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DID SMALLPOX REDUCE HEIGHT? STATURE AND THE STANDARD OF LIVING IN LONDON, 1770-1873

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DID SMALLPOX REDUCE HEIGHT? STATURE AND THE STANDARD OF LIVING IN LONDON, 1770-1873[1]

In this paper, we re-examine the effect of smallpox on the height attained by those who suffered from this disease. To this end, we analyse a dataset assembled by Floud, Wachter and Gregory on the height of recruits into the Marine Society, 1770-1873. Using both time series and cross-sectional analysis, we show that smallpox was indeed an important determinant of height: those who had suffered from smallpox were significantly shorter. This suggests that the increase in heights documented by Floud et al. may be explained not just by increased nutritional intake, but also by the eradication of smallpox.

It is easy to see why smallpox was regarded with such terror prior to the spread of vaccination in the nineteenth century, for it is 'the most infectious disease ever known'.[2] As Macaulay noted, smallpox was the 'most terrible of all the ministers of death'.[3] It exacted a heavy toll of early modern populations, causing a significant proportion of all deaths. For example, Landers finds that it accounted for up to ten percent of deaths in London during the eighteenth century.[4] But its effect on isolated populations was much more severe: over ninety-five percent of those living on the island of Foula died from the disease following its arrival in 1720.[5] Such a death rate was not untypical among populations that had never experienced smallpox before. In one of the largest demographic catastrophies in recorded history, smallpox reduced the Mexican population by ninety percent after its arrival with the *conquistadores*. Those who survived were left pockmarked for life.[6]

In this article, we examine the impact of smallpox on the attained heights of those who survived the ravages of the disease. Floud, Wachter and Gregory's Marine Society dataset,[7] which gives the stature and disease history of teenage boys recruited into the society between 1770 and 1873, offers us a unique opportunity to analyse the effects of smallpox.[8] We show that the disease had a strong negative effect on the average height of survivors. On the basis of the available statistical material, we argue that smallpox reduced attained heights by at least one inch. Since smallpox virtually disappears during the period studied by Floud et al., we argue that at least one third of the rise in heights that they observe[9] was caused by the eradication of smallpox.

Our results have wider implications. Research into historical heights has been the largest single project undertaken by New Economic Historians since the 1970s. It has shed new light on issues as diverse as the standard of living debate and long-term trends in mortality.[10] Yet, as Crafts has observed, 'several problems need to be resolved. One of these is to pin down links between various aspects of the quality of life and height, and another is to establish that heights are meaningful in the sense that the impact of environmental factors on height corresponds to their (dis)utility value ...'.[11] The results of our research help to clarify the relationship between height and well-being. As we will argue, our finding that smallpox reduced height is also important because it implies that well-being and average stature can move in opposite directions.

We proceed as follows. Section I briefly introduces the concept of anthropometric history and discusses the work of Floud et al. on heights during the Industrial Revolution. Section II presents the results of our re-examination of over 26,000 records relating to the heights of Marine Society recruits. Section III discusses the implications of our findings for four areas: our understanding of smallpox and its history, the effects of the Industrial Revolution on the standard of living, the appropriate statistical techniques for analysing truncated height data, and the relationship between height and well-being. Section IV concludes.

I

Biologically, an individual’s attained height is a function of its cumulative nutritional status during childhood. This is commonly defined as nutritional intake minus claims on this intake, which come from work, disease, cold, basic hygiene and basal metabolism.[12] Over the past 100 years we have witnessed a secular increase in heights.[13] Improved health care and better nutrition are generally thought to have been the most important causes of this rise.[14]

The relationship between the determinants of height and per capita income is close enough to tempt some researchers to go as far as estimating national income in the nineteenth century on the basis of anthropometric measures.[15] It is therefore no surprise that anthropometric data has been brought to bear on the continuing controversy on the standard of living during the Industrial Revolution, not least because declining marginal returns have clearly set in with the traditional methods that have been employed since the 1950s.

Floud, Wachter and Gregory use data on the height of recruits in the Royal Marines and British Army, and of boys accepted into the Marine Society to construct an anthropometric history of Britain from 1750 to 1980, and so at one remove to shed new light on the changing standard of living since 1750. Because height is an aggregate function of so many aspects of well-being, including real income, work intensity and the disease environment, they regard it as a much more comprehensive measure of welfare than, say, real income or life expectancy.[16]

Their results for the Industrial Revolution are easy to state. They find that adult heights increase from around 65" for those born in the early 1740s to a temporary peak of 68" for those born in the early 1820s. Attained heights then fall back to under 66" for those born in the late 1840s, a level that persists for around two decades, after which heights begin to rise again, regaining their earlier 1820s peak by the end of the nineteenth century.[17] The stature of Marine Society recruits display similar tendencies, although the fluctuations in attained height are magnified.[18]

These changes in height lead Floud et al to argue that:

> It seems likely that the early part of the Industrial Revolution led to an absolute as well as relative increase in the welfare and nutritional status of the working class, but that the impact of urban growth eroded this increase and even led to decreases in average height as larger proportions of the working-class community were subjected to town life.[19]

These results are in marked contrast to relatively recent work by Lindert and Williamson on real wages. Where Floud et al. find rising heights for those born up to the early 1820s, Lindert and Williamson find stagnation in real wages.[20] And where Floud et al. find declining heights between the 1820s and the middle of the century, Williamson finds a 'surge' in real wages.[21] Floud et al are at pains to state that they are not claiming that Williamson's results for the period after 1820 are incorrect,[22] instead they argue that their evidence 'demonstrates forcibly that, if there were significant gains in real incomes for the working class between the 1820s and the 1850s, they were bought at a very high price.'[23]

Floud et al's rejection of the idea that the eradication of smallpox could have been a major factor increasing height in the early nineteenth century is important because of their 'optimistic' finding of rising heights in this period. If the decline of smallpox raised heights directly, Floud et al.'s discovery of a long-term increase in stature at this time may be less compelling evidence of a rise in the standard of living than they believe.

II

We are able to use Floud et al's dataset on Marine Society recruits to test whether smallpox reduced attained height. We know from studies of less developed countries that infectious diseases have substantial effects on nutritional status.[24] Given the World Health Organisation's success in eradicating smallpox, this dataset represents a unique opportunity to study the effects of this disease on attained height. The dataset is comprehensive, giving the date of recruitment, the age of the recruit (normally in years and months), the subject's height, origin, and whether he was able to read and/or write. Crucially for our purposes, recruitment officers also noted whether the recruit had had smallpox.

There is one obstacle that we have to note before we begin: the effect of changing minimum height requirements. In the same manner as the army or navy, the Marine Society imposed a minimum height requirement on potential recruits, equating lack of stature with lack of physical strength.[25] Our sample of heights is not representative of the population, therefore, but instead suffers from left-hand truncation. Both the official minimum height requirement imposed by the Marine Society and the strictness of its enforcement changed over time.[26] The requirement itself, and changes to it, create problems in estimating changes in average heights over time. Two alternative techniques have been developed to overcome the problem of left-hand truncation: the quartile-bend estimator (QBE) of Floud et al. and the Komlos-Kim method.[27] QBE relies on the well-established fact that the distribution of heights of any given modern population closely approximates a Gaussian or normal distribution.[28] But as we are interested simply in the effect of smallpox on the attained height of individuals, rather than the true population mean itself, we can begin by using uncorrected distributions. We return to the issue of truncation bias later.

