Optimists and Pessimists: a Revision of the Nutritional Status in Britain, 18th and 19th Century

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This version: March 2007

Keywords: height, nutritional status, biological standard of living, living standards, industrial revolution, England

JEL classification: N33, N43, N54

Introduction

It is impossible to quantify the amount of ink spent on the British industrial revolution and on the effects that it had on the population standard of living. The period under consideration and controversy is around the century between 1750 and 1850. Prominent scholarly research has been conducted in order to shed more light on the conditions of the working class during the different phases of the industrial revolution. As correctly predicted by O'Brien and Engerman in 1981 and recalled more recently by Voth, much of the scholarly research has been devoted to improve real wage series, measuring inequality, and to investigate alternative welfare indicators.[1] Important studies about the reconstruction of food-price series, consumption and on intra-household allocation have the merit of having enriched our knowledge about the living conditions of the British working class. Even though the most recent contributions to the literature are more of support to the pessimistic view, there is not a broad consensus on the issue.[2] Optimists who claim the benevolence of the industrial revolution bring as evidence the increase in real wages, especially for the period 1820-1850. The initial estimates of Lindert and Williamson, which implied an increase in real wages by over 80 percent, provided a strong support to the optimists' view.[3] Successive revisions of the wage series reduced the extent of the increase. The most conservative estimates imply a rise from 1778/82 to 1853/57 by less than 30 percent, allowing for unemployment and short-time working.[4] Indeed, what characterizes the debate about the trend in real wages is the estimation of the living costs, whereas there is a widespread agreement about the trend in nominal wages. Therefore the efforts are directed to the creation of more reliable estimates of prices of food items, housing and clothing costs. A recent work of Clark goes in this direction showing new estimates of the cost of living for farm workers and a new series of farm labour real wages. According to Clark, Feinstein's pessimism "is probably too great".[5] In any event, added to the evidence that real wages declined between the 1760s and 1780s,[6] the long-term trend in real wages during the industrial revolution shows, if anything, only a limited increase in purchasing power.

Numerous scholars have contributed to the debate on the standard of living using other welfare indicators. The study of physical stature as a complementary indicator of welfare originated at the beginning of the 1980s.[7] Since then, numerous works focused on the stature of children and adults in order to assess the welfare of populations from a perspective different from the classic economic indicators. The lack of data about income or the unreliability of such information for several historical contexts made the anthropometric approach even more valuable.

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[1] Voth, H.J., "Living standards and the urban environment". In Floud and Johnson (ed.) *The Cambridge Economic History of Britain*.
[2] See Mokyr, "Is there still life in the pessimist case?" and Feinstein, "Pessimism perpetuated".
[3] Lindert and Williamson, "English workers' living standards"
[4] Feinstein, "Pessimism perpetuated". See also Crafts, "English workers' real wages" for a correction of the estimates of Lindert and Williamson.
[5] Clark, "English farm wages", p.498. See also Clark, "The long march of history".
[6] Boyer, *An economic history of the English Poor Law*; Clark, "English farm wages".
[7] We believe that physical stature is a complementary rather than an alternative indicator of welfare.

Height is a measure of the individual's nutritional intake net of claims from the basal metabolism, epidemiological stress, and workload. In particular, height is a measure of the cumulative net nutritional status from birth until the age at which terminal height is reached. In modern and economically developed societies terminal height is reached between the age of 18 and 20 years. In past societies, where the individuals were subjected to a greater epidemiological stress and workload, terminal height was reached at a later stage in life.[8] In this article we shall devote an entire section to this issue showing how the age at terminal height changed over time and what it implies in the debate of the standard of living in industrialising Britain. At the individual level, the relationship between height and income is non-linear. Further, the relationship between height and income seems to have changed over time. While there is a clear positive relationship between height and income in modern industrialized societies, the same does not necessarily occur in historical perspective.[9] We shall see that individuals coming from rural areas, therefore from a presumable lower income area, had a superior height with respect to people from higher income areas such as urban centres. The disease environment, the price and the quality of food items played a more important role for past societies than for modern ones, invalidating then the relationship between height and income. In many studies focusing on the period of the early industrial revolution, an inverse relationship between heights and income has emerged. This "puzzling" evidence has been termed as the early industrial growth puzzle.[10] Declining trends in average nutritional status in economies with rising income per-capita have been estimated for several European countries.[11]

Regarding the British industrial revolution, Roderick Floud, Kenneth Wachter and Annabel Gregory undertook the admirable and pioneering project of collecting information on 108,000 army recruits, born between 1750 and 1880.[12] The primary sources used in their study are the British Army and the Royal Marines, the Marine Society of London, and the Royal Military Academy at Sundhurst. Height distributions drawn from military sample often suffers from a truncation problem: short recruits were discarded in order to provide the army with enough skills and strengths. Therefore raw mean heights are upwardly biased.[13] The British army did not constitute an exception in this sense. After correcting for this problem, Floud and co-authors produced some results which strongly support the optimistic view about the impact of the industrial revolution on the standard of living. They suggested that the long-term trend in average nutritional status of adults was generally upward from the middle of the eighteenth century until the 1820s, thereafter decreasing to the 1860s. For the period 1760-1820, crucial to the debate

[8] See Tanner, *Fetus into man*.
[9] See Steckel, "Stature and the Standard of Living" for a comprehensive overview on the relationship between height and income.
[10] In the American economic history this is known as the antebellum puzzle. See Komlos, "Anomalies in economic history" and Komlos, "The height and weight of West Point cadets"; Komlos, "Shrinking".
[11] For France see Komlos, Hau and Bourguinat, "An anthropometric history"; for the Habsburg monarchy Komlos, *Stature and nutrition*; for Northern Italy A'Hearn, "Anthropometric evidence"; for Sweden Sandberg and Steckel, "Heights and economic history"; for Saxony Cinnirella, "On the road"; for the Netherlands Drukker and Tassenaar, "Shrinking Dutchmen"; for Belgium Alter, Neven and Oris, "Stature in transition".
[12] Floud, Wachter and Gregory, *Height, health and history*.
[13] See the section on data for more detail.

on the standard of living because of the paucity of data on real wages, their estimated trend in height has a lower peak for those born in the 1790s but thereafter it shows a strong improvement until the 1820s. Using a different statistical technique Komlos found partially opposite results: for the period 1760-1800 the average nutritional status declined, improved slightly until the 1820, and thereafter worsened again.[14] The two positions then diverged only about the last four decades of the eighteenth century. Successive estimates of alternative data sources supported the negative trend in height backing the pessimistic view about the effect of the early industrialization period on the British working class conditions.

In this article we use part of the dataset employed by Floud et al. and we re-estimate the trend in nutritional status introducing some new elements. First, in order to minimize problems of heterogeneity we restrict our focus only to recruits of the British army, neglecting the data on the Royal Marines. In this way we avoid any contamination from sources that likely drew from a different underlying population and implemented different recruitment processes. If anything, this approach will produce clearer results.[15] Second, in order to correct for the problem of truncation we consistently use the econometric approach most widely used in the anthropometric literature, namely the truncated normal maximum likelihood estimator. It will allow us to perform a multiple regression analysis. Third, we provide a further contribution to the standard of living debate analysing how the age at terminal height changed during the eighteenth and nineteenth century. Using the information on both the county of birth and that of recruitment, we are able to identify a sub-sample of urban migrants whose origin was a rural area. Comparing this group with a group of individuals who continued to reside in the same rural area, we can observe the effect of urbanisation at different stage of life. Our new estimates provide support to the pessimistic view: height trend declined substantially in the last four decades of the eighteenth century. After a slight improvement around the end of the French wars, the British average nutritional status declined from the 1820s until the 1860s. Firm evidence about the shift of the age at terminal height corroborates our pessimism. Our findings are consistent with the recent estimates of food prices for the second half of the eighteenth century and with the subsistence crisis of the last decade. We also provide an alternative explanation for the decline in the eighteenth century, namely the parliamentary enclosures of open fields and commons and the decline of the cottage industry. For farm labourers, that constitute a large share of our sample, the loss of common rights or allotments meant a significant reduction in food consumption as those lands were mainly devoted to self-sufficiency. In addition farm labourers became more exposed and sensitive to price fluctuations in an economic conjuncture of increasing food-prices.

[14] Komlos, “The secular trend”.

[15] The size of our sample is then around 45,000 observations. See section on data for details.

Data and methodology

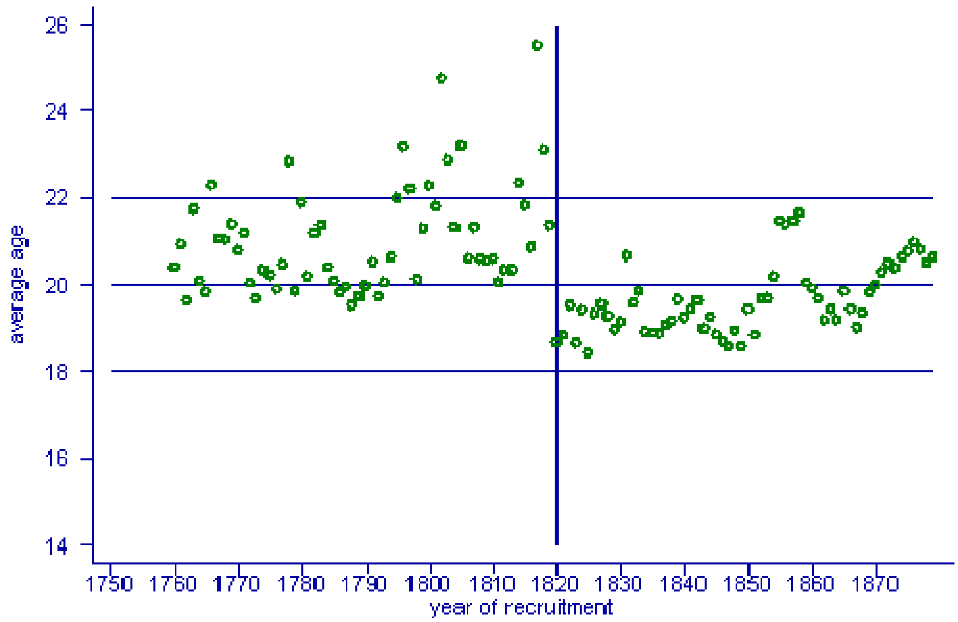
The dataset employed in this paper includes circa 45,000 soldiers born between 1740 and 1865 recruited from the British army.[16] This sample, jointly with the records of the Royal Marines and the Marine Society, has been analysed the first time by Roderick Floud, Kenneth Wachter and Annabel Gregory.[17] Their findings were successively challenged by Komlos who, applying a different statistical technique to the same sample, established different results.[18] The differences between this article and the precedent works on this dataset can be summarized in three aspects: (*i*) we focus only on the British army recruits born in England, Wales and Scotland, avoiding any contamination from other sources; we prefer not to integrate this dataset with the Royal Marines as the two sources are very heterogeneous and the Royal Marines data might suffer from a double truncation;[19] (*ii*) through the whole paper we employ the truncated maximum likelihood estimator which permits to perform a multiple regression analysis; (*iii*) we use both information on the origin and the place of recruitment in order to make some inference about urban migration and its effect on the biological standard of living.

