing and prosperous areas". The abandonment of urban centres meant the loss of a good system of water supply and waste disposal mechanisms. It also probably meant a decline in hygiene standards. It is believed that plague and pestilence were common, and that the incidence of infectious diseases generally increased (Howe 1997). The so-called ‘plague of Justinian’ (which may have been bubonic plague) appeared in a series of fifteen great waves between 541 and 767 AD. Archaeologists have also found increasing evidence of dental enamel characteristic of inadequate diets (Roberts & Cox 2003).

Figure 1 suggests that heights began to increase sometime in the eleventh century. The period after the Norman Conquest was one of population increases and the restoration and development of urban centres. Dietary improvements centred on grain products with bread and ale, the basic staples for most people. Milk was rarely drunk fresh but was usually converted into buttermilk or whey and curds (Hammond 1993). It is possible that climate played an important role in rising heights. From the tenth until the thirteenth century, England “saw the warmest weather of the millennium. This contributed positively to the increased agricultural production of the period and impacted positively on health and fertility” (Roberts & Cox 2003, p. 227). It is therefore not surprising to see an increase in heights of more than 5 cm over a period of 200 years. As temperatures rose, medieval warming enabled people to settle in previously-marginal territories and the food supply was also increased for people living in less marginal areas (for the same or a lower level of effort). According to Pretty (1990, p. 12), “the limit of cultivation was increased by at least 100 metres in altitude compared with [the period] before AD 800”.

Sometime after 1200, heights started to decline. Archaeologists have documented that during the 1200s a process of rural depopulation began, with a decrease in fertility rates and higher mortality through soil exhaustion and shortages of crop seeds. Climatic conditions also deteriorated during this period: the “thirteenth century was generally colder than the previous one … and this was followed by a rapid downturn of temperatures and general climatic instability in the early fourteenth century” (Roberts & Cox 2003). Increasing inequality also might help to explain the decline in heights (see Bekar & Reed 2009).

Economic historians have argued for decades about the extent to which there was a Malthusian crisis in England around 1300.[10] Fortunately, this is a period for which the

[10] There is not space here to summarise the many contributions to this debate. For a straightforward statement of the case for a Malthusian crisis, see Postan (1975). More recent contributions, such as Broadberry et al. (2015), have argued for a more optimistic scenario. A key difference between the ‘pessimists’ and the ‘optimists’ is their estimates of the population of England around 1300. Postan estimated this number at upwards of 6 million, whereas Broadberry et al. prefer a figure of 4.75 million (p. 20). For a discussion of the issues surrounding population numbers at this time, see Hinde (2003, pp. 22-37).

amount of data we have is relatively large. In Figure 3, we compare the development of heights and agricultural output per head. From the mid thirteenth century, heights were declining alongside agricultural production, reaching a minimum value among those born in the first two decades of the fourteenth century. However, starting before the Black Death of 1348-1350 and continuing afterwards, both heights and agricultural production increased substantially. This trajectory is consistent with Postan's thesis that during the thirteenth century the population of England approached its carrying capacity, and the period around 1300 was characterised by land hunger and declining yields caused by over-cropping and a reduction in soil fertility (Postan 1975). The period 1315-1322 was especially difficult with a major famine in 1315-1317, during which around ten per cent of the population probably perished (Kershaw 1973). Among the causes of this crisis, Kershaw lists grain prices, royal taxation for wars and weather conditions. The immediate cause of the famine was torrential rainfall which destroyed crops and fodder and drove grain prices up resulting in widespread starvation and suffering. Slavin (2014) also highlights the impact of a recession in European trade and market failure, with market segmentation, price supervision and preferential trade. It is possible that exposure to the Great Famine in infancy or early childhood had a permanent effect on adult height. This effect may have exaggerated the decline in heights seen during the middle of the fourteenth century, but we emphasise that average heights began to decline several decades before the Great Famine.

[Take in Figure 3]

The Black Death arrived in England in 1348. Close to half of the inhabitants are believed to have perished in the two years following the plague's arrival (Hinde 2003; Smith 2002).[11] The immediate consequences of this for the living standards of the survivors have been much debated, but Figure 3 shows that output growth per person in agriculture, which had been rising since around 1320, continued to increase after the demographic shock, suggesting that living standards may have started to rise as land became more abundant (see Hinde (2003, pp. 44-52) for a summary of the debate). Broadberry et al. (2015) have estimated that the Black Death heralded a major increase in the proportion of calories obtained from meat and dairy produce. The skeletal evidence on heights is consistent with this. They also argued that agricultural productivity rose following the Black Death. While in Figure 2, at the European level Koepke and Steckel identify an increase of stature following the Black Death, their data also show that, during the thirteenth and early fourteenth centuries, heights remained stagnant. After the Black Death heights remained stagnant according to Koepke (2016) and Koepke and Baten (2005) and increasing in the case of Steckel's data (2010). These

[11] A relevant question is whether plague epidemics brought about a systemic change in the way in which the bodies of the dead were disposed of. The evidence for England is that it did not: see Harding (1993).

results are puzzling and illustrate that our data are more sensitive to changes in wellbeing than previously thought.

DeWitte (2014) has also pointed out that improvements in the standard of living benefited the poorer sections of the population most, thus reducing inequality. It seems, therefore, that the evidence from our height data for the thirteenth and fourteenth centuries (and this is the period for which we have most skeletal data) charts a trend which is consistent with other recent evidence on living standards during the period.

Figure 4 shows our height series with the new index of real wages for unskilled English male workers employed on *annual* contracts provided by Humphries and Weisdorf (2016) and Clark's data for comparison (2007). The annual workers' income is the sum of their annual cash payment and the implied value of their in-kind benefits. The use of income from annual work is an important improvement to the long-run wages series as it circumvents problems posed by daily wages paid to casual workers who moved between jobs by considering the number of days worked as being fixed over time (normally at 250 days). We also added the wage estimates of casual workers provided by Clark in this figure to explore the association between heights and wages of casual workers. For the details on casual wages see Clark (2005).

[Take in Figure 4]

A comparison of our height estimates with the income of annual workers suggests that heights increased after the Black Death due to a general rise in the land-labour ratios and improvement in the standard of living. Although our height estimates are based on smaller samples between 1400 and 1650, the skeletal evidence suggests that average heights reached 173-174 cm among those born around 1400 and remained at that level until the early seventeenth century. The convergence between heights and wages continued until about 1500. After 1500, however, wages declined whereas heights did not fall until somewhat later. From 1650 to 1850, our height estimates and real wages seem to diverge. It is likely that wages did not translate into taller heights due to poor health conditions and the nature of work in general, a point expanded in the next paragraph. The divergence between heights and wages post 1650 is greater for real wages based on annual workers' incomes than those based on the incomes of casual workers. Generally, though, our height series provide a more pessimistic perspective on living standards from 1650 than do the real wage estimates.

