Four Essays on the Biological Standard of Living in Europe and America in Historical Perspective

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„Nur wer die Vergangenheit kennt, hat eine Zukunft!“

Wilhelm von Humboldt (1767-1835)

Preface

The aim of this dissertation is to contribute to the understanding of the secular development of human well-being and its determinants in the 18th and 19th century. We do so by considering the biological aspect of the multilayered idea of the standard of living. The concept of the “biological standard of living” as defined by Komlos in 1989 intends to gauge the degree to which a population’s biological processes are affected by socioeconomic and epidemiological factors. The approach points out that the quality of life is determined by more than pure economic power and it particularly stresses the importance of health for human well-being. Physical stature is a variable often used to measure the biological status of a population because it is “an indicator of how well the human organism fared during childhood and adolescence in its socio-economic and epidemiological environment" (Komlos and Snowdon 2005).[1] Height reflects the prevailing environmental conditions since genes indeed set the height potential of an individual, but it is the environment which determines just how much of this potential will, in fact, be realized. It is estimated that c. 20 percent of individual variation in physical stature arise from environmental factors (McEvoy and Visscher 2009, Silventoinen 2003). Hence, we are able to infer information on the general living conditions from a population’s average height trend.

Socio-economic and epidemiological variables affect human height because they influence the nutritional status and consequently the growth process of adolescents. The nutritional status of a person is defined as the balance of his body’s nutritional input and output. The intake is determined by the quantity, quality, and balance of the ingested food. In case of a youth this in turn is influenced by the purchasing power of his family. Height thus reflects the economic situation of a person during youth. The output on the other hand is the sum of the energy needed by the human body for maintenance, repair, work, and growth (Bogin 2001). Simply put, growth gets the energy that is left after the body performed all the other tasks. If

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[1] Other indicators of the biological standard of living are longevity or morbidity.

caloric input is scarce, the body will reallocate the available energy to maintenance in order to ensure survival. Growth has the lowest priority and this fact may be reflected in shorter stature. How much energy is left for growth -- given a fixed input -- thus depends on individual characteristics such as age and sex which affect how much calories are needed for maintenance but it is also affected by personal experiences such as diseases (repair), or physical activity (work). As a consequence, a population's average height does not only reflect the economic but also the epidemiological situation.

Data on physical stature are a valuable source of information because of their availability, reliability, and comparability. Data on human body size are available for periods as early as the beginning of the 18th century and they also comprise neglected social groups such as housewives, subsistence peasants, and slaves (Steckel 1995, Komlos 1992). In contrast to that, traditional measures of welfare such as real wages do not exist for periods that early (or only in dubious quality) or only capture the situation of participants of the labor markets. Knowledge derived from average height is also particularly reliable because a person's stature reflects his living conditions from conception to maturity and is not only snapshot data recorded at one reference date. Thus, height data are less susceptible to outliers in living conditions (Komlos and Kriwy 2002). Height data also lend themselves to comparison, even in the case of international analyses, obviating any need to convert them into a uniform measure (Koch 2012).

The French doctor Louis-René Villermé was the first to establish the link between the prosperity of a population and its height in 1829 (Eveleth and Tanner 1991). 140 years later the historian Le Roy Ladurie used data of French soldiers to investigate the possible socio-economic determinants of body size (see: Ladurie et al. 1969).[2] However, the birth of anthropometric history as a distinct field of research lies in the mid-1970s, when Fogel and Engermann (1974) published their study on American slaves' nutritional status. Subsequently, several anthropometric

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[2] For a more detailed overview on the developments in the field of anthropometry, see Steckel (1995).

studies appeared, based on data sets originally created to depict historical American and European mortality trends (Cuff 1995). From that starting point, research gathered speed. About five studies per year were published from the late 70s to 1994 but c. 23 publications from 1995 to 2008 (Steckel 2009).

Among the most remarkable findings are the “early modern growth puzzle” (Komlos 1998), also called “antebellum puzzle” in the American context (Komlos 1996), the insight that living conditions in the pre-revolutionary American colonies were better than those in Europe (Komlos and Küchenhoff 2012), and that the Americans squandered that same height advantage in the course of the last century (Komlos and Baur 2004).

Each chapter of this dissertation is related to one specific region of the world.