In European military history one of the main legacies of the Napoleonic period was the universal conscription. With the notable exception of the British army, all the European states adopted and maintained during the Restoration period the universal conscription for the army. Instead, the British army decided to apply the universal conscription only at the outset of the First World War.[20] Until then, the army was manned with voluntary forces and integrated with a militia defined by ballot (henceforth Ballot Militia). The institution of the Ballot Militia goes back to 1757 when it was set in order to make up for the shortage of volunteers in the army. Able-bodied men in the range of 18-50 years were eligible for service in the militia forces. It was then a sort of forced recruitment which took place at a county level. Yet, men who were drawn to join the army were given the possibility to send a substitute. This possibility created a true market for substitutes and the fees needed to pay could be quite substantial.[21] The institution of the Ballot Militia was first suspended in 1816 and then abolished during the 1820s.[22] Only in 1852, before the Crimean War, was the Ballot Militia newly reinstituted, though it was not used extensively. Therefore, while the sample recruited until the defeat of Napoleon is made up of volunteers and a random draw from the male population, after 1820 the army sample included only young volunteers, resulting in a smaller mean and standard deviation of soldier's age. We find empirical evidence of the change in the

[16] Floud, R., Long-term Changes in Nutrition, Welfare and Productivity in Britain; Physical and Socio-economic Characteristics of Recruits to the Army and Royal Marines, 1760-1879 [computer file]. Colchester, Essex: UK Data Archive [distributor], July 1986. SN: 2131.
[17] Floud, Wachter and Gregory, *Height, health and history*.
[18] Komlos, "Secular trends". See the introduction for more details on Komlos's findings and a review of the literature.
[19] A separate article will be devoted to the analysis of the circa 20,000 soldiers born in Ireland present in the dataset.
[20] Ilari, V. (1989). Storia del servizio militare in Italia, volume 1: 1506 -1870. Centro militare di studi strategici / Rivista Militare.
[21] Floud, Wachter and Gregory, *Height, health and history*, p.34.
[22] Ilari, "Storia del servizio militare".

recruitment practices. From a graphical inspection of the height distributions, the mean and standard deviation of soldier's age, we find a sort of "structural break" which start with the recruitment year 1820 (figure 1 and 2). After that year, the mean and standard deviation of soldiers' age are systematically smaller than in the previous period. We believe that the presence of the Ballot Militia in the sample recruited before 1820, which introduced a share of random population into the army, contributes in determining larger values of the mean and standard deviation of age. Even though we are not able to identify within the first group the two types of soldiers (volunteers and militia), the difference between the two periods in the underlying population suggests that we should analyse separately pre- and post-1820-recruitment samples.[23]

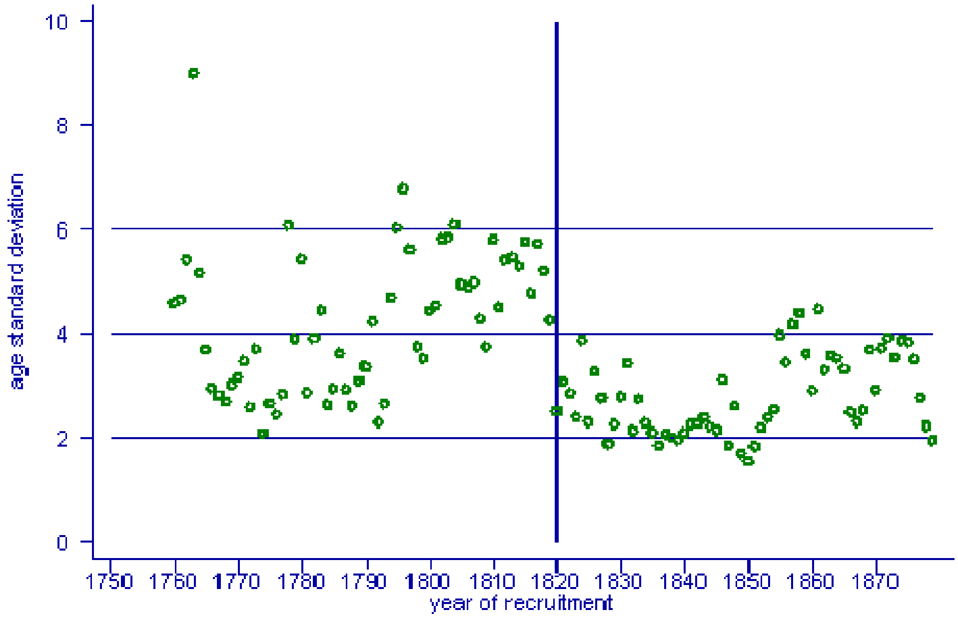
Figure 1. Mean of soldier's age by recruitment year



Source: British army.

[23] Anyway, the analysis of the two parts of the sample together does not alter qualitatively our results.

Figure 2. Soldier's age standard deviation by recruitment year



Source: British army.

The dataset contains detailed information on physical stature, age, year of birth, previous occupation, and the already mentioned place of origin and recruitment.[24] In order to check for systematic differences in the nutritional status between geographic areas, we generated 13 wage-regions following the classification of Hunt.[25] Regarding the soldiers' previous occupation, we followed the industrial classification provided by Armstrong to generate dummy variables for the occupations.[26] In addition, exploiting the information about the place of birth and that of recruitment, we shall define a soldier whose birth-county differs from the county of recruitment as an *internal migrant*. A similar identification strategy was adopted by Nicholas and Shergold for a sample of British convicts used to study inter-county labour mobility.[27] We intend to use a specific sub-sample of urban migrants coming from rural counties in order to test the detrimental effect of urbanization on average nutritional status, and in particular the effect on the determination of age at terminal height.

In table 1 we present some raw descriptive statistics for the whole sample and divided by sub-periods, with the recruitment year 1820 as the watershed.

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[24] For a more detailed and comprehensive description of the British army and whether it is representative of the British working class, you are referred to Floud, Wachter and Gregory, *Height, health and history*, chapter 2 and 3.

[25] Hunt, E. H., *Regional Wage Variation in Britain 1850-1914*. London, 1973.

[26] Armstrong, W. A., "The use of information about occupation". In E. A. Wrigley, ed., *Nineteenth-century society: Essays in the use of quantitative methods for the study of social data*. Cambridge: Cambridge University Press, 1972.

[27] Nicholas and Shergold, "Intercounty labour mobility".

Table 1. Descriptive statistics by sub-period

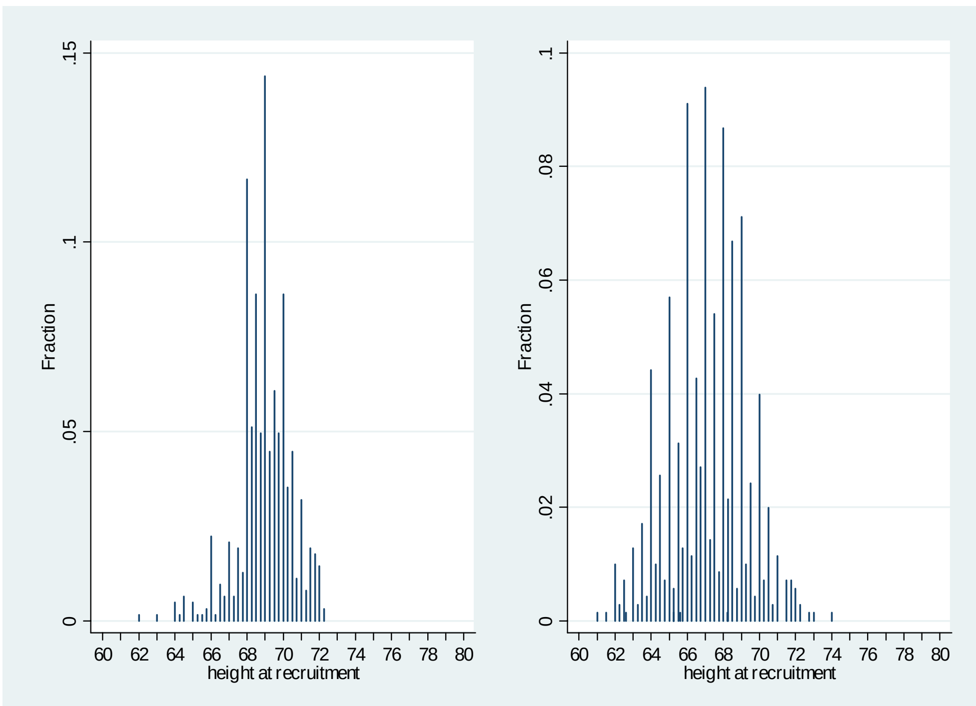
	Whole sample	*Recruited before 1820*	*Recruited after 1820*
Mean height (cm)	169.9	171.1	169.2
	(5.30)	(5.99)	(4.62)
Mean age	20.7	21.6	20.1
	(3.90)	(4.75)	(3.03)
Birth region (%)			
Central Scotland	10.6	13.6	8.6
Cumberland	1.5	2.3	0.9
Lancashire	20.5	18.3	22.0
Lincolnshire	1.7	1.9	1.6
London and Home C.	9.4	5.7	12.0
Midlands	19.5	16.3	21.7
Northern Scotland	6.8	12.0	3.2
Northumberland	1.5	2.1	1.0
Rural Southeast	13.3	13.8	12.9
Rural Wales	3.4	1.9	4.5
South Scotland	2.0	3.3	1.2
South Wales	1.1	1.1	1.0
Southwest	8.7	7.7	9.4
Occupation (%)			
Agriculture	2.5	3.1	2.1
Building	7.1	7.9	6.6
Dealing	1.7	1.6	1.9
Domestic	3.5	1.6	4.8
Labourers	35.4	31.0	38.4
Craftsmen	40.5	44.9	37.4
Mining	3.2	2.3	3.8
No occupation	1.9	4.0	0.4
Other	1.4	2.2	0.9
Service	1.8	0.9	2.4
Transport	1.0	0.4	1.4
Observations	45,451	18,492	26,959

Note: standard deviation in parenthesis. Sample constrained to recruits aged 16-49, born in England, Wales or Scotland.
Source: Floud, R., Long-term Changes in Nutrition, Welfare and Productivity in Britain; Physical and Socio-economic Characteristics of Recruits to the Army and Royal Marines, 1760-1879 [computer file]. Colchester, Essex: UK Data Archive [distributor], July 1986. SN: 2131.