On the basis of the data itself, it can be demonstrated that those recruits who had had smallpox were markedly shorter than those who did not. Figures 1, 2, 3, 4 and 5 give height distributions for recruits aged 13, 14, 15, 16 and 17.

Figure 1. *Height of 13-year olds, full sample*

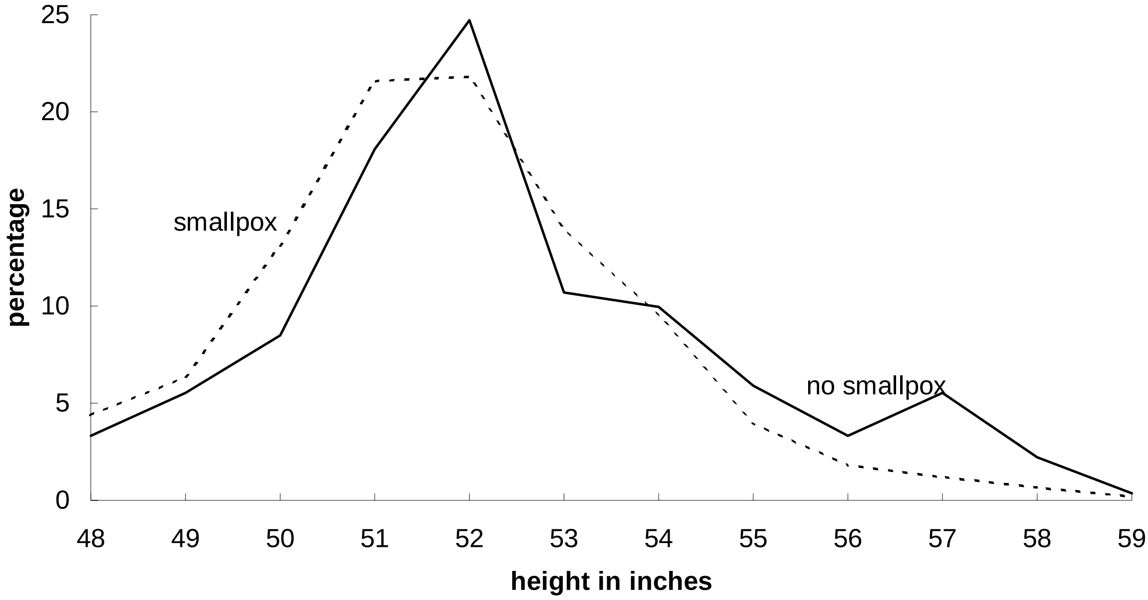


Figure 2. *Height of 14-year olds, full sample*

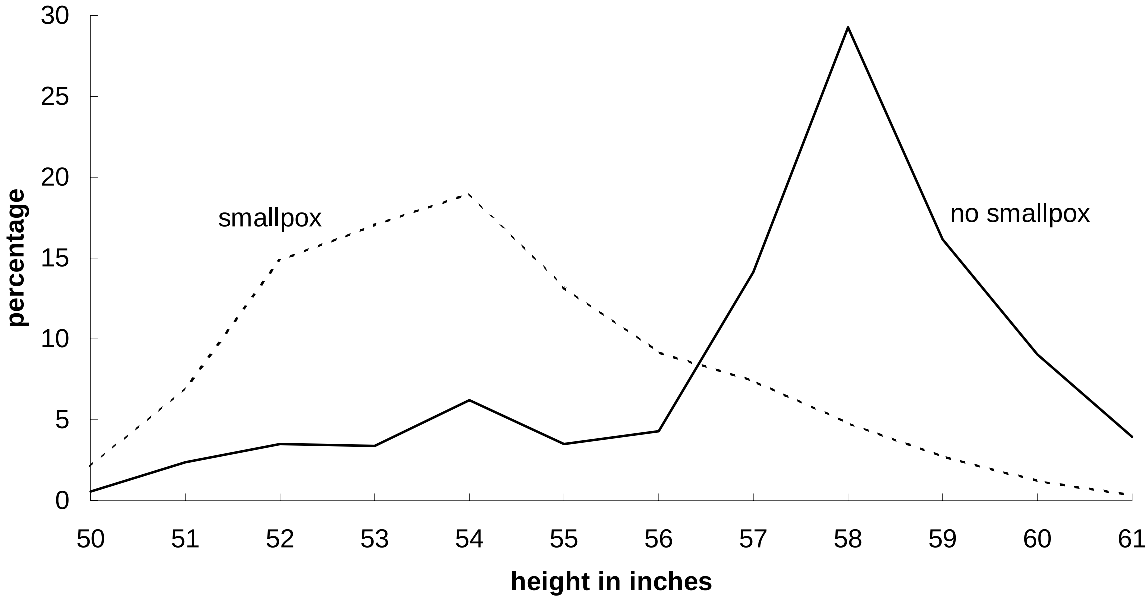


Figure 3. *Height of 15-year olds, full sample*

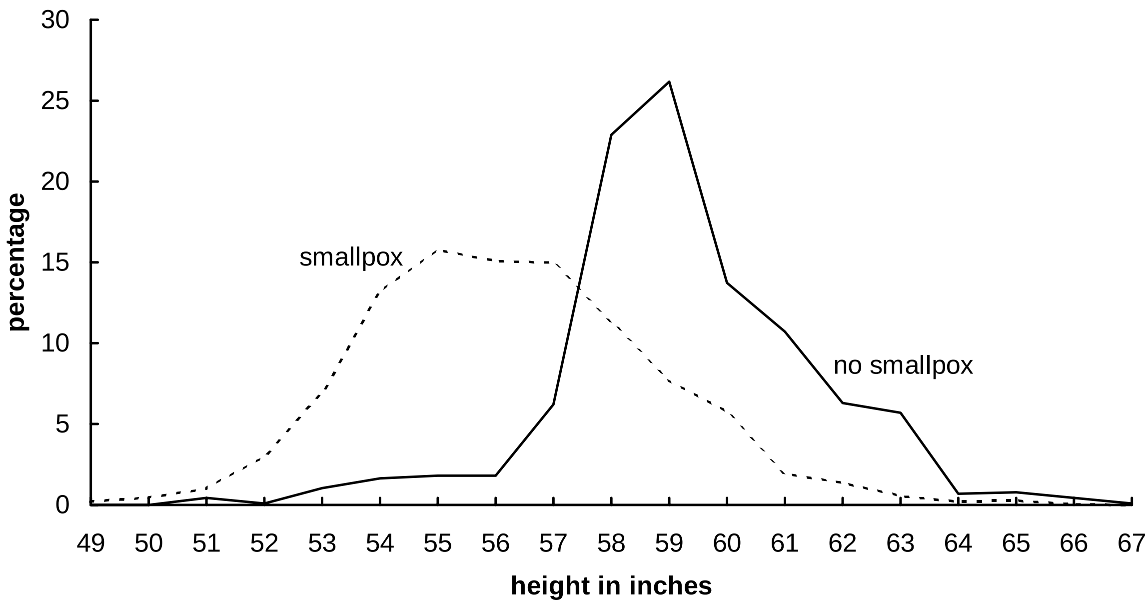


Figure 4. *Height of 16-year olds, full sample*

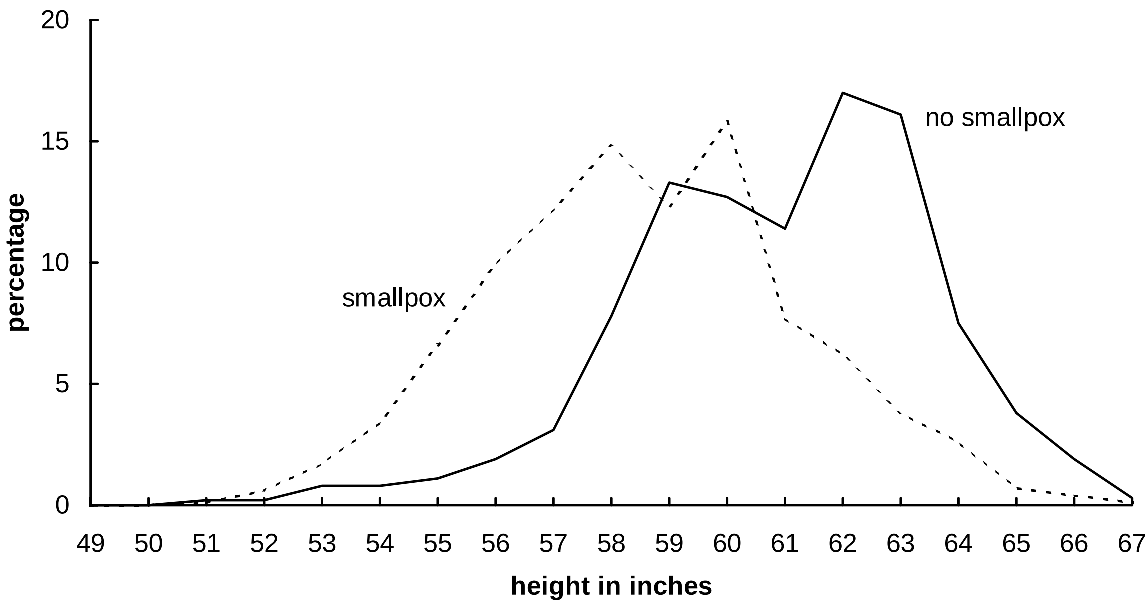
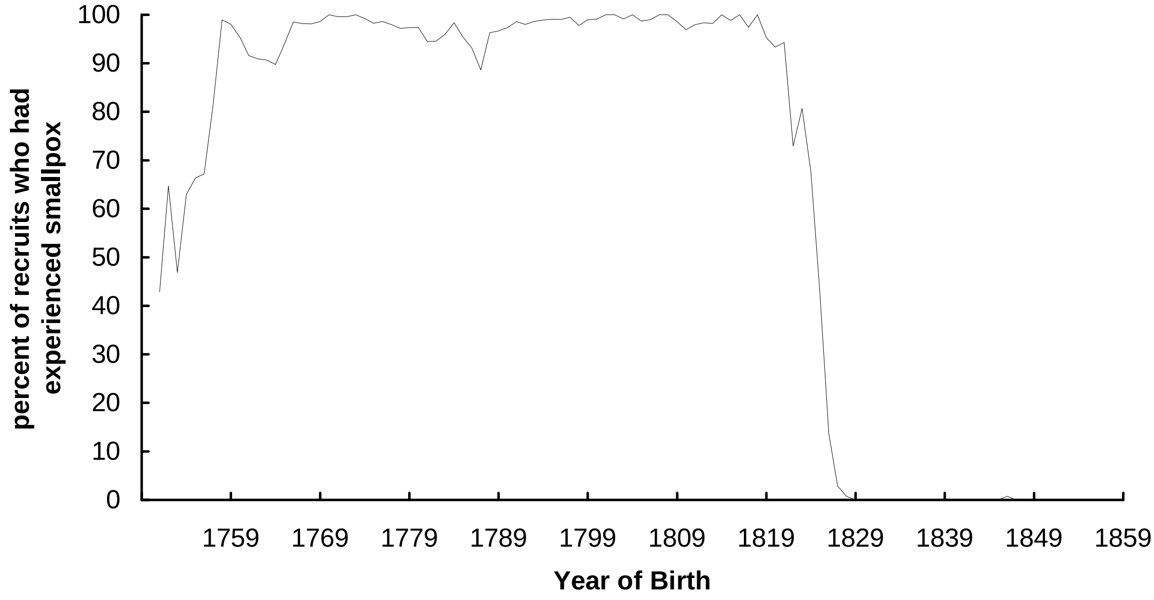


Figure 5. *Height of 17-year olds, full sample*

All distributions show a marked shift to the left for that part of the population that had suffered from smallpox. The difference between the modes for both groups implies a reduction in average height of three inches.[29] Yet the aggregates plotted in figures 1 to 5 suffer from one problem: the number of recruits affected by smallpox in our group varies considerably from decade to decade. In particular, as figure 6 shows, the disease was more prevalent during the first part of the period. Those who suffered from smallpox may not have been shorter only because they had survived a severe illness, but because they were also born in an earlier period, and so experienced a lower standard of living.[30]

Figure 6. *The incidence of smallpox amongst recruits to the Marine Society, 1751-1859*



We use two methods to overcome this potential problem. Firstly, we estimate a regression controlling for the standard of living. A correctly specified equation will eliminate the possibility that smallpox is significant merely because fluctuations in the incidence of smallpox coincide with other changes. We go on to test the result we obtain from our time series regressions by using cross-sectional analysis. This allows us to estimate the effect of smallpox over a short period, i.e. one in which there are few changes in the standard of living for smallpox to capture.