Chapter one estimates secular height trends of Irish and Scottish recruits born between 1740 and 1840. Splines based on truncated power functions are used to allow for a flexible and smooth representation of the trends. Our main finding is that physical stature declined over the course of time in both cases, but not strictly monotonically. While Scottish soldiers were taller than their Irish counterparts, the height trends of both nations tended to be similar, featuring three distinct periods: a decrease in the second half of the 18th century, a rebound in the first two decades of the 19th century; followed by a steep, long-term decline over the next twenty years. Over the course of the hundred-year period under consideration, the average human size of Irish and Scottish men declined by c. 3 and 5 cm, respectively. This pattern is also quite similar to the one previously found for English recruits by Komlos and Küchenhoff (2012).

Chapter two examines the development of the biological standard of living, proxied by average stature, in the 18th century Holy Roman Empire and compares the result with the height trends of neighboring countries as well as with traditional monetary indicators. The basis of our analysis is a large data set of 19.425 recruits to the Habsburg Infantry Regiments 22, 25, 41, and 46. We find that the height of the soldiers decreased by c. 1.5 in. between 1730 and 1780. This decline is consistent with the adverse development of German real wages as calculated by Pfister (2010) and Allen (2001). It is also in line with the height trends of the European neighbors who experienced a decline in height in the 18th century as well. We conclude that the deterioration of the biological standard of living can be explained by three developments: increasing socio-economic inequality, Malthusianism, and, worsening climate.

Chapter three analyzes whether there are spatial patterns in the relationship between explanatory variables and the height of U.S. Union army recruits born in the pre-Civil War period. Furthermore, we examine whether the local disease environment and direct access to food influenced physical stature. We also estimate the secular trend in height between 1823 and 1860. We find that average height of native recruits decreased by c. 2 inches in the pre-war period. In addition, our results indicate that, among other things, immediate access to food, vicinity to transportation, and the epidemiological environment significantly affected average height. The influences of those variables on human size are, however, not globally equal. Spatial analyses reveal geographical patterns in the relationship between the explanatory variables and height. Being a farmer was related to a significant height advantage in the Dairy Belt but only to a minor one in the Cotton Belt. Access to transportation offers a height advantage in the more densely populated areas in the east but a height penalty in the rural western areas.

The fourth chapter is strikingly different from the first three. It determines the effect of education and income on the relationship between BMI and mortality and between physical stature and mortality. The analysis is based on health data collected between 1963 and 1975 by the Norwegian National Health Screening Service. C. 1.7 million subjects were recorded and the Norwegian statistics bureau linked this information to the national death records and to socio-economic information. We use Cox proportional hazards regressions in order to evaluate whether adding income and education as covariates to the regression affects the relationship among BMI, height, and mortality. Previous findings and insights are either not present or ambiguous. We find that the omission of socio-economic status variables does not significantly bias the effect of BMI on most causes of death. The same is true for the cause-effect triangle of height, socio-economic status and mortality.

While the following four chapters jointly compose one single dissertation, each of the chapters is intended to constitute an independent paper. Therefore, the dissertation contains some degree of repetition. However, since each chapter relates to a different country and a distinct main research question, the overlaps are minor. The reader is thus recommended to read the whole thesis instead of skipping chapters.

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Secular height trends in Ireland and Scotland, 1740-1840

We analyze the secular height trends of Irish and Scottish recruits born between 1740 and 1840. Splines are used to allow for a flexible and smooth representation of the trends. Our main finding is that height decreased over time, in both cases, but not strictly monotonically. While Scottish recruits were as a rule taller than their Irish counterparts, the height trends of both nations tended to be similar, featuring three distinct periods: a decrease in the second half of the 18th century, a rebound in the first two decades of the 19th century; followed by a steep, long-term decline over the next twenty years or so. Over the course of the hundred-year period under consideration the average height of Irish and Scottish men declined by c. 3 and 5 cm, respectively. This pattern was also quite similar to the one previously found for English recruits.

The influence of market integration on average height was also analyzed. Every 100 km road distance between the conscript's place of residence and the nearest town translated into an additional 0.6 cm in height.

1.1 Introduction

The fact that most quantitative studies of trends in the standard of living prior to the 20th century are not comprehensive or representative is in large part due to a lack of monetary data. This is certainly so for 18th- and early-19th- century Ireland and Scotland; reliable, comprehensive real-wage series are out of the question in both cases (Mokyr and Ó Gráda, 1988, Gibson and Smout 1995). An alternative quantitative measure, however, is provided by the concept of the biological standard of living (Komlos 1989): an extension on the standard measures, in that it aims to gauge the degree to which a population's biological processes are affected by environmental and socioeconomic factors.