Generally, people younger than 16 years were not admitted into the army; therefore we excluded from the analysis those who reported an age lower than that. As physical stature tends to shrink after the age of 50, in order not to bias our trend estimates we discarded soldiers older than 50 years. The descriptive statistics show that, except for the age composition, there are few differences in the geographic and occupational composition of the two sub-groups. An exception is the share of recruits born in London and the Home Counties which almost doubled in the post-1820 recruitment period. Also the share born in the Midlands and in Lancashire increased but to a lesser extent. The occupational breakdown by sub-period does not show large differences which might bias our results.

The anthropometric history literature derived many of its results from the analysis of army samples. And as usual when dealing with military data-sources, truncated height distributions represent an important statistical issue. The armies tended to employ minimum height requirements in the recruiting process in order ensure a sufficient level of skills and physical strength. This fact poses some problems as the raw mean height of the sample is upwardly biased. Another issue is that the minimum height requirement changed over time.[28] The need to increase the army during war periods provided an incentive to lower the physical standards and to allow shorter people into the army. In figure 3 and 4 we provide some examples of different height distributions with different minimum height requirements for the British army. The differences between the left and the right panel of figure 3 are striking: in 1805, at the onset of the French wars, the minimum height requirement enforced was noticeably lower than in 1787.[29]

Figure 3. Height distribution of soldiers recruited in 1787 (left panel) and 1805 (right panel)



Note: recruits between 16-49 years; 626 observations in the left panel and 704 in the right panel.

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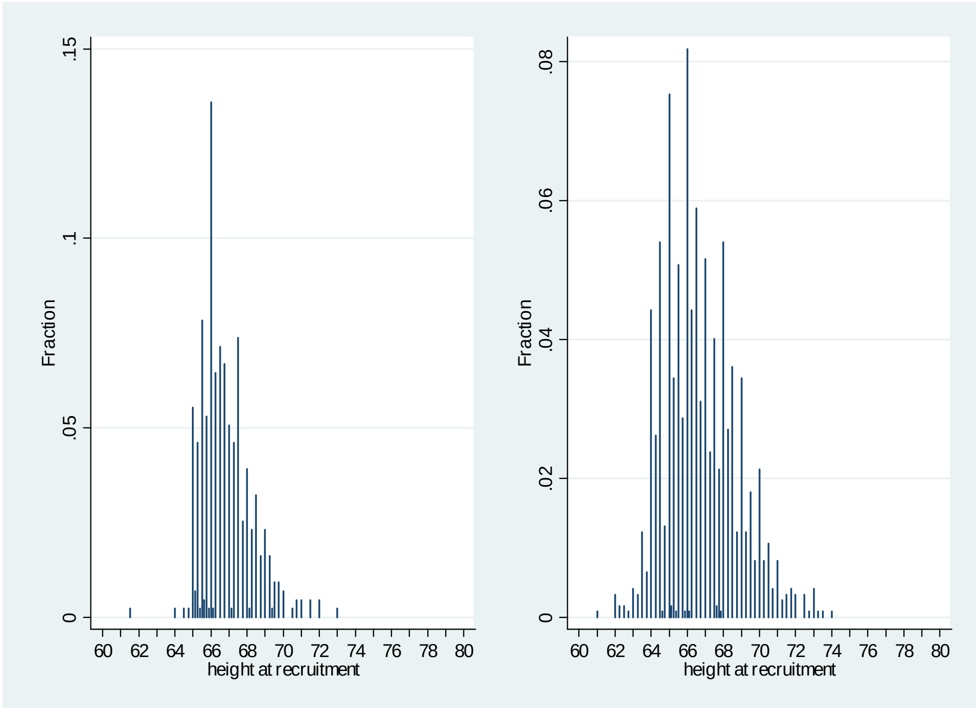
[28] We found that the minimum height requirements applied by armies that switched to a universal conscription tended to be more constant. See the Saxon army in Cinnirella, "On the road to industrialization".

[29] More details on the minimum height requirements applied by the British army in Floud, Wachter and Gregory, *Height, health and history*, p.132.

Figure 4. Height distributions of soldiers recruited in 1820 (left panel) and 1856 (right panel)



Note: recruits between 16-49 years; 434 observations in the left panel and 1124 observations in the right panel.

Several methods have been proposed in order to correct for the bias determined by the minimum height requirements. In their previous estimates, Floud, Wachter and Gregory employed two different methods: the *quantile bend estimator* (QBE)[30] and the *reduced sample maximum likelihood estimator*.[31] Some studies have shown the superiority of the truncated maximum likelihood estimator (MLE) with respect to QBE as the former method allows (*i*) the specification of a flexible truncation point, (*ii*) to perform a multiple regression estimation, (*iii*) the estimation of the population standard deviation, and (*iv*) it is also robust to problems of data-rounding.[32] The number of studies in anthropometric history which employed the truncated maximum likelihood estimator is very large.[33] The implementation of the estimator in the most used statistical-software packages probably contributed to its popularity.

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[30] Wachter, K. W. and Trussell, J., "Estimating historical heights". *Journal of the American Statistical Association* 77, (1982): 279-303.
[31] For a debate about the methodology employed by Floud et al. see: Komlos, "The secular trend" and Floud, Wachter and Gregory, "Measuring historical heights". Also Komlos, "Further thoughts" and Floud, Wachter and Gregory, "Further thoughts".
[32] A'Hearn, B., "A restricted maximum likelihood estimator for truncated height samples". *Economics and Human Biology* 2, (2004): 5-19. Komlos, "How to (and how not to) analyze deficient height samples".
[33] Most recently, A'Hearn, "Anthropometric evidence"; Komlos, Hau and Bourguinat, "An anthropometric history of early-modern France"; Mokyr and O Grada, "Height and health in the United Kingdom"; Baten, "Climate, grain production and nutritional status".

In this article we shall use consistently the truncated MLE. In particular, after inspecting all the height distributions by year of recruitment,[34] we are able to assign different truncation points according to the period of enrolment in the army. As the recruiting process in Britain was, at least in the eighteenth century, fairly decentralised, when inspecting the height distributions we also grouped the recruits by macro-area distinguishing between English and Scottish counties.

The trend in nutritional status

In the previous section we motivated the decision to analyze the military sample in two sub-periods due to the institution of the ballot of militia. We estimated the trend in nutritional status regressing height on cohort dummy variables and a further set of exogenous variables such as age, region of provenance and occupation. In addition, the binary variable urban is expected to capture the possible negative effects of urbanization on the individual's nutritional status. The variable is set equal to one if the recruit was born in a town which had more than 100,000 inhabitants in 1851.[35] Further dummy variables are used in order to control for (possible) atypical recruiting practices that occurred during the Napoleonic and the Crimean war, the two major war-events that characterized the British history in the period under investigation.

In a recent paper, A'Hearn, Baten and Crayen suggest that age-heaping can be used as a proxy for literacy as the two seem to be highly correlated between and within countries. They find that age heaping as a measure of human capital is quite powerful as it yields estimates that are robust across different data sources, time, and space.[36] We also believe that age awareness is a potential indicator of the individual skills in numeracy. Therefore recruits who were able to report their age with a monthly precision (not rounded to the nearest year) are expected to possess greater skills in numeracy, which proxies for a general higher level of education. In our dataset, around 6,700 recruits (10 percent of the total) reported age with a monthly precision. It is important to note that, across the occupations, only 2 percent of recruits within the category of "no-occupation" had such a skill in numeracy. This signals the goodness of the proxy for literacy.

In table 2 we report the estimates of the truncated regressions by sub-periods. The coefficients for the cohort years are omitted for the sake of space. However they are displayed in figure 5 and 6 with a 95 percent confidence interval band. In the truncated regression the assumption of independence among the observations might be violated due to spatial correlation. In particular, outcomes from adjacent observations, such as individuals with the same county of origin, are likely to be correlated. To obviate to this problem our estimates are corrected for clustering, in the sense that observations within each cluster (county of origin) are not necessarily independent, while the assumption of independence across clusters is maintained.

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[34] When the army is manned with volunteers and not through universal conscription, in order to detect the effective minimum height requirement height distributions we suggest analysing the data by recruitment year and not by birth cohort.

[35] The towns are: London, Manchester, Liverpool, Edinburgh, Glasgow, Leeds, Sheffield, Birmingham, Bristol, Newcastle, and Bradford. See Szreter and Mooney, *Urbanization*.