A simple way to overcome the objection that smallpox may simply be capturing changes in the standard of living is to include a real wage index in our regressions. Schwarz gives an annual index of income for builders in London.[31] As virtually all recruits entered the Marine Society in the second decade of their lives, we constructed an index based on Schwarz's, which, for each decade, gives an average of living standards during this and the preceding decade.[32]

Table 1 presents our results from regression analysis. We estimate two similar basic multivariate regressions, using variables contained in the Floud dataset, and controlling for age in different ways. In both cases the dependent variable is attained height, measured in inches. Independent variables consist of dummy variables for having suffered from smallpox, and being able to read and write. Living is a proxy for living standards based on Schwarz's real wage series for London. Since all boys are recruited in their teens, it gives the average of the Schwarz index during the preceding two decades. In addition, we use two alternative independent variables for age on recruitment: ageyears, the age of the recruit in years,[33] or age-specific dummies, e.g. age14. The former measures the average annual increase in height for boys in their teens - annual average growth rates for infants are, of course, much higher.[34] The age-specific dummies capture the additional height of a boy of that age, over and above the stature of his 13 year old contemporary, and avoid the assumption that adolescent height gain is linear.[35] In this case the intercept gives the average height of those recruits younger than thirteen. As we shall see, both formulations yield similar estimates for the effect of smallpox.

Table 1. *The determinants of height, full sample*

	(1)	*(2)*
Smallpox	-0.949	-0.959
	(-16.05)	(-16.69)
Ageyears	1.756	
	(166.35)	
Age14		2.301
		(58.77)
Age15		4.381
		(109.92)
Age16		6.391
		(132.81)
Age17		7.609
		(112.09)
Age18		8.109
		(74.82)
Age19		8.609
		(46.67)
Age20plus		8.663
		(23.14)
Read	0.287	0.283
	(7.14)	(7.27)
Write	0.605	0.556
	(15.39)	(14.60)
Living	0.0912	0.0800
	(50.24)	(44.86)
Intercept	20.541	44.056
	(78.82)	(198.44)
adj. R^2	0.613	0.638
S.E.	2.38	2.30
F	8,360.1	4,220.2
N	26,359	26,359

Notes: *t* statistics are in parentheses. The estimation technique is OLS.