The explanation of the end of the association between height and direct measures of economic well-being is not clear, but we do know from independent evidence that the second half of the sixteenth century and the early years of the seventeenth century were unusually healthy, with crude death rates of around 25 per thousand or lower and that the expectation of life at birth was close to 40 years in the 1580s (Wrigley & Schofield

1989). The introduction of poor laws may also have contributed to raising the well-being of the poorest sectors within society (Slack 1990). As we have so little data for this period, though, to say more than this would be speculative. Heights seem to have begun a sustained fall among cohorts born after the early seventeenth century, a decline which continued until the early nineteenth century. Between around 1650 and 1800 heights and GDP per head moved in opposite directions which is consistent with the comparison between real wages and stature (Broadberry et al. 2015). After 1700 our height data become more abundant, and the trend in stature is still moving in the opposite direction to that in real wages. To try to explain this, we can make the following points.

First, mortality data suggest that the late seventeenth and early eighteenth centuries were notably unhealthy, with an expectation of life at birth was below 35 years throughout the period 1650-1750, compared with the late sixteenth century when the expectation of life at birth was close to 40 years (Wrigley & Schofield 1989, pp. 531-535). There is a sense, important for our argument, that the contrast in mortality between the sixteenth centuries and the period after 1650 is even greater than this, as plague ceased to be a significant cause of death after 1665. If plague was an exogenous cause of death unrelated to general health and well-being, then its disappearance in the 1660s means that the contrast between the sixteenth and late seventeenth centuries in mortality from those causes of death which we consider might have been associated with general health (and hence with stature) was even greater than the difference in the expectation of life at birth would suggest.

Second, we can also consider the nature of work after 1650 and the demands placed on the body's resources by exposure to disease and the use of energy to perform manual work. While we have already seen that after 1650 Britain was an unhealthy place, Voth (2000) finds that during the Industrial Revolution the working year was as long as 330 days in comparison to the findings from Blanchard (1978), who indicates that the medieval working year was something like 165 days long. The numbers provided by Humphries and Weisdorf (2016) are consistent with these figures and show that just after the Black Death the working year was as short as 100 days. The increasing numbers of working days (associated with poorer working conditions in industries) also clarifies why heights could move in the opposite direction to growth after 1650. De Vries (2008) incorporated these arguments into his account of an 'industrious revolution' which made important assumptions regarding the amount of food available to support the work involved and suggested that heights might have declined as a result of increases in work intensity and in the incidence of child labour (see also Humphries 2010). The contrast between trends in height and GDP per head could also stem from the fact that married women and their children did not benefit from the wage growth during industrialization and relied mostly on wages of men. Besides, child labour particularly in urban areas was a breeding ground for longer working hours, poorly regulated child labour and high incidence of sickness and injury that might have impacted health including growth (Humphries 2010).

Third, it has been suggested that the Little Ice Age (LIA) may have affected well-being in the seventeenth century. However, using different palaeo-climatic datasets we have not been able to find any significant relationship between climatic conditions during the LIA and stature.[12] Brooke (2014, p. 459) argues that "if the cold summers and winters of the second stage of the Little Ice Age shaped a wider 'seventeenth-century crisis' across much of the Old World, England escaped the worst of its material effects". In a similar vein, Kelly and Ó Gráda (2014, p. 319) argue that "the economic consequences of any such LIA for English agriculture … were modest at most" and Roberts and Cox (2003, p. 228) observe that "generally, while climate and food shortages caused deaths up to the mid-fourteenth century, there[after] historical sources suggest that mortality peaks seemed to related to epidemics rather than famines". Kelly and Ó Gráda (2014) have also argued that the LIA is a statistical consequence of the Slutsky Effect, a statistical artefact through manipulating the climatic data (which have a constant mean and variance) using moving averages in order to smooth the climatic volatility; see White (2014) for an opposing view.

Fourth, the decline in heights after 1650 could be associated with increasing social and economic inequality. Boix (2015) claims that during this period height differences across classes in Europe increased dramatically due to more unequal societies. Lindert and Williamson (1982) found that the Gini coefficient in England and Wales was about 0.47 and that the top 10% of the population owned more than 40% of the income share. Associated with the number of working days, when Fogel (1994) calculated the calorie consumption by percentile in England in 1790 he found that the top percentile consumed 4,329 kcal per day, twice the median intake and three times the consumption of the lowest percentile.

The development of heights between 1750 and 1850 in England has been probably the most widely debated topic in anthropometric history.[13] Floud et al. (1990) argue that there was a slow and irregular improvement in the average height of successive cohorts of British males born between the 1740s and 1840s, while Komlos and Küchenhoff (2012), Cinnirella (2008), and Meredith and Oxley (2014) argue that stature declined between the 1740s and 1850s. Many of these studies are based on measurements of the

[12] We explored different datasets available at the National Centers for Environmental Information's website: http://www.ncdc.noaa.gov/data-access/paleoclimatology-data/datasets/climate-reconstruction.

[13] See the debates between Floud and his colleges and Komlos published in the *Economic History Review* in 1993.

heights of military recruits, and the differences in trends are associated with the fact that different studies use data from different branches of the army (for a review see Harris et al. 2015 and Harris 2016). Our data provide some evidence of heights declining by 1.0-1.5 cm between the cohorts born around 1730 and 1830, very similar to the trend and level shown by Meredith and Oxley (2014) but clearly lower than the decline in stature of up to five inches (12.7 cm) suggested by Komlos and Küchenhoff (2012). Indeed, regardless the differences in levels and rates of growth, our height data are consistent with the calculations of calorie availability from Allen (2005), Muldrew (2011), Broadberry et al. (2015) and Meredith and Oxley (2014) to an extent, which all show a decline in the number of calories per head.[14] Yet, Floud et al.'s estimates B, despite showing a slight decline from 2,615 to 2,595 between 1750 and 1800 show little change throughout the period: from 1800 and 1850 calorie availability increased from 2,595 to 2,667 (Floud et al. 2015, p. 160; Harris 2016). We should add a caveat here, though, in that between 1700 and 1850 an increasing proportion of our data comes from London.[15] The disease environment in eighteenth-century London was extremely harsh, as increasing economic integration and the expansion of the urban network both reduced local subsistence crises and drove a progressive endemicisation of many infectious diseases (McNeill 1998).

8. Health, height and history

Finally, we place our results within the context of other health and economic variables that are available at the European level. We compare our results with the data from Steckel (2010), who created European health indices to summarise community health by converting skeletal data into specific rates of morbidity, following the frequency and severity of lesions in the skeletal remains as well as an index of degenerative joint diseases to measure physical activity and work load. Since this index is weighted by a range of indicators, not just stature, it should provide a better account of wellbeing across the last 2000 years in Europe. Additionally, while it is particularly difficult to reconstruct stature as the femur or tibia needs to be well preserved, information on skeletal lesions of infectious origin is more readily available, allowing one to build a reliable index of periostitis and infection. Similarly, the wear and tear on the joints of

[14] In the comparison we use estimates B (corrected) from Floud et al. (2011). For the details see Harris et al. (2015).