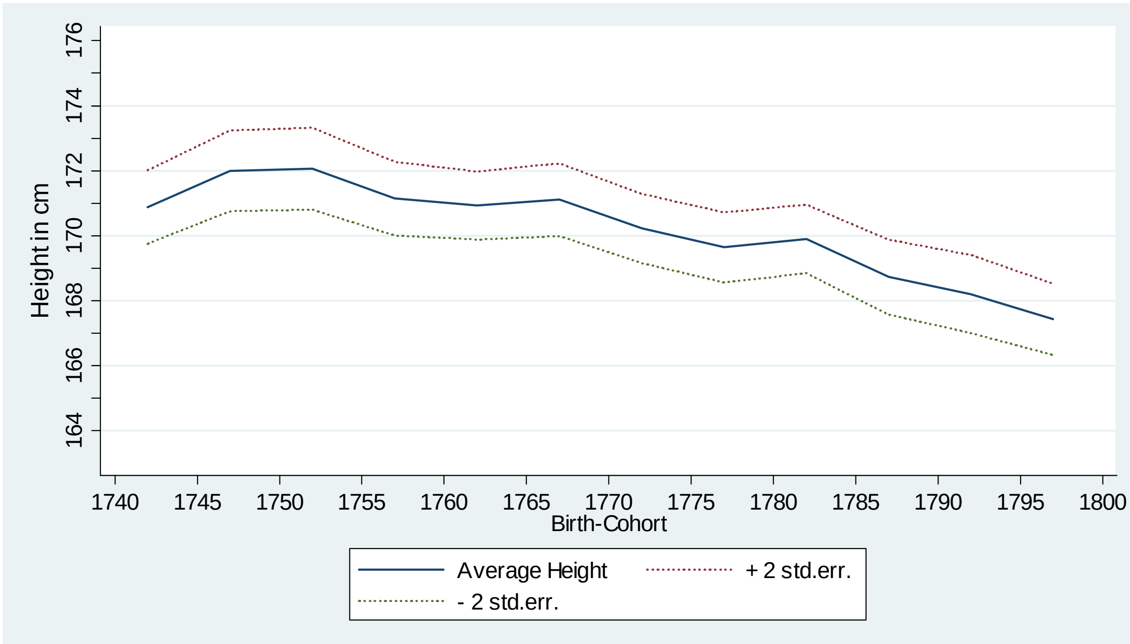
[36] See A'Hearn, B., Baten, J. and Crayen, D., *Quantifying quantitative literacy*.

As shown in figure 5 and 6, the secular trend in nutritional status is overall decreasing across the 130 years under consideration. In the eighteenth century, after reaching a peak in 1745-55, the average nutritional status steadily diminished until the outset of the French wars. The 18th c peak was reached in 1745-55 and was not reached again during the period under consideration. There was more variation in the nineteenth century but the general tendency was for heights to diminish. The trend estimated here presents significant differences with respect to a previous trend established by Floud et al.: (*i*) the peak in height is reached in the 1750s instead of the 1760s, anticipating then the decline in nutritional status by a decade; (*ii*) more importantly, because linked to the debate about living standards and early industrialization, the strong upward trend from the 1790s until 1820s outlined by Floud and co-authors is here limited to the cohorts between 1805-09 and 1810-14. Their claim that "the era of the early industrial revolution led to an improving standard of living"[37] finds here no support. Our findings are also corroborated by several alternative estimates of heights trends, including those for women. [38]

Age-effect and height-velocity are issues that will be treated in detail in the next section. Here it is worth mentioning the "effect" of the Napoleonic recruitment: soldiers recruited between 1805 and 1814 were circa 1.4 cm shorter. The need to man the army during the war diminished substantially the physical requirements. The same phenomenon took place during the recruitment for the Crimean war, though on a smaller scale (0.34 cm). A problem of multicollinearity could potentially arise between the dummy variable for the Napoleonic recruitment and recruits born between 1780 and 1790. Yet, from the inspection of the correlation between the above mentioned variables we can eliminate the potential problem of multicollinearity. Unexpectedly we find a detrimental effect of urban agglomerates only for those born in the nineteenth century that suffered a nutritional disadvantage of circa 1.2 cm, whereas the effect is not statistically different from zero for the previous period. Hygienic conditions of rapidly increasing towns, food prices and quality, and claims on nutrients due to excessive workload are usual explanations for the urban penalty. In the next section we shall present further evidence on the negative effects of urbanizations.

[37] Floud, Wachter and Gregory, *Height, health and history*, p.151.
[38] Komlos, "Secular trend"; Nicholas and Steckel, "Heights and living standards"; Johnson and Nicholas, "Male and Female Living Standards", Mokyr and O'Grada, "Height and health", Nicholas and Oxley, "The living standards of women".

Figure 5. Secular trend in height, 1740-1800



Note: The standard errors are adjusted for clustering and accounts for the covariance with the constant.
Source: Table 1

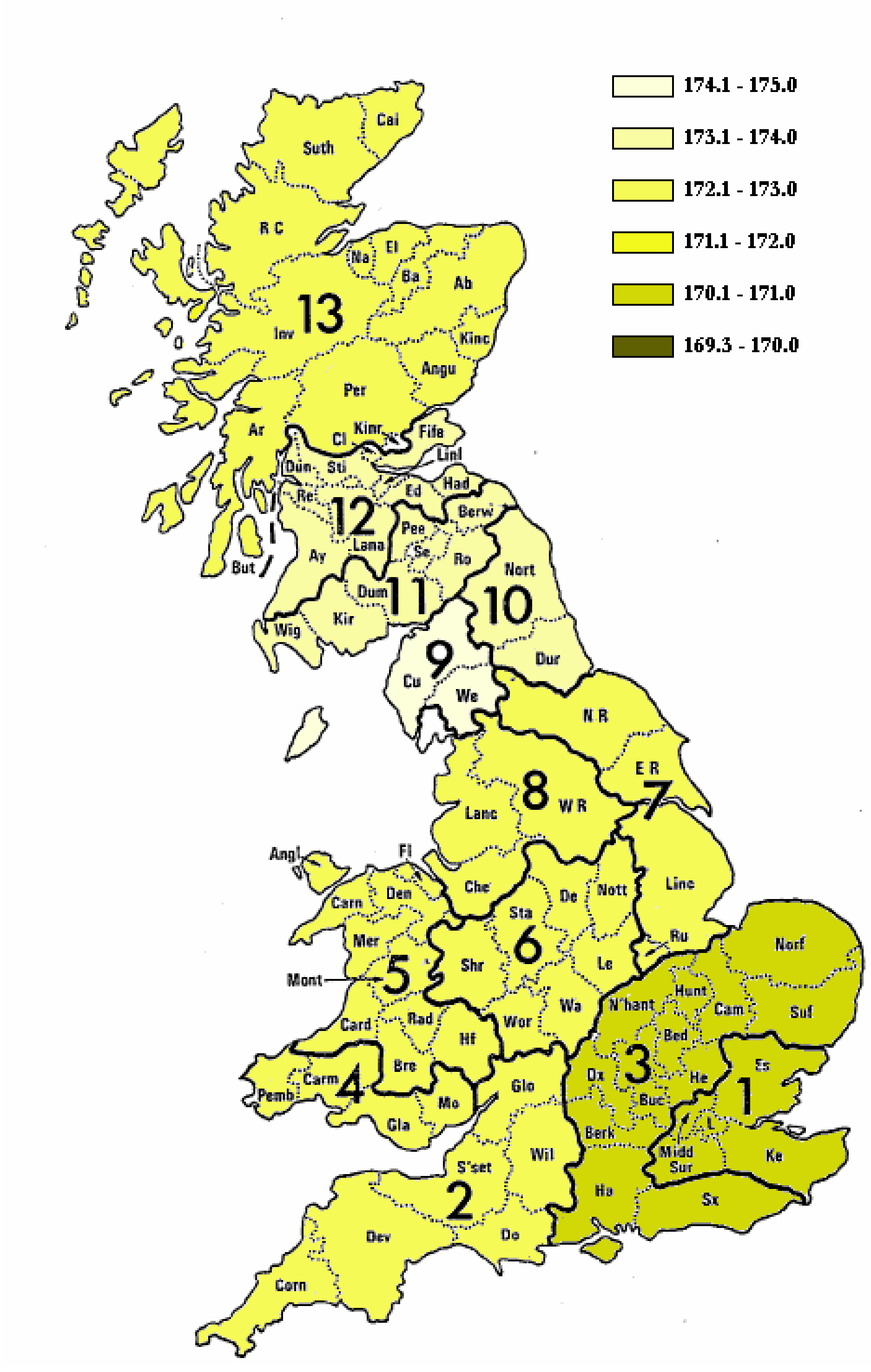
Figure 6. Secular trend in height, 1800-1870

Note: The standard errors are adjusted for clustering and accounts for the covariance with the constant. The trend is standardized for soldiers born in London and Home Counties who worked in manufacturing.
Source: Table 1

Regarding the estimated occupation differentials, recruits who were classified as domestic servants were systematically shorter with respect to the reference category of craftsmen (mainly weavers, tailors and shoemakers). The nutritional disadvantage of domestic servants persisted until the nineteenth century. Recruits previously employed in services (mainly clerks) and in the category *other* show also a conspicuous height advantage which increased over time. A clerk was probably an individual able to read and write with duties such as accounting. Therefore it is not surprising that they enjoyed a significant nutritional advantage and that such advantage increased over time, although only in relative terms. The same happened to the individuals who fall in the category *other* which we believe including former students. The fact that they were classified as "without any previous occupation" and, most importantly, the fact that the mean age within this group is 16.6 (the 75th percentile has the value of 19), clearly point to identify the category *other* with students. Then, the result for students is very interesting as it shows that there was a clear return to education in terms of nutritional status and it increased over time with respect to craftsmen. We cannot directly assess to which extent the source of the nutritional advantage for students came from the "demand" or the "supply" side: on one hand, education can be read as a proxy for family income which therefore leads to a better nutrition in terms of quantity and quality (supply side); on the other hand, given the caloric intake, fewer claims on nutrients (demand side) due to a limited or non-existent child labour might have played a substantial role in obtaining a superior nutritional status for students. Similarly, we find a strong and positive association between the proxy for literacy and nutritional status: Those recruits who reported their age with a month precision had circa a 2.5-2.6 cm advantage across the two centuries. Interestingly, the magnitude of this nutritional advantage maintained constant over time.