It is apparent that personal characteristics are highly efficient predictors of measured height - the t-statistics are all large. The F-tests strongly reject the possibility that all coefficients are jointly zero, and the R^2 adjusted for the number of degrees of freedom is large in both cases.[36] Unsurprisingly, the effect of age is the largest factor determining height. As we would expect, both the ability to read and to write have a positive impact, reflecting the fact that these variables tend to indicate social status. Note that, if we multiply the coefficient on ageyears in regression (1) by 13 and add this to the intercept, the result is 43.4 inches, which is close to the intercept in regression (2) - 44.1 inches. Both figures refer to the height of a thirteen year old boy. The living variable adds between 7.6 and 10.6 inches to the height of our adolescents. This explains the low level of the intercept in regression (2) compared with figure 1.

In comparison with the results implied by figures 1-4, smallpox has a less severe effect on height. Yet even if we control for individual characteristics and changes in living standards, smallpox unambiguously reduces height. Both equations show t-statistics in excess of 16 on the smallpox dummy, which implies that we can be more than 99% certain that our result did not arise by chance. Also, the reduction in height caused by smallpox is large: our regressions imply that the average recruit who suffered from the disease was almost one inch smaller than his uninfected contemporary. Adding real wages as an independent variable demonstrates that our earlier results are robust to the criticism that the changing incidence of smallpox makes our smallpox dummy significant only because it mirrors the rise in the standard of living. These results also confirm that height acts as a broader measure of well-being than real wages, in precisely the way suggested by Floud et al.[37]

We can test this result by using cross-sectional analysis. This not only eliminates the possibility that the changing incidence of smallpox is capturing contemporaneous changes in the standard of living or other, unobserved, factors, but by using a period in which there are no changes in the official minimum height standard, we are also able to avoid the problem of changing truncation bias. Floud et al. list a number of such periods;[38] only one of these has at least 100 boys belonging to each group (those with or without smallpox): 1770-75. For this period, we again re-estimate both of our equations. The results are given in table 2.

Table 2. *The determinants of height, 1770-1775 (year of recruitment)*

	(3)	*(4)*
Smallpox	-0.518	-0.561
	(-2.69)	(-2.943)
Ageyears	1.44	
	(26.92)	
Age14		1.700
		(9.02)
Age15		3.778
		(16.98)
Age16		5.162
		(19.98)
Age17		5.759
		(15.15)
Age18		6.411
		(10.67)
Age19		7.236
		(11.70)
Age20plus		10.55
		(7.787)
Read	0.044	0.0171
	(0.22)	(0.09)
Write	0.407	0.421
	(1.89)	(2.00)
Intercept	34.410	52.862
	(42.919)	(247.39)
adj. R^2	0.432	0.450
S.E.	2.37	2.33
F	189.4	82.1
N	991	991
of which, with smallpox	795	795
without smallpox	196	196

Notes: *t* statistics are in parentheses. The estimation technique is OLS

Again, our two methods for correcting for age give very similar estimates of the effect of smallpox. Smallpox once again emerges as a statistically significant and negative factor determining height. It is worth noting that the cross-sectional data suggests that smallpox had a smaller effect on attained height than the time series analysis implies - a little over half an inch rather than just under an inch[39] In the next section we show that truncation bias implies that half an inch is an underestimate of smallpox's true effect on attained height.

This cross-sectional analysis reinforces our time series results. It demonstrates that the negative and significant impact of smallpox is not a spurious result arising from unobserved changes of other factors over time - the effect of smallpox on height is evident even in a very short period during which the truncation point stayed constant.

We have now established that, on average, smallpox reduces attained height. But our different methods have given different magnitudes for the size of the effect. We now show that the minimum height requirement leads regression analysis to underestimate the mean effect of smallpox on attained height. We know that the Marine Society had a minimum height requirement in operation at all times, and that both the standard itself, and the strictness of its implementation varied over time. Variations in the minimum height requirement were used by the Marine Society to regulate their supply of boys to match the demand that the navy placed for them. As such, it was not a trivial hurdle that all potential recruits could pass, but a real obstacle designed to reduce the number of boys accepted.[40] For anthropometric historians this leads to the problem of truncation bias: namely that estimating the average height from the observed (truncated) distribution will yield an overestimate of the true average: short people are systematically under-represented. The over-estimate will be more severe, the higher the proportion of people that are excluded.

By establishing that smallpox reduced the attained height of Marine Society recruits, we have shown that Marine Society recruits were drawn from two distinct populations: those who had had smallpox, and those who had not. The minimum height requirement applied to both populations without distinction. As those who had had smallpox were on average shorter, they were more likely to have been excluded by the minimum height requirement. We have already stated that the larger the proportion of people excluded, the larger the over-estimate of average height. It follows that, whilst truncation bias ensures that we over-estimate the average height of both groups, it means that we overestimate the height of those who had had smallpox to a greater extent. This in turn means that using uncorrected distributions leads us to underestimate the difference in height between the two populations, that is, to underestimate the effect of smallpox on attained height.

Truncation bias means that we cannot use the data as it stands to estimate the means of our two populations accurately, or even to the same degree of inaccuracy. The mode, however, is a more robust measure of central tendency than the mean since it is not influenced by the 'tails' of the distribution. We can use this property to assess the impact of smallpox on height using our cross-sectional data. In so doing, we are assuming that there are no other significant factors that differ within the population. Figures 7, 8 and 9 show the heights of 13, 14 and 15 year olds respectively.[41]