[15] Its social composition may also have been changing so that it was increasingly drawn from the lower social and economic groups represented in St Bride's Lower Churchyard, Farringdon, rather than the higher status groups buried in Chelsea Old Church. DeWitte et al. (2015) show that the age distribution of the deaths from St Bride's Lower Churchyard was different from that of graveyards in higher status areas of London, although the difference is almost entirely accounted for by the proportions of infant and child deaths.

the skeleton are “also frequently observed in archaeological skeletal remains” (Steckel 2010, p. 7). Although Steckel’s sample is widely distributed across Europe with the exception of the south-central Mediterranean counties (e.g., France, Italy and Spain are absent), from a total of 80 cemeteries only 9 came from England (Steckel 2010, Figure 2).

Figure 5 compares our estimated heights for England during the last 2000 years with three of these indices. The extent to which the series move together over time is significant. After the Romans left Britain all the evidence points to a decline in health in Europe that only ceased around the 900s. Yet, while it seems that the health index improved in the 900s, the rate of infectious diseases did not lessen until the 900s and this may explain why heights in England did not start to improve until the turn of the millennium. The extent to which all the health indicators deteriorated during the thirteenth and early fourteenth centuries and recovered after the Black Death is also significant.

[Take in Figure 5]

The main period of divergence between the trend in height revealed by the English skeletal remains and the health index series derived from European archaeological evidence by Steckel and his colleagues is between the late fifteenth century and 1700. The initial divergence is most obviously with the index of infection, but is observed with all indices. The main hypothesis provided by Steckel (2004; 2010) behind the worsening health since the fifteenth century in Europe is the spell of cold of the LIA. However, as already seen, new evidence suggests that the impact of the LIA in England was, at most, modest. Still, if Steckel is right and the impact of the LIA was greater in continental Europe than in England, it has the potential to explain the divergence in health. Another possible explanation, although hotly debated, is provided by Allen (2014), who argues that the industrial revolution was the result of Britain’s high wage economy in the seventeenth century (in this period the assumption of 250 days of work per year, although not ideal, does make more sense); for a critique of Allen’s high wage economy see Humphries (2013). Allen (2014) compared an index of real wages since the Middle Ages for different European countries, and not only showed that wages in England were substantially higher than in any other European country but that the divergence in wages between Britain and the rest of Europe started around the sixteenth century. He also compared the height of Europeans in the pre-industrial world and showed that the British (at 169-172 cm) were the tallest European men in the last quarter of the eighteenth century, arguing that “it is … quite plausible that real wages as low as those of continental laborers would imply a lifetime of nutritional deprivation and, therefore, stunted growth” (Allen 2001, p. 431).

8. Conclusions

This article explores the development of health in England across the last two millennia. Using individual data from skeletal remains found in different archaeological excavations we reconstructed stature taking advantage of the high correlation between the length of the femur and stature. While data on skeletal remains allow us to look in a holistic way at well-being, and at periods for which data on other indicators are absent, using skeletal data is fraught with difficulty, and our results should be considered only after recognising this. For instance, we do not directly observe the stature of these individuals, but rather take advantage of the high correlation between stature and the length of the femur. We cannot control for the age at which mature height was reached, but rather adopt the classification made by archaeologists that the age group 18-49 years represents adults who had achieved their mature heights. Beyond gathering information about the place individuals were buried, we do not know in any detail whose bones we are looking at or the exact period in which they lived.

Despite these important caveats, we believe that our results shed new light on the development of health in England over the very long run. Heights increased during the Roman period and then steadily fell during the 'Dark Ages' in the early medieval period. At the turn of the millennium, heights grew rapidly, but after 1200 they started to decline with the deteriorating agricultural productivity. Heights reached a minimum among those born during the decade of the Great Famine, but then recovered and rose throughout most of the fourteenth century. For more than 200 years after 1400 they remained constant, but began to fall from the cohorts born in the early seventeenth century. This trajectory is not captured by other height series at the European level.

Since the nineteenth century, average heights for males in England have increased substantially (Floud et al. 1990; Hatton 2014). By 1900 they reached 172 cm and then carried on increasing to 175 cm in 1950 and 177 cm in 1970, being among the tallest of any population worldwide. However, taking a long perspective of time, our data show that average heights in England in parts of the medieval era, and between 1400 and 1700 were similar to those of the twentieth century. Indeed, it could be argued that the period that is in need of most explanation is that of low heights between 1650 and 1850. The apparent increase in heights after 1850 merely brought average heights back to their medieval levels by the early twentieth century. If mean heights are a good measure of general well-being, then progress into previously uncharted territory did not begin until less than 100 years ago.

References

Allen, R. C. (2005). English and Welsh Agriculture, 1300-1850: Outputs, Inputs and Income. Retrieved from (https://pdfs.semanticscholar.org/9519/5a45a9819eb9590ecf81f47ee77adbf182f3.pdf).

Allen, R. C. (2001). The Great Divergence in European Wages and Prices from the Middle Ages to the First World War. *Explorations in Economic History*, 38(4), 411-47.

Allen, R. C. (2014). The High Wage Economy and the Industrial Revolution: A Restatement. *Economic History Review*, 68(1), 1-22.

Bass, W. M. (2005 [1971]). *Human Osteology: A Laboratory and Field Manual* Missouri Archaeological Society Special Publications Num. 2.

Bekar, C. T., & Reed, C. (2009). Risk, Asset markets and Inequality: Evidence from Medieval England. *University of Oxford Discussion Paper in Economic and Social History*, 79.

Blanchard, I. (1978). Labour Productivity and Work Psychology in the English MiningIndustry, 1400-1600. *The Economic History Review*, 31(1), 1-24.

Boix, C. (2015). *Political Order and Inequality: Their Foundations and their Consequences for Human Welfare*. Cambridge University Press.

Bonsall, L. (2013). *Variations in the Health Status of Urban Populations in Roman Britain: A comparison of Skeletal samples from Major and Minor towns*. Unpublished PhD thesis, University of Edinburgh.

Bowman, J. (1994). Water is Best: Would Pindar still think so?. In B. Cartledge (Ed.), *Health and the Environment: the Linacre Lectures 1992-1923*. Oxford University Press., pp. 85-125.

Brickely, M., Miles, A., and Stainer, H. (1999). *The Cross Bones Burial Ground, Redcross Way, Southwark, London: Archaeological Excavations (1991-1998) for the London Underground limited Jubilee Line extension Project*. London, Museum of London Archaeological Services.

Broadberry, S., Campbell, B., Klein, A., Overton, M. & van Leeuwen, B. (2015). *British Economic Growth, 1270-1870.* Cambridge University Press.