The biological standard of living is generally proxyed by the average height of the population in question, since it provides a reflection of the prevailing environmental conditions. Genes determine the height potential of an individual; the environment determines just how much of this potential will, in fact, be realized. It is estimated that c. 80 percent of the individual height variation is attributable to genetic predisposition; c. 20 percent to environmental factors (McEvoy and Visscher 2009). In the case of our sample, the absence of any genetic adaptations in the population means that its variation over time was purely a function of environmental factors.[1]

Medical research has confirmed that human stature is influenced by nutritional intake as well as by the epidemiological environment and thus can be used as a proxy for the biological standard of living (Komlos 1987, 1992). As a measure of the standard of living, height data offer advantages. First, written information about heights are available for periods as early as the beginning of the 18th century (Steckel 1995). Second, because they reflect living conditions for the first twenty years of life and not just at a given reference date, they are less susceptible to outliers (Komlos and Kriwy 2002). Third, height data lend themselves to comparison, even in the case of international analyses, obviating any need to convert them into a uniform measure. Available, reliable, and easily comparable,

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[1] This is because genetic adaptation occurs over the course of not one but many centuries.

height data are the obvious choice for a proxy in the analyses presented in the following pages.

There is quite a consensus in the field of anthropometry that during the 18th and 19th centuries agricultural populations tended to be taller than urban or industrial ones removed from the source of nutrients. Hence, the Irish were on average taller than their contemporaries elsewhere in Europe. Komlos and Cinnirella (2007) estimate the heights of 18th-century American soldiers of Irish and of English descent at 168 and 165 cm, respectively. Nicholas and Steckel (1991) confirm this finding in their study of 18th-century convict and indentured servants. Mokyr and Ó Gráda (1988) report that Irishmen recruited by the East India Company were about a third of an inch taller than their English counterparts. Female convicts, who were born in the second half of the 19th century, and transported to Australia permit Oxley (2004) to report that the Irish height advantage extended to women. It was c. 1.2 cm.

There is a consensus that the height advantage of the Irish was due chiefly to the nutrition provided by the potato, their primary staple (Oxley 2004), supplemented by dairy products. In addition, food could be prepared inexpensively thanks to plentiful supplies of fuel, in the form of peat (Ó Gráda 1991). Nicholas and Steckel (1992) suggest that it was not just a nutritious diet but also epidemiological isolation that account for the Irish height advantage: a hypothesis in line with the finding of Komlos (1985, 1987) that proximity to food sources offered an important nutritional, and hence biological, advantage prior to industrialization; the fact that in the second half of the 18th century much of the Irish population was unaffected by industrialization and urbanization is thus reflected in the Irish-English height difference (Komlos 1993a). Further evidence in support of this thesis is provided by research indicating that preindustrial populations were often taller than those undergoing industrialization (Nicholas and Steckel 1992, Komlos 1989).[2] Only the

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[2] Nicholas and Steckel (1991) also find that during the Industrial Revolution an age-height gap opened between English and Irish adolescents, whereas adult rural Englishmen were no shorter than their Irish compeers: a finding that supports the thesis that industrialization, and the consequent urbanization, had an adverse effect on biological growth; however, there is evidence that the average height of the poorer sectors of the English population had already begun to decline (Komlos 1993b).

living standard of the upper class was unaffected by such adverse developments because of their high income (Komlos 1998, 1990).

Scotsmen were also taller than the English. Nicholas and Steckel (1997) conclude -- on the basis of convicts transported to Australia between 1817 and 1840 -- that they were as a rule taller than their neighbors to the south. Riggs (1994) finds that during the early 19th century the Scottish suffered a decline in their biological standard of living; Komlos (1993b), however, contends that this decline, which occurred in Ireland as well, did not begin until the 1830s, and somewhat later in England, and that it was due to Malthusian population pressure.

While our data source -- 1740 to 1840 -- British military records -- is one that was previously gathered and studied by Floud et al. (1990), our analyses apply more advanced statistical methods to estimate the secular height trends and combine the army and marines data in a more careful fashion. In addition, it also expands the urban height penalty discussion by using distance to the nearest town or port as a measure of market integration instead of applying a town dummy variable.