Figure 7. *Height of 13-year olds, 1770-75*

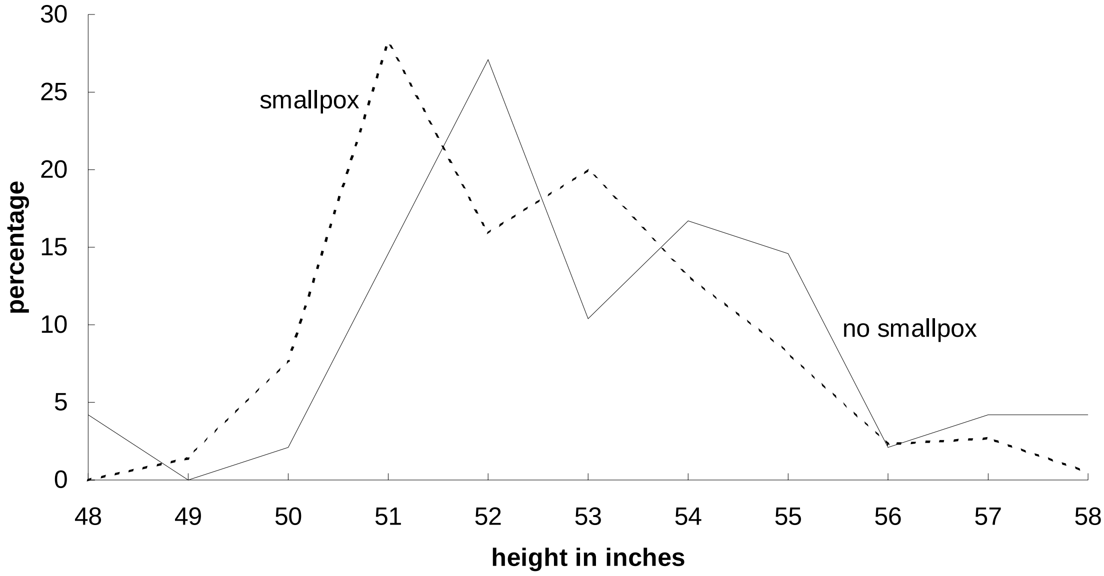


Figure 8. *Height of 14-year olds, 1770-75*

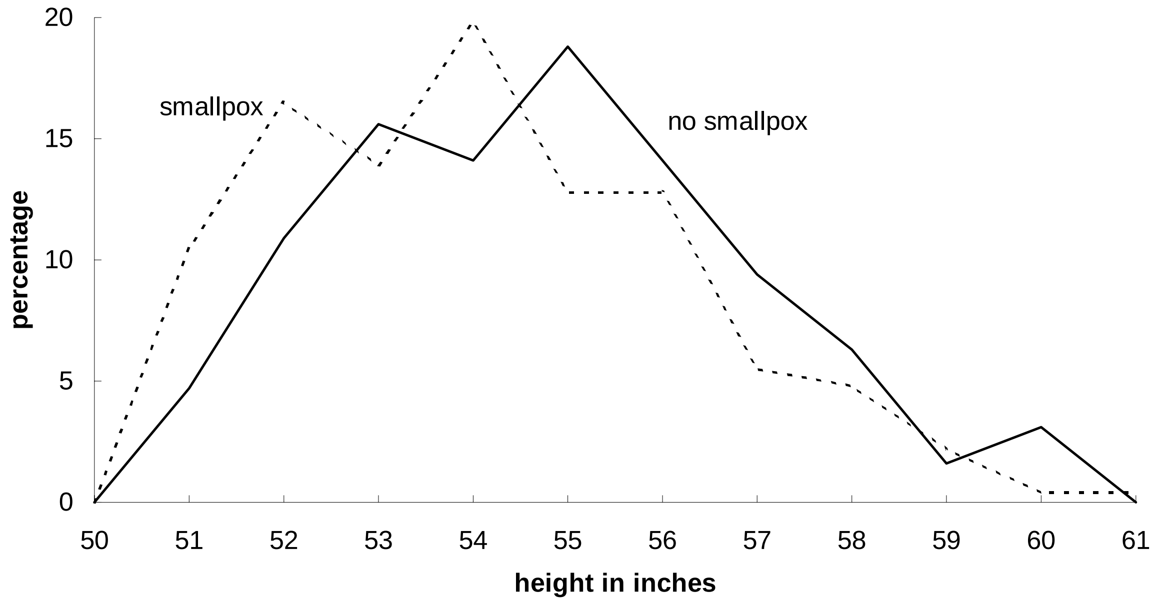
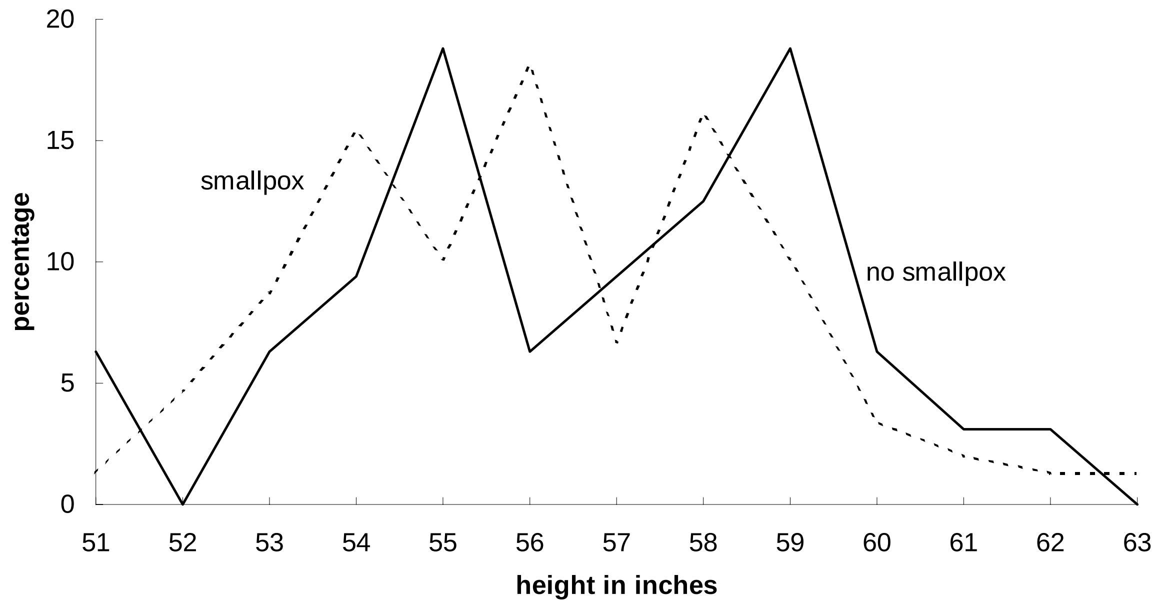


Figure 9. *Height of 15-year olds, 1770-75*



In all three cases, visual inspection shows that the height distribution for those who have had smallpox is to the left of that for those who have not had smallpox. For 13 and 14 year olds, the modal boy who has suffered smallpox is one inch shorter than his contemporary who has escaped the disease. These distributions are sufficiently unambiguous, and the mode a sufficiently robust concept to make this our best estimate of smallpox's effect on height attained at these ages.[42] Given that adolescent heights exhibit greater elasticity to all factors than adult heights,[43] we cannot be sure that all of this height loss will remain to adulthood.[44] The magnitude of this result means that smallpox is not only a *statistically* significant factor determining height, but it was also *historically* important:[45] accounting for one third of the height increase found by Floud et al. for fourteen year olds.[46]

III

The implications of our work are fourfold. They affect our understanding of the role of smallpox, the standard of living during the industrial revolution, the validity of the statistical techniques that have been used, and the applicability of anthropometric history itself.

By demonstrating that smallpox unambiguously reduced attained height, we have been able to re-establish a hypothesis originally proposed by Landauer. He claimed that the victory over smallpox, achieved in the first half of the nineteenth century, was an important factor raising heights.[47] Our result is contrary to the view of Floud and Wachter, who, in their first article on anthropometric history, suggest that the Landauer hypothesis 'is not so far supported by research on the Marine Society data,'[48] a conclusion they do not reverse in later work.[49]

Floud et al's rejection of Landauer's hypothesis is an important element in their analysis of the standard of living during the industrial revolution. They have argued that height is a useful measure of welfare in the broadest sense. They are at pains to stress that nutritional status should not be confused with calorie intake, let alone real income.[50] If we were, however, to extend McKeown's celebrated 'Sherlock Holmes' elimination technique to explain their finding that heights were rising steadily for those born in England between 1750 and 1820, their data and assessments would suggest that real wages were increasing.[51] Average nutritional status was on the rise and, according to the authors, there is little to suggest that claims on nutritional intake diminished. Housing conditions for the lower classes were poor, with no clear pattern of improvement during the late eighteenth or early nineteenth century apparent.[52] Equally, amelioration of the disease environment is conspicuous by its absence: 'In summarising the evidence of mortality and morbidity, it seems likely that there was some deterioration both in the late eighteenth century and, particularly, in the second quarter of the nineteenth century.' [53]

If, as Floud et al. seem to suggest, the claims on energy intake increased, or at best remained constant, only rising real incomes could have tipped the scales in favour of greater heights.

Floud et al. do not carry out a partial factor analysis with this conclusion in mind, but their work strongly suggests such an argument.