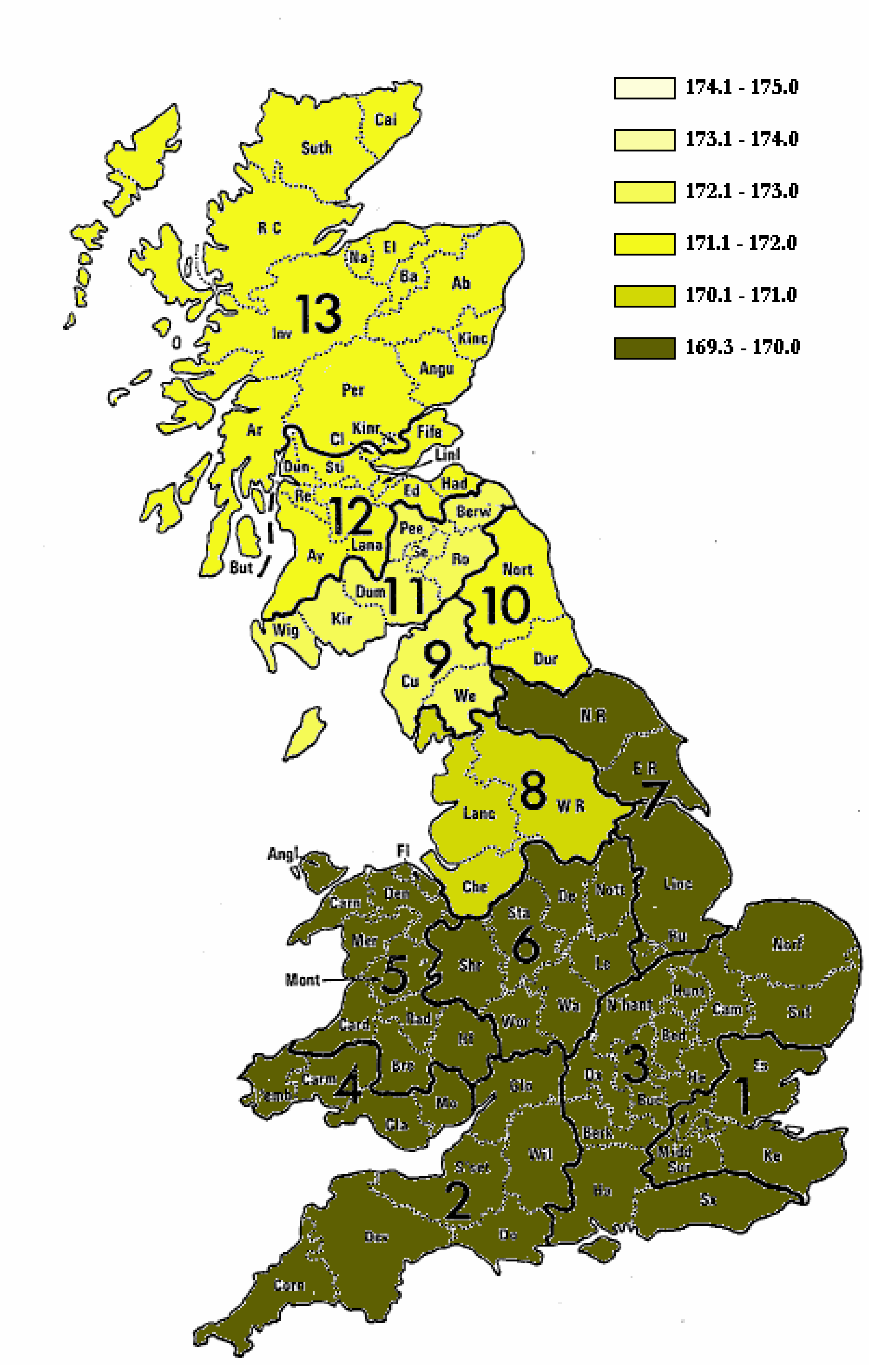
We use our new estimates to show how the nutritional status evolved in the different British wage-regions during the industrial revolution. After controlling for urbanization, the region of London and Home Counties was still the poorest in terms of average nutritional status across the two centuries. In addition, for the whole period under consideration we find a clear north-south gradient in height, which becomes more evident in the nineteenth century. The three regions which had the tallest population in both sub-periods are Cumberland, Northumberland and South Scotland. Also the remaining regions of Scotland, as already shown by Floud et al., enjoyed a comparatively superior nutritional status. These findings are displayed in Figure 7 and 8. From the comparison of the colour gradation (shorter measures of heights are associated with darker colours), the figures clearly show that (*i*) physical statures declined substantially over time and across all regions; (*ii*) the northern regions kept a superior nutritional status with respect to southern and central regions.

Figure 7. Mean heights by wage-region, birth cohort 1760-64



Note: Standardized for adults, craftsmen.
Source: Table 1. Picture scanned from Hunt, *Regional wage variations*. Own re-elaboration.

Figure 8. Mean heights by wage-region, birth cohort 1800-04



Note: standardized for age 22, craftsmen.
Source: Table 1. Picture scanned from Hunt, *Regional wage variation*. Own re-elaboration.

Table 2. Truncated regression by sub-period

Variables	*Recruited before 1820*	*Standard errors*	*Recruited after 1820*	*Standard errors*
Age				
16	-6.62***	0.303	-11.19***	0.882
17	-4.15***	0.277	-8.19***	0.519
18	-1.97***	0.238	-3.21***	0.205
19	-0.63***	0.176	-1.72***	0.187
20	0.29	0.244	-1.20***	0.210
21	0.69***	0.206	-0.23	0.203
22	0.81***	0.185	*Reference group*	
Adults (23-49)	*Reference group*		-0.33	0.227
Birth-cohort				
	Output omitted		Output omitted	
Origin				
London and Home Counties	*Reference group*		*Reference group*	
Southwest	1.20*	0.674	0.18	0.483
Rural Southeast	0.67	0.498	0.25	0.402
South Wales	1.22**	0.583	-0.27	0.354
Rural Wales	1.30*	0.667	0.07	0.498
Midlands	1.48***	0.515	-0.32	0.377
Lincolnshire	1.18**	0.464	0.36	0.295
Lancashire	1.62***	0.609	1.02***	0.352
Cumberland	3.31***	0.599	2.70***	0.328
Northumberland	2.98***	0.478	2.62***	0.702
South Scotland	2.47***	0.547	2.88***	0.459
Central Scotland	2.31***	0.523	1.85***	0.451
North Scotland	2.06***	0.506	2.51***	0.539
Napoleonic recr.	-1.38***	0.306		
Crimean-war recr.			-0.34*	0.204
Urban	-0.08	0.329	-1.25***	0.376
Literacy (proxy)	2.66*	1.408	2.56***	0.242
Occupation				
Craftsman	*Reference group*		*Reference group*	
Agriculture	1.64***	0.301	0.29	0.408
Building	0.60***	0.214	0.03	0.219
Dealing	0.58	0.433	0.63	0.472
Domestic	-0.84**	0.376	-0.67***	0.232
Labourers	0.02	0.146	0.37***	0.131
Mining	0.75**	0.335	-0.28	0.363
Service	1.83***	0.619	2.23***	0.274
Transport	-0.88	0.805	-0.45	0.393
Other	1.25***	0.401	1.84***	0.657
No occupation	-2.49***	0.639	0.86	0.595

Constant	170.93***	0.523	169.35***	0.492
Observations	15,740		23,031	

Note: coefficients are reported in cm. Standard errors are adjusted for clustering.

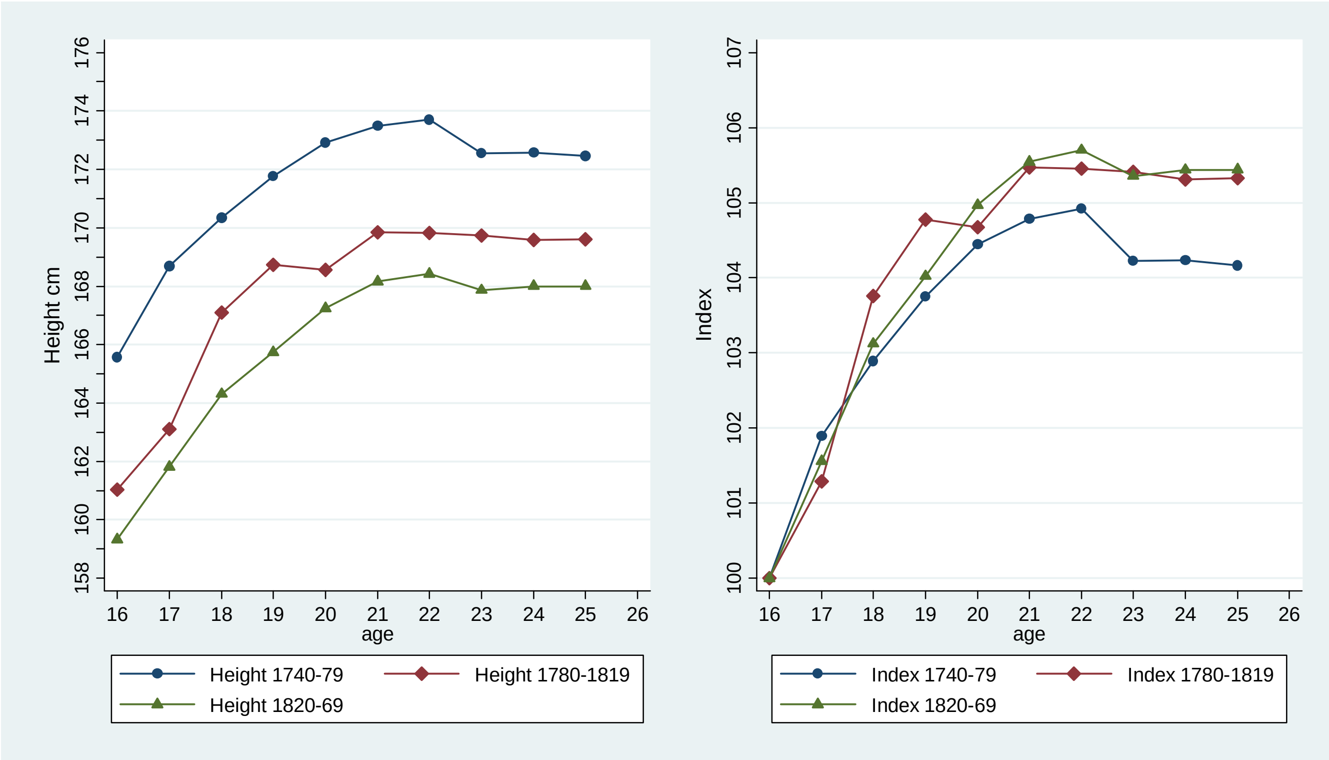
Height velocity in England during the industrial revolution

In the anthropometric history literature the analysis of the adolescent growth spurt and age at terminal height is generally complementary to the study of the secular trend. An insufficient caloric intake, insults from the interaction with the epidemiological environment, and an excessive workload during childhood or adolescence will affect not only the measure of final height but also the path of the height-by-age profile. In modern and economically developed societies terminal height is reached between the age of 18 and 20.[39] Previous studies have shown that for past societies the growth spurt and final height were reached with some delay comparatively to modern societies (Floud et al 1990; Komlos 1989; Nicholas and Steckel 1991; Johnson and Nicholas 1995). In particular for the period of the industrial revolution, final height was generally reached between age 22 and 23.In this section we shall investigate the evolution across time of the height-by-age profile and the difference in the growth path between rural and urban sub-populations.