Brooke, J. L. (2014). *Climate Change and the Course of Global History.* Cambridge University Press.

Camenisch, C., Keller, K. M., Salvisberg, M., Amann, B., Bauch, M., Blumer, S., Brázdil, R., Brönnimann, S., Büntgen, U., Campbell, B. M. S., Fernández-Donado, L., Fleitmann, D., Glaser, R., González-Rouco, F., Grosjean, M., Hoffmann, R. C., Huhtamaa, H., Joos, F., Kiss, A., Kotyza, O., Lehner, F., Luterbacher, J., Maughan, N., Neukom, R., Novy, T., Pribyl, K., Raible, C. C., Riemann, D., Schuh, M., Slavin, P., Werner, J. P., and Wetter, O. (2016). The 1430s: A Cold Period of Extraordinary internal Climate variability during the early Spörer Minimum with social and economic impacts in North-Western and Central Europe. *Climate of the Past*, 12, 2,107-26.

Cameron, M. L. (1993). *Anglo-Saxon Medicine*. Cambridge University Press.

Cinnirella, F. (2008). Optimists or Pessimists? A Reconsideration of Nutritional Status in Britain, 1740-1865. *European Review of Economic History*, 12(3), 325-54.

Clark, G. (2005). The Condition of the Working Class in England, 1209-2004. *Journal of Political Economy*, 113(1), pp. 307-340.

Clark, G. (2007). The Long March of History: Farm Wages, Population, and Economic Growth, England 1209-1869. *Economic History Review*, 60(1), 97-135.

Clark, G. (2018). Growth or Stagnation? Farming in England, 1200-1800. *Economic History*

Review. Retrieved from http://onlinelibrary.wiley.com/doi/10.1111/ehr.12528/pdf

Coale, A. J., Demeny, P., & Vaughan, B. (1983). *Regional Model Life tables and Stable Populations*. Academic Press Inc., 2nd edition.

de Beer, H. (2004). Observations on the History of Dutch Physical Stature from the late-Middle Ages to the Present. *Economics and Human Biology* 2(1), 45-55.

de Vries, J. (2008). *The Industrious Revolution: Consumer Behavior and the Household Economy, 1650 to the present*. Cambridge University Press.

DeWitte, S. N. (2014). Mortality risk and survival in the aftermath of the medieval Black Death. *PLOS One*, 9(5), 1-8.

DeWitte, S. N., Hugher-Morey, G., Bekvalac, J. & Karsten, J. (2015). Wealth, Health and Frailty in Industrial-era London. *Annals of Human Biology*, 43(3), 241-254

Feinstein, C. H. (1998). Pessimism Perpetuated: Real Wages and the Standard of Living in Britain during and after the Industrial Revolution. *The Journal of Economic History*, 58(3), 625-658.

Floud, R., Fogel, R. W., Harris, B. & Hong, S. C. (2011). *The Changing Body: Health, Nutrition, and Human Development in the Western World since 1700*. Cambridge University Press.

Floud, R., Wachter, K. W. & Gregory, A. (1990). *Height, Health and History: Nutritional Status in the United Kingdom, 1750-1980*. Cambridge University Press.

Fogel, R. W. (1994). Economic Growth, Population Theory, and Physiology: The Bearing of Long-term processes on the making of Economic Policy. *American Economic Review*, 84(3), 369-395.

Galofré-Vilà, G. (2017). Growth and Maturity: A Quantitative Systematic Review and Network Analysis in Anthropometric History. *Economics and Human Biology*. Retrieved from https://doi.org/10.1016/j.ehb.2017.12.003.

Hammond, P. W. (1993). *Food and Feast in Medieval England*. Alan Sutton Publishing.

Harding, V. (1993). Burial of the Plague Dead in early Modern London. In Champion, J. A. I. (Ed.,) *Epidemic Disease in London*. Centre for Metropolitan History, pp. 53-64.

Harris, B. (2016). Food Supply, Health and Economic Development in England and Wales duirng the Eighteenth and Nineteenth centuries. *Scientia Danica, Series H, Humanistica*, 4(7), 141-154.

Harris, B., Floud, R. & Hong, S. C. (2015). How many Calories? Food availability in England and Wales in the 18th and 19th centuries. *Research in Economic History*, 31, 111-191.

Hatton, T. J., (2014). How have Europeans Grown so Tall?. *Oxford Economic Papers*, 66(2), 349-372.

Hinde, A. (2003). *England's Population: A history since the Domesday Survey*. Bloomsbury Academic.

Howe, M. G. (1997). *People, Environment, Disease and Death: Medical geography of Britain throughout the Ages*. University of Wales Press.

Humphries, J. (2010). *Childhood and Child Labour in the British Industrial Revolution*. Cambridge University Press.

Humphries, J. (2013). The Lure of Aggregates and the Pitfalls of the Patriarchal Perspective: A Critique of the High Wage Economy interpretation of the British Industrial Revolution. *Economic History Review*, 66(3), 693-714.

Humphries, J., & Weisdorf, J. (2016). 'Unreal Wages'? A New Empirical Foundation for the

Study of Living Standards and Economic Growht in England, 1260-1860. *University of Oxford Discussion Papers in Economic and Social History*, 147.

Kelly, M. and Ó Gráda, C. (2014). The Waning of the Little Ice Age: Climate Change in Early Modern Europe. *Journal of Interdisciplinary History*, 44(2), 301-325.

Kershaw, I. (1973). The Great Famine and Agrarian Crisis in England 1315-1322. *Past & Present*, 59(1), 3-50.

Koepke, N. (2016). The Biological Standard of Living in Europe from the Late Iron Age to the Little Ice Age. In Komlos, J. & Kelly, I. (Eds.) *The Oxford Handbook of Economics and Human Biology*. Oxford University Press, 70-109.

Koepke, N. & Baten, J. (2005). The Biological Standard of Living in Europe during the Last two Millennia. *European Review of Economic History*, 9(1), 61-95.

Koepke, N. (2008). Regional Differences and Temporal Development of the Nutritional Status in Europe from 8th century BC to 18th century AD. Unpublished PhD thesis, University of Tübingen.

Komlos, J. & Küchenhoff, H. (2012). The Diminution of the Physical Stature of the English Male Population in the Eighteenth century. *Cliometrica*, 6(1), 45-62

Kunitz, S. J. (1987). Making a Long Story Short: A Note on Men's Height and Mortality in England from the First through the Nineteenth centuries. *Medical History*, 31(3), 269-280.

Lawrence, C. H. (1984). *Medieval Monasticism: Forms of Religious Life in Western Europe in the Middle Ages*. Pearson Education.

Lindert, P. H., & Williamson, J. G. (1982). Revising England's Social Tables 1688-1812. *Explorations in Economic History*, 19(4), 385-408.

Mattingly, D. (2006). *An Imperial Possession: Britain in the Roman Empire*. Penguin Publishing Group.