It is in this context that the role of smallpox is important. If some of the rise in heights of those born in the first quarter of the nineteenth century is attributable to the conquest of smallpox, this constitutes a substantial reservation to Floud et al's belief that their height data indicates improvements in diet.[54] Instead the rise in heights is seen as a consequence of improvements in both nutritional intake and the disease environment. But we make no claims that our results imply that well-being was falling: our best estimate of the effect of smallpox on the height of adolescents is one inch; Floud et al. find that the height of 14 year olds increased by a little over three inches between the middle of the eighteenth and the beginning of the nineteenth century.

The implications of our research into smallpox go beyond the interpretation of the standard of living during the Industrial Revolution. Human heights are one of the few phenomena in nature that have an almost Gaussian distribution.[55] Floud et al., for example, reproduce a graph showing the height distribution of Italian conscripts prior to the First World War to convey this basic fact.[56] Their QBE programme for correcting for left hand truncation bias is predicated on the assumption of normality in the underlying distribution.[57] Trussell and Wachter, who devised QBE, point to modern populations to establish that heights are normally distributed.[58] If this assumption about the underlying population does not hold, QBE is not a valid method for correcting for missing observations. In the case of pre-modern populations, it would be anachronistic to assume automatically that heights are normally distributed. Modern populations may approach their genetic potential since food is abundant and life-threatening diseases are all but absent.[59] Insults to nutritional status in the past were, however, large and had more severe effects as a significant proportion of the population was close to subsistence level. Hence, normality should not be assumed; as we have shown, the individuals in Floud et al.'s Marine Society data come from two distinct populations - those who had had smallpox and those who had not. There is no reason to expect that their aggregate will be normally distributed.[60] Under such conditions, QBE is not a reliable method for assessing the mean height.[61]

If the necessary conditions for QBE do not hold, the results of Floud et al.'s work must be qualified. But in practical terms, the implications of our findings on smallpox for their work are limited, because their Marine Society dataset contains information on the prevalence of smallpox. In the extreme case, this would allow the re-estimation, via QBE, for the two separate populations, those with smallpox, and those without.[62] In fact, the history of the disease means that this would be of limited value: Floud et al.'s data shows that, for most cohorts, the vast majority of individuals fell into one of the two populations. The two exceptions are the period that we have used for our cross-sectional analysis, 1770-75, and the period in which smallpox was actually eradicated, 1820-40. Our conclusions are an important caveat to the interpretation of the anthropometric history of the first quarter of the nineteenth century, but in no sense should they be taken as a wider criticism of the validity or results of Floud et al.'s work.

That is not to say, as Floud et al. themselves recognise,[63] that there is not more work to be done, both on the basis of their dataset, and on other information. For example, it has been noted that quite a few of the distributions in Floud et al.'s dataset appear to be bimodal, indicating that they were drawn from two distinct populations.[64] Whilst bimodality is less apparent in our frequency distributions for 1770-5,[65] we do not, as yet, have sufficient evidence that smallpox is the only cause of bimodality in the height distributions. Bimodality may be responsible for some of the peculiarities yielded by the use of the QBE program: until 1800, for example, 23 year olds are estimated to be taller than 24-27 year olds.[66]

Finally, our result that those who had not suffered from smallpox were taller than their contemporaries opens wider questions about the link between attained height and well-being, both for individuals and for populations as a whole. Certainly, those individuals who escaped smallpox following the development of inoculation could regard themselves lucky. Indeed, the resulting rise in height suggests that the conquest of smallpox in the early nineteenth century represented a major improvement in the standard of living for millions. But in an earlier era, in which smallpox was epidemic rather than endemic, it is less clear that a sixteen year old who had not had smallpox would count himself lucky. Smallpox, just like most other childhood diseases, is considerably more lethal for adults.[67] If an individual is sure to catch it at some stage, it is far better that they suffer it as a child than as an adult. If smallpox is epidemic, catching it as a child raises well-being, but paradoxically reduces attained height. The clearest case is that of migrants. We know that those who grew up in epidemiologically isolated rural areas were taller than their city born contemporaries,[68] but when they migrated to London they stood a high chance of catching smallpox on arrival.[69] As adults, they were unlikely to survive.[70] The cause of their higher stature - the absence of disease as a child - left them ill-prepared for city life.

A parallel argument can be made for society as a whole. Moving from a disease environment in which smallpox in epidemic to one in which it is endemic represents a rise in the level of well-being in two senses. Firstly, as mortality from smallpox is considerably lower for children than for adults, endemic smallpox will claim fewer victims. Secondly, as McNeill notes, 'Periodic outbreaks of such viral diseases as measles and smallpox could be very costly ... In such a circumstance, deaths among young adults and parents would be far more costly to the community than the deaths of an equal number of small children.'[71] In economic terms, the loss of a child represents a smaller loss of human capital than that of an adult; further, only adults can leave behind them widows and orphans.

This transition from an epidemic to an endemic disease environment has been termed *l'unification microbienne* by Le Roy Ladurie[72] - the unification of the globe by disease. It is this process that Kunitz identifies in the eighteenth century, arguing that the 'growth of population and increasing integration of national economies led to a change in the human-crowd diseases, notably measles and smallpox, transforming them into more benign childhood diseases.'[73] The importance of this process for anthropometric history cannot be overstated. As diseases cease to be life-threatening to adults but are instead suffered by virtually all children, attained heights will fall, that is, an *improvement* in the disease environment causes attained heights to *fall*.[74]

The implications of *l'unification microbienne* for trends in observed heights are considerable. This, rather than an impending Malthusian catastrophe, may explain the peculiar decline in heights found by Komlos in the eighteenth-century Habsburg monarchy.[75] He demonstrates that height reductions were most dramatic in those areas that were closest to Vienna, which were the first to be integrated into the national market.[76] It was exactly this process of market integration that Kunitz had in mind when he described the benevolent consequences of *l'unification microbienne*, and stunting may have been its necessary corollary. Far from being close to catastrophe, Komlos' data way well indicate that the area around Vienna was developing a more favourable disease environment. Unlike Floud et al.'s Marine Society dataset, his Habsburg dataset does not give information on recruits' experiences of disease. Without such information, it is not possible to establish if the trend in Austrian heights that he observes is caused by reductions in nutritional intake or changes in the disease environment.

IV

By demonstrating that smallpox reduced attained heights, this paper confirms the central tenet of anthropometric history: namely that height acts as an aggregate measure, capturing not only the effect of real wages via changes in nutritional intake, but also of the disease environment. We find that smallpox reduced the height of adolescents by one inch. As such, the discovery of the smallpox vaccination caused not just a rise in the standard of living for millions, but a rise that was unprecedented in medical history.[77] This in turn has implications for our understanding of the period in which smallpox was eradicated, 1820-40. In this period Floud et al find that the height of adolescents grew substantially - by around three inches[78]- which in the absence of any changes in the disease environment could be taken to imply significant increases in nutritional intake. By establishing that the eradication of smallpox would be expected to increase attained heights by one inch, we show that any inferred increases in nutritional intake in this period must be reduced accordingly.

Our work also suggests caution in the use of historical height data. Firstly, the statistical techniques that have been used extensively in anthropometric history, including both QBE and the Komlos-Kim method, rely on the assumed normality of historical heights. By demonstrating that recruits to the Marine Society formed two populations - those who had suffered smallpox, and those who had not - we show that this assumption does not hold in this case, and certainly cannot be made for all historical populations. This demonstrates the need for caution in assessing whether historical data does in fact conform to the criteria needed for the various statistical techniques to yield reliable results. Of course, suitable statistical techniques that were robust to non-normality in the data would provide an alternative solution to this problem. Finally, our knowledge of changing disease environments, combined with our finding that smallpox reduced height, shows that there are some circumstances in which height and well-being can move in opposite directions. This was not the case for Britain during the industrial revolution, but does have potentially large implications for continental Europe and the United States at this time, as both experienced *l'unification microbienne* at a later date. Only with additional information on the incidence of smallpox and other infectious diseases can height be used as a robust indicator of well-being in such countries.