In figure 9 we show the English (England and Wales) height-by-age profile for three sub-periods: 1740-1779, 1780-1819, and 1820-1869. The three curves are derived from separate truncated regressions performed by relevant subgroup. Usual controls for time-trend, origin and occupation are used. We use here a non-parametric approach, namely we insert dummy variables in the regression analysis in order to estimate the age coefficients. The differences in the levels in figure 9 (left panel) confirm the declining secular trend presented in the previous section: recruits born in 1820-69 were notably shorter at all ages relative to the preceding cohorts. The three curves, apparently parallel, have different growth rates. On the right panel of figure 9 we report the differences in the growth rates standardizing height at age 16. The cohorts who were taller at age 16 grew less subsequently. This is the case because the cohort with the greater average height at age 16 experienced the adolescent growth spurt earlier than the later cohorts. With reduced nutritional status the growth spurt is delayed, and as a consequence, the later cohorts grew more after age 16. Besides showing a faster growth rate, later birth-cohorts delayed also the age at which they attained their final height. The non-parametric approach shows that for all three sub-groups the final height was attained at around age 22 (i.e., between age 22 and 22.9).

[39] Eveleth, P.B. and Tanner, J.M., Worldwide variation in human growth (Cambridge, 1976).

Figure 9. Height-age profile by time-period



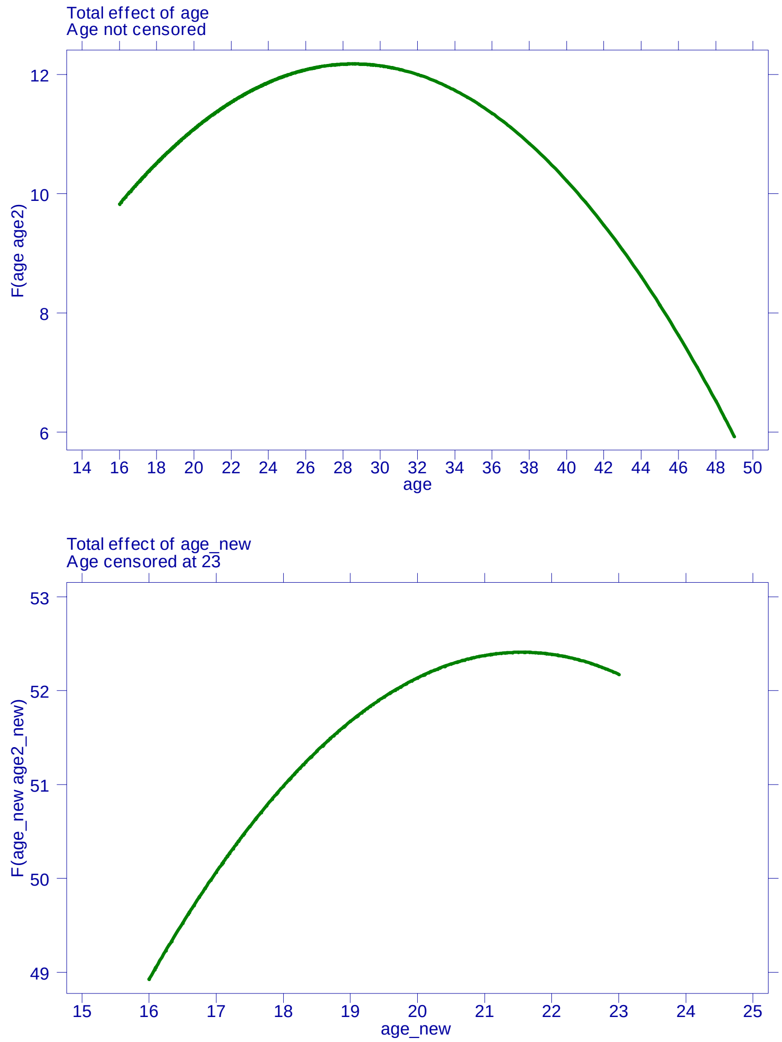
Note: The index is set equal to 100 for height at age 16.

In order to be able to determine the exact age at which final height was attained, we need to employ age as a continuous variable in the regression analysis. Yet this approach poses some problems as we need to specify a functional form. The relationship between height and age is known to be nonlinear and concave with decreasing marginal returns. The insertion of age in its linear and quadratic form would lead to a model misspecification as we would allow also for a negative effect of age for large values of the independent variable (figure 10, graph on top). To obviate to this problem we decided to censor the original variable for age: the new variable will take on a constant value 23 if the original variable is equal or greater than 23.

$$age\_new \begin{cases} = age & if\ age < 23 \\ \\ = 23 & if\ age \geq 23 \end{cases}$$

The new variable behaves as the empirical evidence suggests, namely we constrain the effect of age on height to be zero for values greater than 23 years. We keep the quadratic form of the new censored variable in order to allow for decreasing marginal returns. Due to the fact that the maximum of the quadratic function lies somewhere before the age of 23, the censorship still enables us to compute the maximum of the function (figure 3, graph on bottom).

Figure 10. Non-linear effect of age on height



Note: the graph on top shows the total effect of age with age in its linear and quadratic form. The graph at the bottom shows the total effect when the variable is truncated at age 23.

There are slight differences in age at terminal height across the three sub-periods (table 3). The later cohorts show a deferment of about one third of a year. This finding, though small in magnitude, adds further evidence to the fact that early industrialization (1780-1819) and the successive period of stronger industrialization (1820-1869) were detrimental for the English population biological standard of living.

Table 3. Height at terminal height for three cohort groups

Cohort	*Age at terminal height*	*95% confidence interval*
1740-1779	21.32	21.04, 21.60
1780-1819	21.51	21.28, 21.73
1820-1869	21.67	21.29, 22.06

The inspection of the height-by-age profile provides more insights when studying the effects of urbanization on the biological standard of living. In what follows we intend to explore the detrimental effects of the urban environment on the individuals' nutritional status. From the results of the regression analysis in the previous section, we showed that urbanization had a significant negative impact on the individuals' nutritional status from the cohorts born in 1820 (circa 1.5 cm). In order to show how urbanization affected also the height-by-age profile we adopt a comparative approach: We select a group of individuals who shared a similar rural environment; then we compare the height-by-age profile of those who remained in the rural environment with those who, at some point in time, decided to leave the countryside toward an urban environment. We employ the same setting of Boyer and Hatton (1997) who investigated the determinants of male migration from southern and eastern rural counties to six urban destinations.[40] The authors found that real wage/expected income gap, distance between origin and destination, and the size of the migrant stock had significant effects on migration rates (Boyer and Hatton 1997 p.712). In a previous paper Nicholas and Shergold analysed a sample of British convicts shipped to Australia and found that skilled and educated individuals had higher probabilities of being inter-county migrants. Their finding seems to be robust to short- and long-run distance migration.

Through the information on both the counties of birth and that of recruitment we can construct a sample of migrants whose rural-urban migration pattern resembles that of Boyer and Hatton. We have 3,733 soldiers who were born and recruited in the southern agricultural counties, whereas 2,736 soldiers were born in the same rural counties but recruited in an urban one. We hypothesize that the urban migrants, before recruitment in the army, were exposed to the precarious hygienic conditions typical of a rapidly growing urban centre, to some economic stress in terms of more expensive food items (and likely of lower quality), and to an increment of the workload. Those effects should be mirrored by the height-by-age profile of the migrants sub-group, likely with a significant deferment of age at terminal height. The comparison with those who resided in the southern rural counties could reveal a sort of "net effect" of urbanization. In order to understand which people selected into the migration sub-group, we first performed a probit estimation. A standard t-test of means shows that urban migrants were circa 0.7 inch (ca. 1.8 cm) shorter and the difference is statistically significant at 5% significance level. In addition, we estimate a standard probit model to determine which characteristics increased the likelihood of being an urban migrant (the output of the probit regression is

[40] The 19 origin rural counties are: Beds., Herts., Berks., Bucks., Oxon., Sussex, Hants., Hunts, Cambs., Suffolk, Norfolk, Wilts., Dorset, Devon, Somerset, Cornwall, Northants., Rutland, and Lincs.
The six destinations are London and the Home Counties (excluding the rural counties of Surrey, Kent, and Essex), Lancashire and Cheshire, Yorkshire, the west midlands, the east midlands, and south Wales.
See also Boyer and Hatton, *Migration and labour market integration*.

not reported here). A possible interesting result regards the coefficients associated to the dummy variables for the Napoleonic and Crimean-war recruitment which are not statistically significant. This "non-result" might indicate that migration towards industrial districts or towns was initially motivated by the search of new job opportunities rather than military employment. In order to check for the occupational characteristics of the migrants we adopted the Armstrong's industrial classification which groups the occupations according to the degree of skills embodied.[41] Probit estimates show that professionals and skilled individuals were more likely to be urban migrants; unskilled people had 14% less probabilities of being urban migrants with respect to skilled; professionals were 37% more likely than skilled people. Admittedly, in the probit analysis there might be a problem of reverse causality: the lack of information about when people decided to migrate does not permit to assess clearly whether higher skilled people decided to migrate, or migration itself occurred before the acquisition of skills in town. In favour of the reverse causality story, the coefficient associated to the proxy for education[42] - which in the previous section resulted being strongly and positively correlated with height - is not statistically different from zero in the probit regression. In synthesis: (*i*) urban migrants appear to be on average shorter then their counterparts who stayed at home; (*ii*) they had a higher skilled job; (*iii*) their level of education (proxied by age rounding) was not superior with respect to the rural residents.