McGhee, R. (1981). Archaeological Evidence for Climatic Change during the Last 5000 years. In Wigley, T. M. L., Ingram, M. J. & Farmer, G. (Eds.), *Climate and History: Studies in Past Climates and their Impact on Man*. Cambridge University Press, pp. 162-179.

McNeill, W. H. (1998). *Plagues and Peoples*. Anchor Books.

Meredith, D., & Oxley, D. (2014). Food and Fodder: Feeding England, 1700-1900. *Past & Present*, 222(1), 163-214.

Molleson, T., & Cox, M. (1993). The Spitalfields Project, Vol. 2. The Anthropology: The Middling Sort. *Research Report* 86, *Council for British Archaeology*.

Muldrew, C. (2011). *Food, Energy and the Creation of Industriousness: Work and Material Culture in Agrarian England 1550-1780*. Cambridge University Press.

Pattison, J. E. (2008). Is it Necessary to Assume an Apartheid-Like Social Structure in Anglo-Saxon England?. *Proceedings of the Royal Society B*, 275(1650), 2423-2429.

Phelps Brown, E. H., & Hopkins, S. H. (1956). Seven Centuries of the Prices of Consumables, Copared with Builders' Wage-Rates. *Economica*, 23(92), 296-314.

Postan, M. M. (1975). *The Medieval Economy and Society: An Economic History of Britain in the Middle Ages*. University of California Press.

Pretty, J., (1990). Sustainable Agriculture in the Middle Ages: The English Manor. *Agricultural History Review*, 38(1), 1-19.

Razzell, P. E. & Spence, C. (2006). The Hazards of Wealth: Adult Mortality in Pre-Twentieth Century England. *Social History of Medicine*, 19(3), 381-405.

Razzell, P. E. & Spence, C. (2007). The History of Infant, Child and Adult Mortality in London, 1550-1850. *London Journal*, 32(3), 271-292.

Roberts, C. (2009). Health and Welfare in Medieval England: The Human Skeletal Remains Contextualised. In Gilchrist, R. & Reynolds, A. (Eds.), *Reflections: 50 Years of Medieval Archaeology 1957-2007*. Society for Medieval Archaeology Monographs, 30, 307-325.

Roberts, C. A., & Cox, M. (2003). *Health and Disease in Britain: From Prehistory to the Present Day*. Sutton Publisher.

Rodwell, W., Atkins, C., Badham, S. & Waldron, T. (2007). *St Peter's, Barton-upon-Humber, Lincolnshire: A Parish Church and its Community*. Oxbow Books.

Schweich, M., (2005). Diachronic Effects of Bio-cultural Factors on Stature and Body proportions in British Archaeological Populations. Unpublished PhD thesis, University of Bradford.

Slack, P. (1990). *The English Poor Law, 1531-1782*. Cambridge University Press.

Slavin, P. (2014). Market Failure during the Great Famine in England and Wales (1315-1317). *Past & Present*, 222(1), 9-49.

Smith, R. M. (2002). Plagues and Peoples: The Long Demographic Cycle 1250-1670. In Slack P. and Ward, R. (Eds.), *The Peopling of Britain: The Shaping of a Human Landscape*. Oxford University Press., pp. 177-209.

Steckel, R. H. (2004). New Light on the 'Dark Ages: The Remarkably Tall Stature of Northern European men during the Medieval era. *Social Science History*, 28(2), 211-29.

Steckel, R. H. (2010). The Little Ice Age and Health: Europe from the Early Middle Ages to the Nineteenth century. Retrieved from http://www.econ.ucla.edu/workshops/papers/History/Steckel.pdf

Steckel, R. H. (2013). Biological Measures of Economic History. *Annual Review of Economics*, 5, 401-423.

Steckel, R. H., & Rose, J. C. (2002). *The Backbone of History: Health and Nutrition in the Western Hemisphere*. Cambridge University Press.

Steckel, R. H., Sciulli, P. W., & Rose, J. C. (2002). A Health Index from Skeletal Remains. In Steckel, R. H., & Rose, J. C. (Eds.), *The Backbone of History: Health and Nutrition in the Western Hemisphere*. Cambridge University Press, pp. 61-93.

Tanner, J. M. (1962). *Growth at Adolescence: With a General Consideration of the Effects of Hereditary and Environmental factors upon Growth and Maturation from Birth to Maturity*. Blackwell Scientific Publication.

Trotter, M., & Gleser, G. C. (1952). Estimation of Stature from Long Bones of American Whites and Negroes. *American Journal of Physical Anthropology*, 10(4), 463-514.

Trotter, M., & Gleser, G. C. (1958). A Re-Evaluation of Estimation of Stature based on Measurements of Stature taken during Life and of Long bones after Death. *American Journal of Physical Anthropology*, 16(1), 79-123.

Voth, H.-J. (2000). *Time and Work in England 1750-1830*. Oxford University Press.

Waldron, T. (2007). *St. Peter's Barton-Upon-Humber, Lincolnshire: A Parish Church and its Community*. Oxbow Books.

White, S. (2014). The Real Little Ice Age. *Journal of Interdisciplinary History*, 44(3), 327-352.

Wrigley, E. A., & Schofield, R. S. (1989). *The Population History of England, 1541-1871: A Reconstruction*. Cambridge University Press.

Table 1. Details of skeletal remains data

Cemetery's location	Period	Sources	Original sample	Gender		Age (for males)		Right femur
				Male	Other	Adults	Other	
Ancaster, Lincolnshire	Roman	Bonsall (2013)	271	105	166	75	30	54
Baldock, Hertfordshire	Roman	Schweich (2005)	68	34	34	34	n/a	29
Chelsea Old Church, London	Post-Medieval	Museum of London	198	78	120	78	n/a	37
East Smithfield Black Death, London	Medieval	Museum of London	636	189	447	189	n/a	61
Eccles, Kent	Medieval	Schweich (2005)	65	37	28	37	n/a	28
Farringdon: St. Bride's lower churchyard, London	Post-Medieval	Museum of London	551	200	351	200	n/a	76
Fishergate, York	Medieval	Schweich (2005)	224	170	54	142	28	119
Langthorne, Essex	Medieval	Schweich (2005)	158	149	9	149	n/a	123
Merton Priory, London	Medieval	Museum of London	676	392	284	392	n/a	39
Raunds, Northamptonshire	Medieval	Schweich (2005)	101	55	46	55	n/a	43
St. Martin's Church, Birmingham	Post-Medieval	Schweich (2005)	137	79	58	78	1	69
St. Mary Graces, London	Medieval	Museum of London	309	100	209	100	n/a	26
St. Peter's Church, Barton-upon-Humber, Lincolnshire	Med./Post-Medieval	Rodwell et al. (2007)	613	164	449	125	39	77
St. Saviour, Bermondsey Abbey, London	Medieval	Museum of London	199	145	54	145	n/a	52
St. Thomas Hospital	Med./Post-Medieval	Museum of London	193	58	135	58	n/a	14
Towton, North Yorkshire	Medieval	Schweich (2005)	37	37	n/a	36	1	31
Winchester, Hampshire	Roman	Bonsall (2013)	310	225	85	177	48	43
Total			4,746	2,217	2,529	2,070	147	921