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[2] Smith, *Speckled monster,* p. 15.

[3] Macaulay, *History of England*, II, p. 498.

[4] Landers, *Death and the metropolis,* p. 95 ff.

[5] Razzell, *Conquest of Smallpox*, pp. 118-9; Smith, *Speckled monster*, p. 173.

[6] The classical studies are Borah and Cook, *The Aboriginal population of central Mexico in 1548*; idem, *The Indian Population of Central Mexico, 1531-1610* and idem, *The Aboriginal population of central Mexico on the eve of the Spanish conquest*. See also Brooks, ‘Revising the conquest of Mexico’ and McCaa, ‘Spanish and Nahuatl views’.

[7] ESRC SN 2134 (Long-term changes in nutrition, welfare and productivity in Britain: physical and socio-economic characteristics of boys recruited into the Marine Society, 1770-1873).

[8] Komlos uses smallpox vaccination as a independent variable, but he does not test for the relationship between the disease itself and stature, Komlos, 'Secular trend', p. 130f.

[9] Floud, Wachter and Gregory, *Height, health and history*, tab. 4.1, pp. 140-9, tab. 4.3, pp. 167-9.

[10] Ibid., p. 275ff; Fogel, 'New sources and new techniques', p. 13ff.

[11] Crafts, 'Cliometrics, 1971-1986: A Survey', p. 189.

[12] Floud, Wachter and Gregory, *Height, health and history*, p. 17; Fogel, 'New sources and new techniques', p. 7.

[13] Height increases amongst citizens of some Western industrialised countries seem to have come to an end; Tanner, *Foetus into man*, p. 159.

[14] ibid., p. 161; Floud, Wachter and Gregory, *Height, health, and history*, p. 135.

[15] Brinkman, Drukker, and Slot, 'Height and income'. For a critique of this paper, see Mandemakers and Van Zanden, 'Height of conscripts'. The most important works in anthropometric history include Floud, Wachter and Gregory, *Height, health and history*, Fogel, 'New sources and new techniques'; and Komlos, *Nutrition and economic development.*

[16] Floud, Wachter and Gregory, *Height, health, and history*, p. 304.

[17] ibid., tab. 4.1, pp. 148-9, fig. 7.1, p. 289. These - and other - results have generated some controversy, however, see Komlos, 'Secular trend'.

[18] Floud, Wachter and Gregory, *Height, health, and history*, compare tab. 4.1, pp. 148-9 to tab. 4.3, pp. 167-9; fig. 7.1, p. 289.

[19] They state that 'This finding is the main contribution of this book to the lengthy debate about the standard of living of the British working class.' ibid., p. 326.

[20] ibid., p. 288; Williamson, *Did British capitalism breed inequality?*, tab. 2.8, p. 17; Lindert and Williamson, 'English workers' living standards', tab. 5, p. 13.

[21] Floud, Wachter and Gregory, *Height, health, and history*, pp. 304-5, Williamson, *Did British capitalism breed inequality?*, tab. 2.8, p. 17, p. 32, n. 12.

[22] For 'the 1820s onwards, ... simply to reject the real wage evidence out of hand would be foolish.' Floud, Wachter and Gregory, *Height, health, and history*, p. 304.

[23] ibid., p. 305. Williamson leaves open the door to such a possibility: Williamson, *Did British Capitalism Breed Inequality?*, p. 19.

[24] Recent research on Kenyan children demonstrates the severe effect that childhood diseases can have on nutritional status. Children infected with measles saw their energy intake fall by 75% during the attack, resulting in a negative average overall balance of 169kJ/kg per day; see Duggan, Alway, and Milner, 'Nutritional cost of measles', p. 64. See also Duncan, Scott, and Duncan, 'Smallpox epidemics' p. 255; Landers, 'Mortality and metropolis', pp. 69, 72.

[25] Floud, Wachter and Gregory, *Height, health, and history*, p. 164.

[26] ibid., pp. 164-5.

[27] ibid., pp. 118-9; Wachter and Trussell, 'Estimating historical heights'; Komlos and Kim, 'Estimating trends'. The 'reduced sample maximum likelihood estimation' technique (RSMLE) also developed as part of Floud et al.'s project represents a different way of correcting for truncation which uses *a priori* information on truncation points; see Wachter and Trussell, 'Estimating historical heights', Floud, Wachter and Gregory, *Height, health, and history*, pp. 119-27.

[28] Floud, Wachter and Gregory, *Height, health and history*, p. 13

[29] The smaller difference for 13 year olds is probably due to the limited sample size - since only 272 recruits in this age group had not suffered from smallpox, some intervals contain merely six observations. The same result can be obtained from a simple multivariate regression. When dummy variables for smallpox, the ability to read and to write, as well as age in years are used as explanatory variables, the average reduction in height is estimated as 2.568 inches. The t-statistic on the smallpox dummy is 58.79, implying less than a 0.01% probability of the result arising by chance.

[30] It is *possible* that some of the recruits coded as having had smallpox were actually inoculated, i.e. given a mild strain of the disease. This would imply that their nutritional status was less adversely affected in . If this were the case, we would expect the distribution of those people recorded as having smallpox to be bimodal. This is not the case in figures 1 to 5. Even if this were the case, it would serve to reinforce our results. Our finding of a significant difference between those recorded as having had smallpox and the control group (no pox) would *understate* the true difference between those who genuinely had smallpox and those who did not have any form of the disease - those merely inoculated improve the 'average' for the pox group. We wish to thank Peter Razzell for raising this point.

[31] Schwarz, 'Standard of living'.

[32] We cannot overcome the objection that smallpox may simply be capturing rises in the standard of living by using a set of decade dummies. This is a standard remedy: changes in the coefficients decade by decade are then used as indicators of changes in living standards. For our purposes, though, this would be logically flawed - the advantage of the decade dummy technique is that it measures residual changes in mean height that are not explained by shifts in factors such as age distribution. This residual captures the net effect of all other factors on nutritional status, such as income, weather, housing conditions - and disease. Since we are interested in assessing the impact of smallpox, it would be methodologically incorrect to also include decade dummies. We would expect any regression using both decade dummies and smallpox as independent variables to suffer from multicollinearity. The eigenvalue test for multicollinearity confirms the presence of considerable multicollinearity in such a regression. Correlations between the decade dummies and SMALLPOX are considerable. Almost all of the decade dummies have large fractions of the variance associated with eigenvalue 14 - the single most important eigenvalue for SMALLPOX. This demonstrates that multicollinearity is clearly present. Eigenvalue 13, which accounts for over 33% of the variance of SMALLPOX, is also important for DEC1790, DEC1800, DEC1820, DEC1830, DEC1840. Full details are available from the authors. Cf. Belsley, Kuh and Welsch, *Regression Diagnostics.*

[33] Age in months is not, however, significant.

[34] Floud, Wachter and Gregory, *Height, health and history*, fig. 1.2, p. 10, fig. 1.3, p. 11. The total additional growth caused by the early infant growth spurt is captured in the intercept term, which is of no further interest to us.

[35] ibid., fig. 1.2, p. 10

[36] This is particularly noteworthy in comparison with the results reported by Komlos; see Komlos, *Nutrition and economic development*, p. 243, Komlos, 'Secular trend', p. 131.