After defining some characteristics of the urban migrants, we are interested in computing the age at which their final height was attained. Separate regressions are performed and origin county dummies are used to control for possible geographical effects on the nutritional status of both migrants and non-migrants.[43] The quadratic function for the urban migrants has a maximum at age 22.43; for those who stayed in the rural southern and eastern counties the maximum height was attained at age 21.39. The difference in age of more than one year is statistically significant at a 5% significance level. The height-by-age profiles of the two sub-groups are shown in figure 11: on the left panel we present the profile with the actual heights, whereas on the right panel there is the index standardized at age 16. The final predicted height for the two sub-groups is very similar lying in the range 170-171 cm. Except for height at age 16 the profile of the rural group is always superior to the urban migrants. The index on the right panel of figure 11 shows a pattern which is the opposite of what we showed in figure 9: the urban group grew comparatively "less" than its rural counterpart. In particular, from age 16 to age 18 the rural youths grew by 3% whereas the urban boys by a mere 1%. To ensure that these results are not biased due to a different age composition, in figure 12 we report the age distributions of the two regression samples which are almost identical.

Therefore looking at the growth rates, adolescents that migrated toward industrial or urban centres seem to have borne to a larger extent the negative consequences of urban migration. Even though we cannot directly identify when and which urban effect modified the growth process of the migrant, we provide substantial evidence about the existence of such urban effect. The deferment of age at terminal height is only one of the

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[41] We have 4 categories: professionals, skilled, unskilled, and no occupation.

[42] Age rounding was used as a proxy for education (or literacy) in the height trend estimates.

[43] Given the paucity of observations regressions are performed for the entire period, 1740-1870. Time-dummies are used as usual.

signals of the detrimental effects that urbanization brought about on the individuals' biological standard of living. The large difference in the growth rate in the interval 16-18 years shows that the transition from a rural to an urban environment, at a relatively early stage of life, might have put at serious risk the individual's biological standard of living.

Figure 11. Height-by-age profile for urban and rural populations

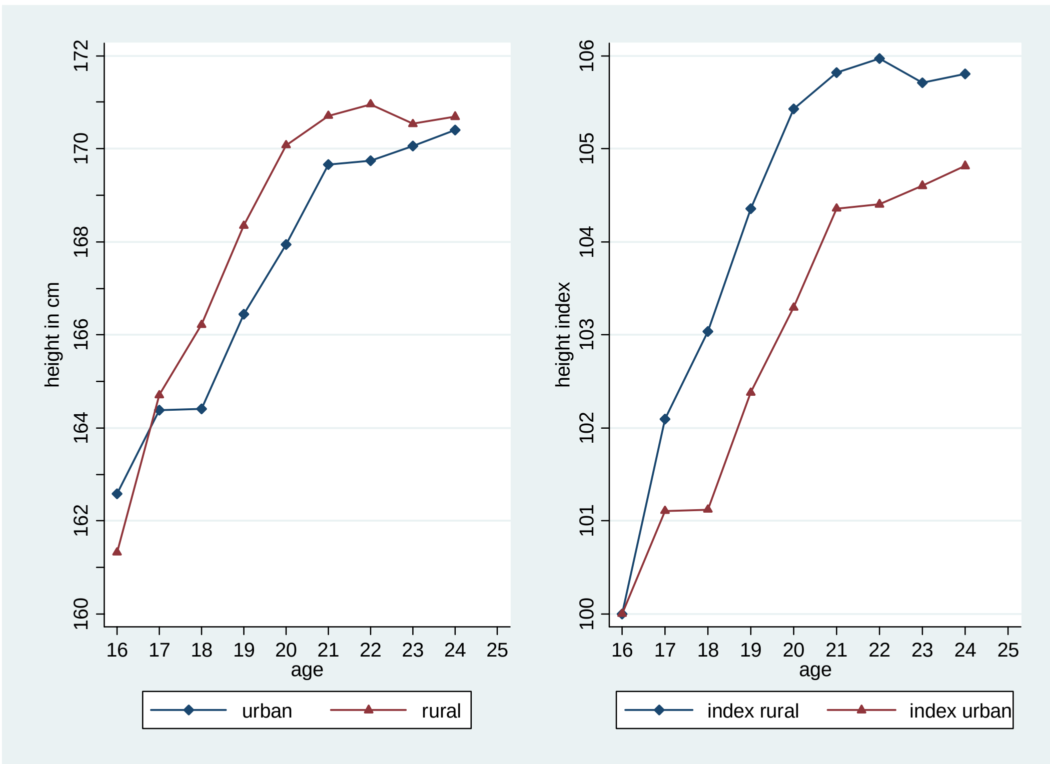
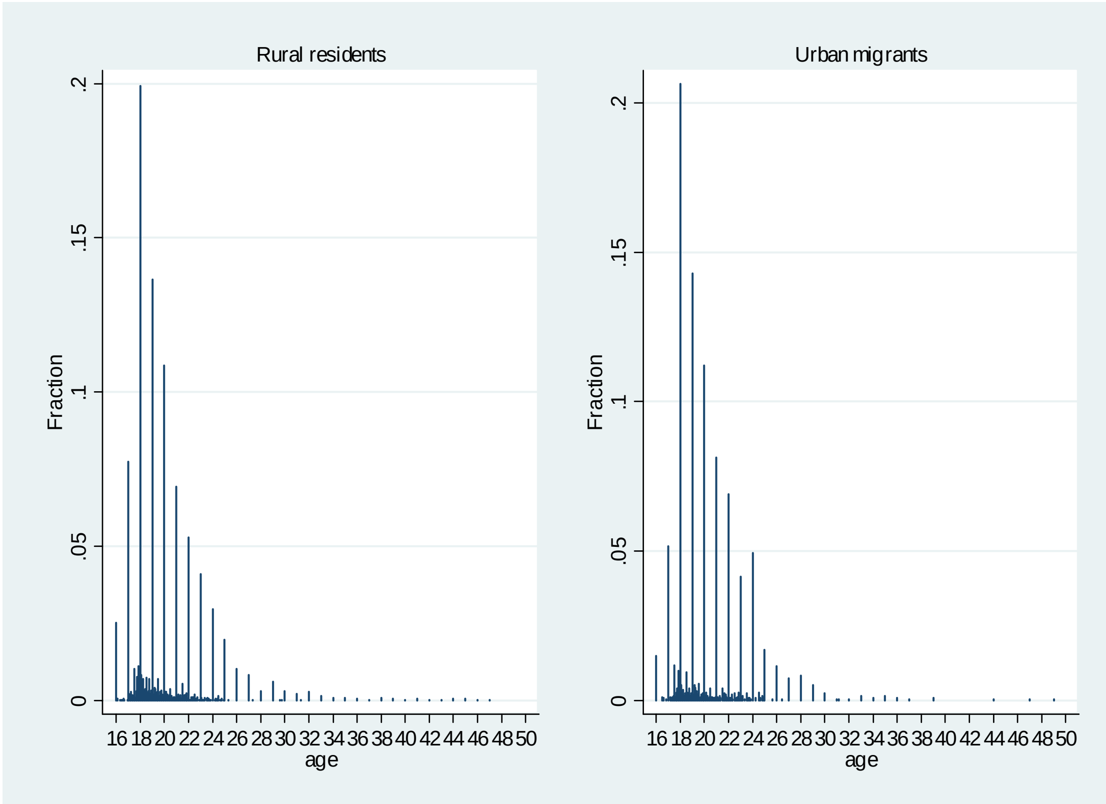


Figure 12. Age distribution of rural residents and urban migrants



Source: see text

Discussion

We presented new estimates which show that average nutritional status declined substantially in the second half of the eighteenth century. Physical stature recovered slightly only for the cohorts born between 1805-09 and 1810-14. The period of the 1820s, 1830s and part of the 1840s were also years of decline in terms of biological standard of living. There are remarkable differences with the previous estimates of Floud, Wachter and Gregory, especially concerning the trend of the period 1780-1820. Their claim of an improving standard of living during the phase of early industrialization finds here no support. Instead, our results are more in line with those presented by Komlos and successively supported also by other alternative evidences.[44]

The results provided in this article are consistent with the trend in food prices and wage rates estimated for the second half of the eighteenth century. In particular, there is plenty of evidence that food prices rose substantially in the last third of the eighteenth century; the price of wheat, for instance, increased by 76.3% between 1740-50 and 1785-95.[45] Similarly in a recent paper, Clark presents new estimates of price indexes for different food items. As shown in figure 13 the trend for all the items is strongly

[44] Nicholas and Steckel, "Heights and living standards".
[45] Boyer, *English Poor law*.

increasing for the whole period 1750-1800. Also new figures on farm labour real wages support the view of declining standard of living for the last four decades of the eighteenth century. Farm labour real wage declined substantially from 1740-49 until 1770-79 across all regions; the wage decline in the southeast and southwest persisted until 1820 (table 4).[46] It is important to note that 35 percent of our sample is constituted by day labourers, and that 33 percent of them originated from the south (another 15 percent came from the Midlands). Therefore we believe that the economic change of the English rural-south plays an important role in explaining the trend in nutritional status.