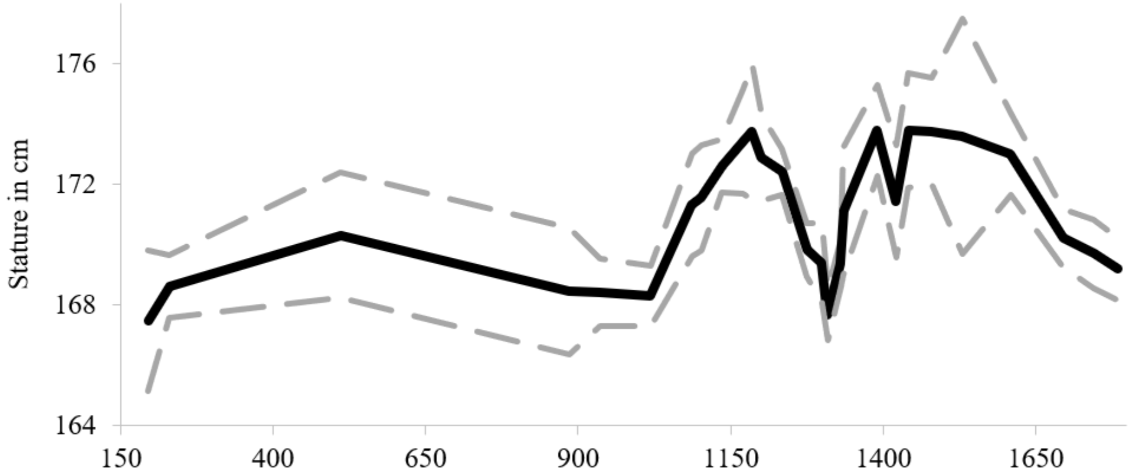
Note*:* In the column 'period', 'other' include female, children and unsexed and the column 'male', 'other' includes old, young and uncertain individuals. More disaggregated figures are available under request. Only male data were used for St. Peter's Church.

Table 2. Estimated mean heights by period

Start year	End year	Mid-point	Average year of birth	Estimated sample size	Estimated mean height	Estimated standard error
200	270	235	195	14.3	167.50	1.26
270	410	340	300	82.7	168.55	0.60
500	600	550	510	28.0	170.32	1.22
900	950	925	885	21.5	168.48	1.21
950	1000	975	935	69.5	168.42	0.58
1001	1116	1059	1019	119.0	168.30	0.51
1117	1135	1126	1086	13.2	168.95	1.21
1135	1150	1143	1103	16.4	170.10	1.16
1150	1200	1175	1135	33.0	172.64	0.82
1200	1220	1210	1170	13.3	172.64	1.29
1220	1230	1225	1185	6.9	172.78	1.80
1230	1250	1240	1200	42.2	172.88	0.72
1250	1299	1275	1235	120.2	172.67	0.43
1300	1330	1315	1275	104.8	169.60	0.50
1330	1348	1339	1299	56.8	169.42	0.68
1348	1350	1349	1309	195.3	167.70	0.43
1350	1390	1370	1330	148.8	169.39	0.40
1390	1400	1395	1355	16.4	171.12	1.11
1400	1461	1431	1391	34.6	174.29	0.84
1461	1462	1462	1422	36.6	171.44	0.95
1462	1500	1481	1441	21.6	174.29	1.06
1500	1538	1519	1479	25.4	174.19	0.98
1538	1600	1569	1529	4.1	173.59	2.46
1600	1699	1650	1610	64.5	172.98	0.72
1700	1770	1735	1695	119.0	170.43	0.51
1770	1800	1785	1745	92.8	169.79	0.60
1800	1849	1825	1785	113.3	169.27	0.55

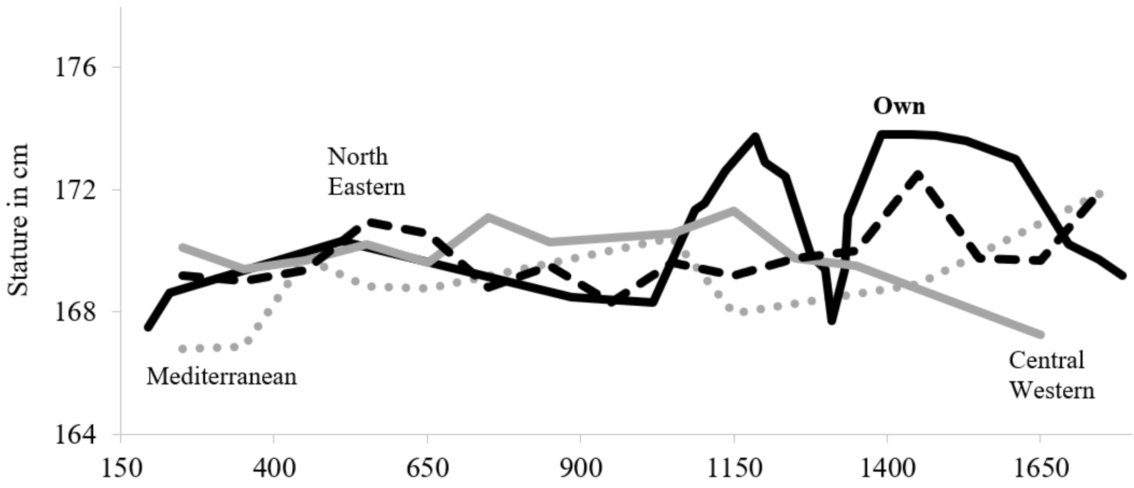
Note: The average year of birth is obtained by subtracting 40 years from the mid-point of each period. The estimation of the sample size for each period uses the numbers given in the right-hand column of Table 1 and assumes that deaths are distributed uniformly across the periods covered by each data set as listed in Appendix Table A1. The estimation of the mean height for each period uses a weighted average of the means of the heights contributing to the data for that period. Standard errors have been calculated using variances estimated for each period by taking a weighted average of the variances of the heights in the samples contributing to that period. ***Sources:*** Table 1 and Appendix Table A1.