[37] Floud, Wachter and Gregory, *Height, health and history*, p. 304; we discuss some reservations in section III, below.

[38] ibid., p. 164.

[39] Given the size of the standard errors, we can only be certain that the difference between the coefficients in tab. 1 and 2 is 0.1 inches.

[40] Floud, Wachter and Gregory, *Height, health and history*, p. 164

[41] Problems of small sample size prevent us from using other age cohorts. For example, for 16 year-olds without smallpox, there are only three height categories with more than two observations.

[42] We make no claims that the size of the effect of smallpox will be invariant across time. For example, there is evidence that smallpox became more virulent during the seventeenth century, leading to higher fatality rates, Appleby, 'Epidemics and famine in the little ice age', p. 69, Creighton, *History of epidemics*, II, p. 434; Duncan, Scott, and Duncan, 'Smallpox epidemics', p. 255. For a general taxonomy of the different types of smallpox and their effects, see Smith, *Speckled monster*; app. 1, pp. 179-82.

[43] Floud, Wachter and Gregory, *Height, health, and history*, p. 17, fig. 7.1, p. 289.

[44] It must be borne in mind that even severely stunted individuals may experience catch-up growth if they resume an adequate diet. Cf. Tanner, 'Growth as a target-seeking function'. American slaves are a case in point; see Steckel, 'Peculiar population', pp. 721-6, Floud, Wachter and Gregory, *Height, health, and history*, pp. 246-7. Despite this, we find no evidence in our cross-sectional data that those who had had smallpox grew at a significantly faster rate between the ages of 18 and 25 than those who had not had smallpox.

[45] See McCloskey, *Rhetoric of economics*, pp. 154-73, on this often neglected distinction.

[46] Floud, Wachter and Gregory, *Height, health and history*, fig. 7.1, p. 289.

[47] Landauer and Whiting, 'Infantile stimulation and adult stature', p. 1007ff; Landauer, 'Infantile vaccination', pp. 499-503. Strictly speaking, Landauer argues that the disappearance of smallpox increased heights because of the stimulating effect of the vaccination itself. Our evidence suggests that the rise in heights is caused by improvements in net nutritional status.

[48] Floud and Wachter 'Poverty and physical stature', p. 440.

[49] Floud, Wachter and Gregory, *Height, health, and history*, pp. 295-6.

[50] Ibid., pp. 18-9.

[51] McKeown, *Modern rise of population*, p. 15ff.

[52] Landers, 'From Colyton to Waterloo', p. 115-7; Landers, *Death and the metropolis*, pp. 68-70, 101; Floud, Wachter and Gregory, *Height, health, and history*, pp. 298-300, Williamson, *Coping with city growth*, ch. 9.

[53] Floud, Wachter and Gregory, *Height, health, and history*, p. 298.

[54] Ibid., p. 302.

[55] Of course, a Gaussian distribution strictly implies that there exist people of negative height. This is obviously not true.

[56] Floud, Wachter and Gregory, *Height, health, and history*, fig 1.4, p. 14.

[57] Wachter and Trussell, 'Estimating historical heights', pp. 279-93.

[58] In their original article, Wachter and Trussell suggest that both RSMLE and QBE be used on the same population; only if results from both methods indicate equivalent trends should the results be regarded as robust. Floud et al. do not adopt this cautionary approach.

[59] Height increases amongst the citizens of some Western countries seem to have come to an end, suggesting that they are approaching their genetic potential. Cf. Tanner, *Foetus into man*, p. 159.

[60] See Komlos, 'Secular trend', p. 122 for examples of bimodality.

[61] The same criticism applies to the Komlos-Kim methods, which also assumes normality. Cf. Komlos and Kim, 'Estimating trends', p. 117f.

[62] Whilst the British Army and Royal Marine data does not contain such information, the Marine Society data would allow us to chart the course of smallpox accurately. It should be noted that, in principle, smallpox is only one of the many diseases which may have caused deviations from normality in the underlying populations.

[63] Floud, Wachter and Gregory, *Height, health, and history*, p. 325.

[64] Komlos, 'Secular trend', p. 122.

[65] Multimodality is only apparent in the frequency distribution for 15 year olds. We suspect that this is caused by small sample problems: whereas N_{13} = 268 (220 with, 48 without) and N_{14}=337 (273 with, 64 without), N_{15}=181 (149 with, 32 without). Each of the two modes in the no smallpox distribution represents just six people.

[66] Floud, Wachter and Gregory, *Height, health, and history*, fig 7.1, p. 289.

[67] In Aynho, Northamptonshire in 1723-24, it was found that those aged 0-10 had a fatality rate of 14.3%, and those aged 10-20 a fatality rate of 8.5%. For those between 20 and 30, the respective fig. was 24%, rising to 25% for those 30-40. Over the age of 40, the fatality rate was 40%. Razzell, *Conquest of smallpox*, p. 126. Contemporaries were aware of the special danger to adults and went to great lengths to avoid the danger of infection. As one witness in court remarked: 'The smallpox was in our family, and I never had it, so I had my victuals out of the house.' Robert Randall, 19 years old, Old Bailey Sessions Papers, case no. 103, 1760 (crime committed on 3 December, 1759).

[68] Floud, Wachter and Gregory show that recruits who had worked with animals were considerably taller than those who came from other occupations. *Height, health, and history*, fig. 5.7, p. 220 Cf. also S. Nicholas and R. H. Steckel, 'Tall but poor: nutrition, health and living standards in pre-famine Ireland' (National Bureau of Economic Research, Historical Paper 39, 1992).

[69] Landers, *Death and the metropolis*, pp. 121-2, Landers, 'Mortality and metropolis' p. 69. Recent research confirms that smallpox was endemic in a number of large towns during the eighteenth century, while small towns suffered from periodic outbreaks of epidemics (approximately every five years), Duncan, Scott, and Duncan, 'Smallpox epidemics', pp. 260, 265. Their evidence suggests that smaller outbreaks did also occur in the larger cities, but with a much higher frequency, causing much lower overall volatility of mortality rates.

[70] 'Innumerable examples illustrate the disastrous repercussions of new disease encounters for previously inexperienced populations.' McNeill, 'Migration patterns', p. 27.

[71] ibid., p. 31.

[72] Le Roy Ladurie, 'A concept'. The model of a relatively stable and high 'background' level of mortality in the towns, and more volatile death rates in rural areas was first proposed by McNeill, 'Migration patterns'. Wrigley and Schofield, *Population history*, pp. 677-81 argue that this transition took place in sixteenth- and seventeenth-century England.

[73] Kunitz, 'Speculations', p. 349; Landers finds that smallpox burials fall as a percentage of all burials in London Bills from a peak of 10.5% in the 1760s to 7.3% in the 1800s and to 3.5% in the 1820s; Landers, 'Mortality and metropolis', tab. 10, p. 72.

[74]Note that the improvement in the disease environment does not imply that the number of people catching the disease fell; rather it implies that those catching the disease did so at an age when they were better able to survive it.

[75] From which it was, according to Komlos, only narrowly rescued by enlightened government intervention; Komlos, *Nutrition and economic development*, p. 160.

[76] Komlos argues that Austrian peasants reduced their own consumption as a result of market integration; ibid., p. 106.

[77] Razzell comes to the same conclusion on the basis of reductions in mortality, *Conquest of smallpox*, p. 158

[78] Floud, Wachter and Gregory, *Height, health, and history*, fig 7.1, p. 289.