In this regard, parliamentary enclosures of open fields and commons, especially during the 1760s and 1770s, probably played an important role in shaping the nutritional status of the British people in addition to the substantial increase in prices due to rapid population growth and urbanization. The categories of people mostly touched by the enclosures were day labourers and cottagers. For the labourers, the effect of enclosures was typically the loss of common rights and/or allotments. In grain-producing areas where the arable land was enclosed already before 1750, the loss of allotments was a typical phenomenon. The rise in land-value, determined by the rise in wheat price, provided an incentive to the farmers to take away the land that had been previously allotted to farm labourers.[47] As the allotments were a primary source of food for the labourers and their family, such a loss very likely caused a significant reduction in food consumption with a consequent deterioration of the nutritional status.[48] As pointed out by Boyer, the loss of allotments and commons rights made agricultural labourers more dependent and more sensitive to fluctuations of food-prices. Our estimates support this hypothesis as we show that recruits from the south-eastern counties had an inferior nutritional status in the eighteenth century with respect to all the other regions. In his seminal paper on parliamentary enclosures and labour supply, Chambers (1953) claimed that the loss of land from the enclosures was compensated by an increase in the wage rate and by an increase in the agricultural labour demand. Chambers and other scholars, notably Landes (1969), rejected then the hypothesis that the enclosures created a pool of workers which in turn increased the supply of labour for industry in the early industrialization process. This position has been challenged, among others, by Crafts (1978) and Boyer (1990). The new estimates of Clark (2001, 2007) about farm labour wage reject the claim of rising wage rates as result of enclosure in the second half of the eighteenth century (Table 4). Therefore, the worsening of the nutritional status in the southeast was in part an endogenous response to the effect of the enclosures and of rising land value which deprived them from a stable source of food. Prices of food, on the rise because of population growth, had both a direct and an indirect effect on the average nutritional status as they affected the value of land which became an extreme worthy asset to farmers.

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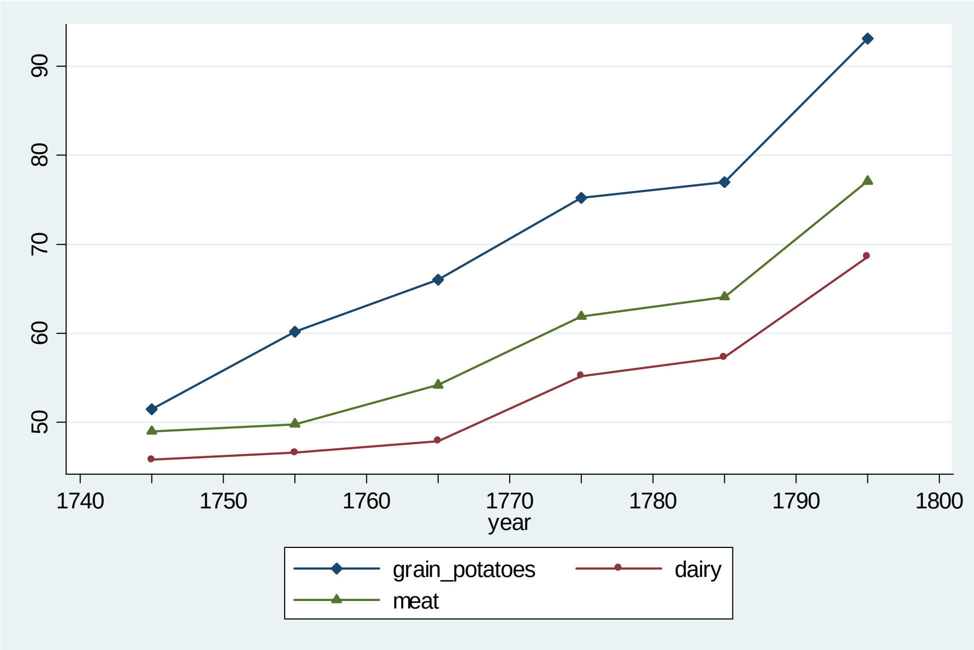
[46] Clark, 2001 and 2007

[47] Hobsbawm, *Industry and Empire*.

[48] Boyer, *English poor law*, p.36.

Figure 13. Price indexes of food items



Source: Clark, "The long march of history".

In order to show that our sample is representative of recruits whose families were affected by the enclosures, we test the correlation between enclosures and internal migration. A previous study of Crafts (1978) showed a significant correlation between enclosures and the rate of migration in counties affected by the enclosures. We test whether this correlation is also present in our sample. Counties most affected by parliamentary enclosures before 1793 were Northampton, Oxford, Huntingdon, and Buckingham. Counties least affected by enclosures were Kent, Essex, Sussex, Suffolk, and Hertford.[49] We run a probit model for internal migration constrained to the cohorts born before 1793 in the two blocks of counties supra mentioned. We control for age, time trend, and occupation. Dummy variables for the counties most and least affected by the enclosures are inserted in the model in order to test our hypothesis. The regression sample contains 1,134 observations, with 65 percent of migrants. Results from the probit estimation show that the probability of being a migrant for a recruit born before 1793 in the counties most affected by the parliamentary enclosures was 16 percent higher than for migrants born in the least affected counties. The coefficient is highly statistically significant (99 percent confidence interval). We are aware that the determinants of internal migration are multiple and that this result cannot be considered as conclusive. Nonetheless, looking at the occupational and geographical composition of the sample, and the correlation between migration-counties and enclosure-counties, we are fairly confident that the recruits in this sample are representative of rural-south families that were likely affected by the parliamentary enclosures.

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[49] See Turner, 1980; Boyer, *English Poor Law*.

For the nineteenth century we estimate a nutritional improvement for the category of labourers with respect to the previous period, even though small in magnitude (0.3 cm, see table 2 in the previous section). This result is consistent with the increase in the wage rate that affected farm labourers in the nineteenth century as a result of the mass migration toward urban centres.

Table 4. Farm labour wage rate by macro-region

Decade	*North*	*Midlands*	*Southeast*	*Southwest*	*All*
1740-49	106	120	109	135	118
1750-59	106	107	97	110	105
1760-69	106	105	98	109	104
1770-79	100	100	100	100	100
1780-89	103	116	106	99	107
1790-99	101	114	102	93	103
1800-09	102	109	87	97	98
1810-19	113	127	91	91	104
1820-29	153	146	103	112	125
1830-39	166	154	109	118	132
1840-49	173	161	111	125	138
1850-59	197	164	115	136	147
1860-69	204	165	115	143	150

Note: index equal to 100 for decade 1770-79.
Source: Clark, "Farm wages".

The decline of cottage industry which took place across the two centuries, especially in the south, represents another potential explanation of the north-south divide in terms of nutritional status. It plays an important role not only because it was a complementary employment opportunity for agricultural labourers, but also because cottage industry represented a source of employment for women and children. The negative correlation between poor relief expenditures and earnings from cottage industry suggest the importance that the latter had in economically sustaining the family. We believe that the decline of cottage industry in the south contributed to the deterioration of the nutritional status and constitutes an additional explanation of the north-south divide in the biological standard of living.

The trend in nutritional status estimated here for the nineteenth century shares many similarities with the one estimated by Floud et al. The trend is corroborated also by the studies of Nicholas and Steckel, Johnson and Nicholas, and Komlos.[50] In our case, the decline in heights starts right after the Napoleonic wars, whereas the estimates of Floud and co-authors place the beginning of the decline around the end of the1820s. However the decline in nutritional status during the hungry thirties and forties is here confirmed. Therefore the trend in height during the second and third quarter of the nineteenth century provides support to a more pessimistic view about the standard of living of the British

[50] Nicholas and Steckel, "Heights and living standards of English workers"; Johnson and Nicholas, "Male and female living standards".

working class during the industrial revolution. Yet, also the more cautious estimates of real wages by Feinstein, allowing for unemployment and short-time working, maintain that from 1778/82 to 1853/57 there was an increase in real weekly earnings, though less than 30 percent.[51] Therefore the early industrialization puzzle, with increasing real wage and declining heights, seems to be confirmed also here. However, in order to get a better understanding of the trend in nutritional status, probably would be more profitable to shift the attention from the individual to the family level. The underlying question then becomes: Was the increment in the real wage large enough to allow a sufficient sustenance of the family in a framework of rising fertility? The evidence on the change in nutritional status between the 1820s and the 1860s suggest a negative answer to this question. Also Feinstein stressed that allowing for the demographic change, the standard of living of the average family might have been reduced by 10 percent.[52] The evidence on the shift of the age at terminal height in the nineteenth century points to the same direction: We have showed that there is a significant difference between the height-by-age profiles of the two centuries. This difference can be ascribed to a larger epidemiological and economic stress for the cohorts born in the nineteenth century.

Certainly the deterioration of the average nutritional status is not mono-causal. The effects of high relative price of food, poor housing, public health, or food adulteration, which are variables difficult to measure properly, can partially explain the declining trend in heights showed by the truncated regression. The same applies to the large incidence of child labour in the British society. We showed that the nutritional advantage of those recruits, presumably students, who did not state any previous occupation (therefore with few or no child labour experience) enjoyed a nutritional advantage equal to 1.25 cm in the eighteenth century, which rose to 1.84 cm in the nineteenth century. These estimates might provide quantification in terms of biological standard of living of the trade-off between education and child labour.

In conclusion, the early industrialization puzzle is probably not so puzzling anymore when we consider the family unit rather than the single individual. In fact, the (possible) increment in the real wage of the nineteenth century did not benefit directly the recruits here measured (who otherwise would not have joined the army). The heights of the recruits that we observe are the endogenous response to the socio-economic dynamics within the family nucleus. The heights of the period 1820-1870 mirror the inability or impossibility to maintain an adequate nutritional status within the family. The limited rise in the wage rate experienced by the working class of the nineteenth century was not enough to cope with a setting of increasing fertility. Or more simply, a trade-off between quality and quantity of children might have taken place. In a maximizing-utility framework, working class families of the nineteenth century were deliberately willing to have more children at the cost of a lower average nutritional status within the family. Institutions like the English Poor Law might have worked to favour this behaviour. The fact that, despite the increase in farm labour wage, 80 percent of rural south-eastern parishes continued to pay child allowances in 1832 plays decisively in favour of this hypothesis.[53]

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[51] Feinstein, "Pessimism perpetuated".
[52] Feinstein, "Pessimism perpetuated", p.650.
[53] Boyer, *English poor law*, p.49.

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