Figure 1. Stature in England across the last 2000 years



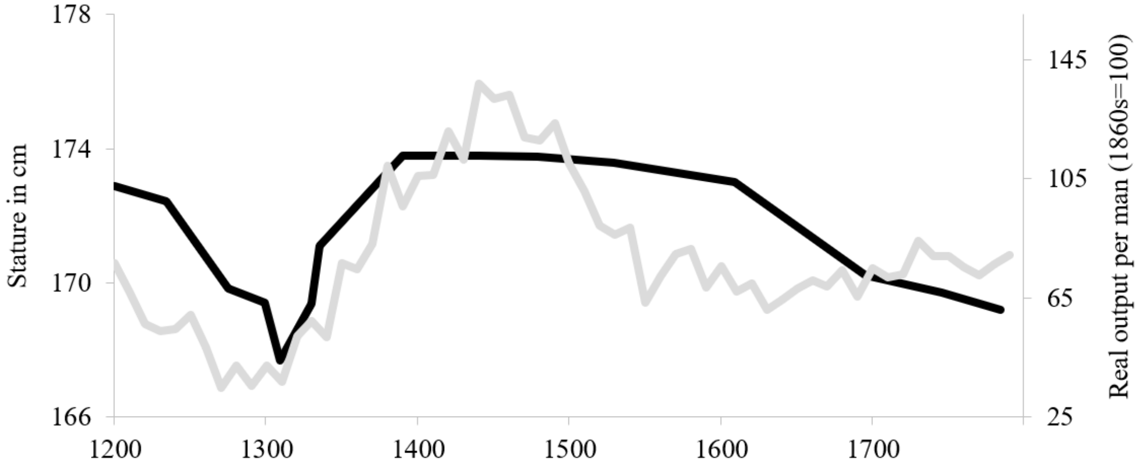
Note: When constructing this graph, heights have been plotted against the estimated years of birth shown in Table 2. Grey dotted lines denote estimated 95% confidence intervals. ***Source:*** Table 2.

Figure 2. Stature in England and Europe



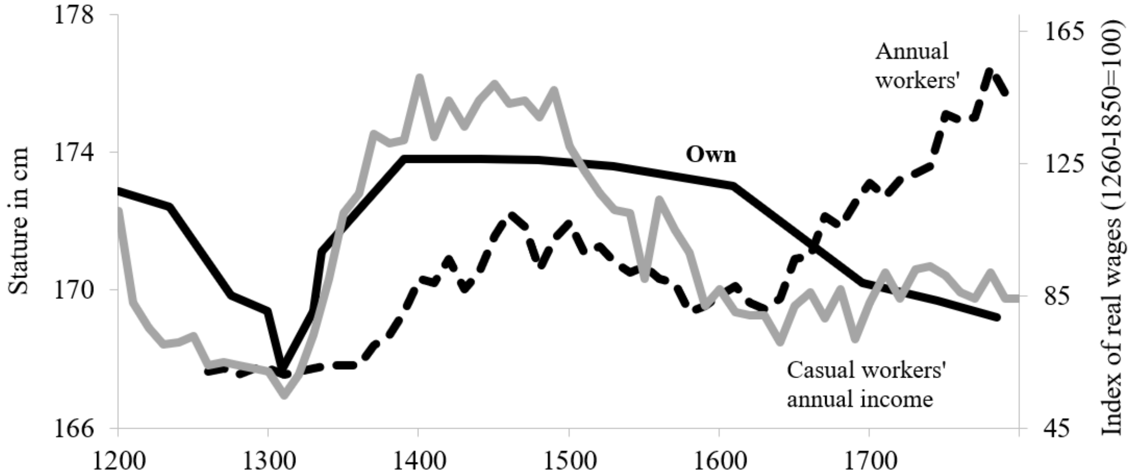
Notes: When constructing this graph, heights have been plotted against the estimated years of birth shown in Table 2 (omitting the data point based largely on skeletons from the Towton battlefield). We centred Koepke's century data at the middle of the century so that, for instance, data for the fourth century is centred at 350 AD. ***Sources:*** For height data (Own) see Table 2 and for the stature in Central Western Europe, North Eastern Europe and Mediterranean Europe see Koepke (2016, p. 83).

Figure 3. Output in English agriculture and stature



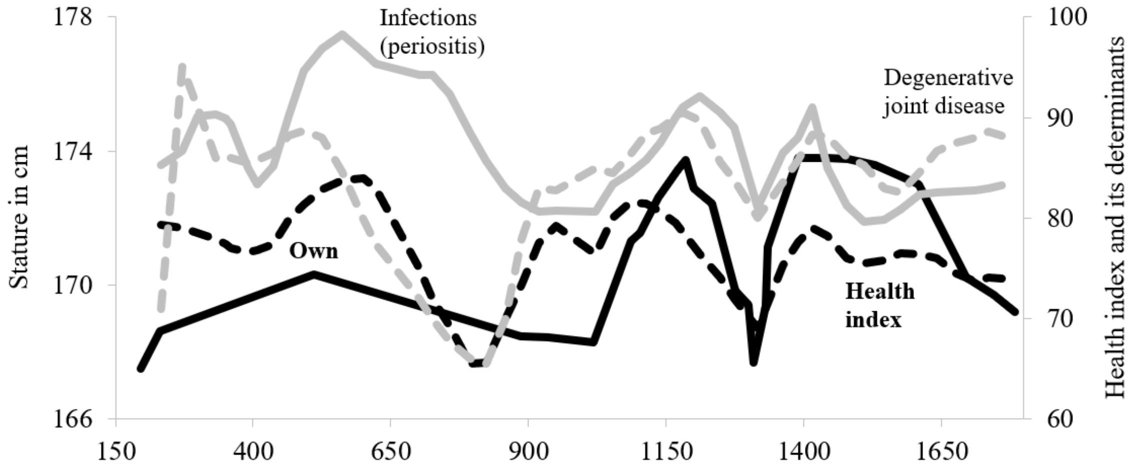
Notes: When constructing this graph, heights have been plotted against the estimated years of birth shown in Table 2. We omit from this figure the anomalous stature point based mainly on the skeletons from the Towton battlefield. The grey line shows real output per man (1860s=100) ***Sources****:* Height data (black line) from Table 2; for real output per man (grey line) see Clark (2018).

Figure 4. Stature and indices of real wages, 1260-1850



Note: For the real wages data we replicated Figure 4 (p. 16) from Humphries and Weisdorf (2016). ***Sources:*** Height data (Own) from Table 2 plotted against estimated years of birth (omitting the data based largely on the skeletons from the Towton battlefield); for real wages based on annual workers' income, see Humphries and Weisdorf (2016); and for real wages based on the annual income of casual workers, see Clark (2007).

Figure 5. Stature in England and health in Europe



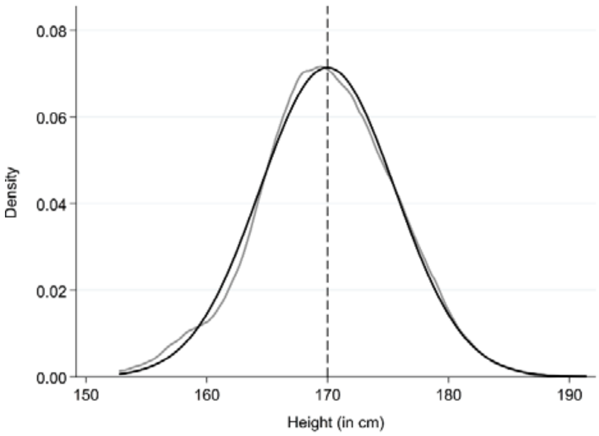
Notes: When constructing this graph, heights have been plotted against the estimated years of birth shown in Table 2. We also adjusted the health index data for the year of birth. We omit from this figure the anomalous stature point based mainly on the skeletons from the Towton battlefield. ***Sources:*** For height data (Own) see Table 2; for the health indices see Steckel (2010).

Appendix

Table A1. Details of skeletal remains data by source and time period

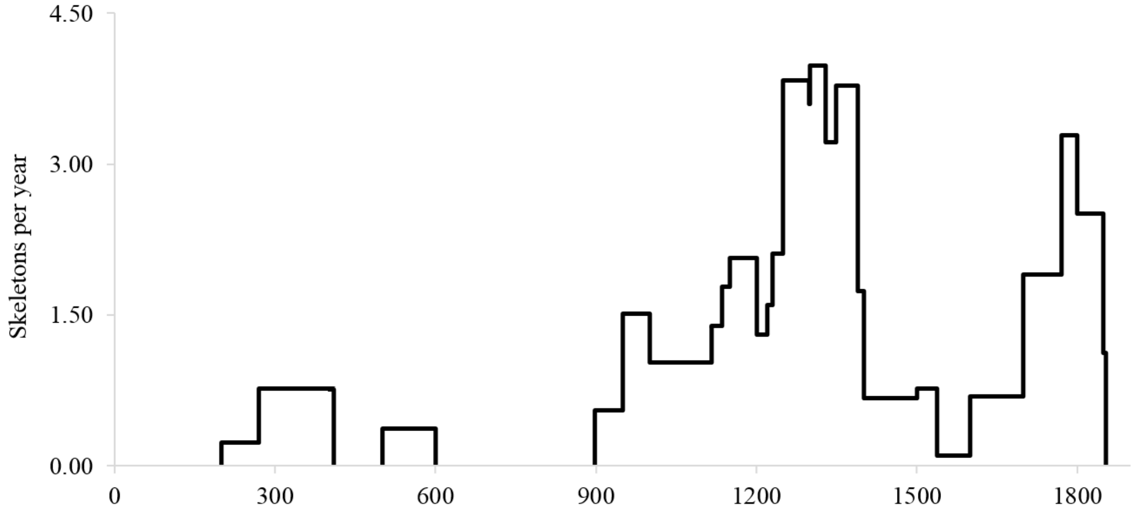
Cemetery's Location	Mean height	Estimated height other authors	Centre period	Start of period	End of period	Remarks on social and economic position
Ancaster, Lincolnshire	169.10	169.0	340	270	410	Working class population including craftsmen, traders and farmers.
Baldock, Herfordshire	168.59	167.7	1345	1300	1390	Settlement cemetery of traders and small peasant farmers.
Chelsea Old Church, London	168.42	168.4	1775	1700	1850	High status individuals living in the outskirts and rural areas of London.
East Smithfield Black Death	167.64	167.6	1349	1348	1350	People that died during the Black Death.
Eccles, Kent	170.32	172.3	550	500	600	Settlement cemetery from a homogenous population.
Farringdon: St. Brides Lower Churchyard	169.00	169.0	1809	1770	1849	People who lived in the Parish of St Bride's. Low socioeconomic status.
Farringdon: St. Brides Lower Churchyard	170.34	n/a	1775	1700	1850	People who lived in the Parish of St Bride's. Low socioeconomic status.
Fishergate, York	168.30	168.8	1058	1001	1116	Mostly lay population but also high-status members of the society.
Langthorne, Essex	171.12	171.1	1290	1230	1350	High-status monastic site.
Merton Priory, London	174.32		1168	1117	1220	Monastic and lay individuals with evidence for an integrated community.
Merton Priory, London	174.50		1260	1220	1300	Monastic and lay individuals with evidence for an integrated community.
Merton Priory, London	168.80	171.3	1345	1300	1390	Monastic and lay individuals with evidence for an integrated community.
Merton Priory, London	171.01		1444	1350	1538	Monastic and lay individuals with evidence for an integrated community.
Merton Priory, London	174.46		1464	1390	1538	Monastic and lay individuals with evidence for an integrated community.
Raunds, Northamptonshire	168.48	170.6	950	900	1000	Community cemetery.
St. Martin's Church, Birmingham	171.32	171.0	1750	1700	1800	Urban parish cemetery mostly from low and middling backgrounds.
St. Mary Graces, London	174.22	n/a	1469	1400	1538	Monks and important lay people but also middle and lower classes.
St. Mary Graces, London	170.34	170.1	1375	1350	1400	Monks and important lay people but also middle and lower classes.
St. Peter's Church, Barton-upon-Humber, Lincolnshire	173.59		1599	1500	1699	Working class of traders and small peasant farmers.
St. Peter's Church, Barton-upon-Humber, Lincolnshire	172.42	~172	1224	1150	1299	Working class of traders and small peasant farmers.
St. Peter's Church, Barton-upon-Humber, Lincolnshire	168.40		975	950	1000	Working class of traders and small peasant farmers.
St. Peter's Church, Barton-upon-Humber, Lincolnshire	168.40		1133	1117	1150	Working class of traders and small peasant farmers.
St. Saviour, Bermondsey Abbey, London	171.28		1175	1150	1200	Monks' cemetery.
St. Saviour, Bermondsey Abbey, London	171.37	171.59	1290	1250	1330	Monks' cemetery.
St. Saviour, Bermondsey Abbey, London	172.46		1182	1135	1230	Monks' cemetery.
St. Thomas Hospital	172.91	172.9	1649	1600	1699	Low status sick people who needed a refuge or medical attention.
Towton, North Yorkshire	171.40	172.7	1461	1461	1461	Battlefield victims in a mass grave from a heterogeneous sample.
Winchester, Hampshire	167.50	167.6	305	200	410	Working class population including craftsmen, traders and farmers.

Figure A1. Mature male height distribution reconstructed from the right femur



Note: The black line represents the normal-density distribution and the grey line the kernel-density distribution for male mature heights. The distribution has a mean of 169.72 cm (showed by the dashed vertical line) with an associated standard deviation of 5.59 cm and minimum and maximum heights of 152.80 and 191.36 cm respectively.
Sources: See Table 1 and Appendix Table A1.

Figure A2. Amount of data contributing to estimates in each interval



Note: Skeletons from plague cemeteries in London in 1348-1350 and from the Battle of Towton in 1461 have been excluded when preparing this figure. ***Sources:*** See Table 1 and Appendix Table A1.