1.2 Data

Data Source

Roderick Floud and his colleagues compiled a dataset consisting of the records of approximately 130,000 British recruits, drawn from the description books of the Army and Royal Marines, held at the Public Record Office (1986).[3] We drew our data from this data set, consisting of two sub-samples, the records of approximately 10,000 Scottish recruits and about twice as many Irish ones. The English part of the sample was analysed recently by Cinnirella (2008) and Komlos and Küchenhoff (2012).

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[3] Roderick Floud, 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.

Characteristics of the data

During the 18th and 19th centuries, entry into the British military -- both the Army and the Royal Marines -- was voluntary. Since service meant a long-term commitment at a low pay, it was viewed as the employer of last resort, and to fulfill its quota was therefore obliged to accept volunteers who would have been rejected by other employers (Floud et al. 1990). Karsten (1983) describes just how dire the situation was when he claims, “The Irish soldier among Britain's 'regulars,' then, was typically a Catholic of low income, poorer than those who took up arms against Britain from time to time, and poorer than those who did not serve,” no doubt economic distress played an important role in young men choosing to enlist, and it therefore follows that these hungry young might not be representative of the Irish or Scottish population. The dire economic situation in Ireland accounted not only for the fact that the Irish composed a disproportionately large percentage of British servicemen but also for their willingness to set aside their hostility toward the English and do their duty as soldiers (Bartlett 1997).

The need for recruits varied over time -- soaring, for instance, during the Napoleonic Wars (1803-1815) -- and the British military had to adapt its enlistment process accordingly. Minimum height requirements were adjusted or ignored, the length of service was shortened, the base pay was increased, and bonuses were paid. These improvements in the extrinsic incentive structure as well as the introduction of a ballot system probably altered the social composition of the military, and could have affected mean heights. What is more, patriotic fervor may have prompted some adolescents (who had yet to achieve their full growth) to lie their way past the minimum-age requirement thereby causing an upward bias in average reported age and a downward bias in average actual adult height (Komlos 1993b). The fact that war was imminent, and hence there was an increased risk of getting killed, may have dissuaded others. Cinnirella (2008) deals with this dilemma in the case of English recruits, by undertaking two independent estimates of recruitment trends, before and after the introduction of the ballot system. In a further regression Cinnirella uses a war dummy variable to control for the effect of the upcoming war.

We have chosen a different strategy: making estimates for the entire period under consideration (1740-1840), without interruption. We feel confident in this approach because we have socio-economic background information (occupation before recruitment) to allow us to control for changes in the military's socio-economic composition to some extent. The unpopularity of recruitment into the new militia by ballot forced the government to almost immediately fall back on the old system, of volunteers and substitutes in Ireland (Bartlett 1983). As a consequence, there was probably not such a dramatic change in recruitment practices in Ireland as there was in England. The Scots, who were regarded as unreliable, were not even allowed to set up ballot militias (Devine 2001). Third, in reality young Irishmen and Scotsmen had no reason to feel any patriotic identification with the English who were often seen as oppressors. Therefore we believe that a continuous estimation of the trend is most appropriate for our analysis.

Place of birth

We have data on the county of birth for the entire sample of recruits, and on the more detailed scale of the town or village of birth for a subsample only. We use all 30 county dummy variables to the regression because aggregation means a loss of precision, whereas the loss of 30 degrees of freedom is negligible relative to the several thousand observations available. Sufficient observations for each county are available.

Occupational information

The occupational status of the recruits pertains to their socio-economic background during youth, since there was little intergenerational mobility during the period under study and we can therefore take their occupational status as proxy for the status of their parents. We apply the occupational categories created by Anderson (1987) as described in Floud et al. (1990).

1.3 Method and specification

Estimating secular height trends using military recruitment data generally involves three choices: a method that accounts for the fact that military height data are truncated (since there is a minimum-height cutoff and sometimes also a maximum-height cutoff); a functional form of the time variable (more specifically, the birth year), allowing for both smoothness and flexibility within the trend; and the determination of the truncation points as defined by the minimum height requirement (MHR) of the military.

To compensate for the truncation, we apply the truncated maximum likelihood estimator (truncated MLE), the current standard method to handle truncated data. In order to account for any non-linearities in the height trend, most such anthropometric studies feature a dummy variable representation of the continuous time variable, the birth year, which is metrical (e.g.: Hiermeyer, 2010). The advantage of a dummy variable representation is that it provides certain flexibility in that it describes the secular trend as a curve composed of segments, each of which has a slope of its own. The disadvantage of the dummy variable representation is that it is not smooth. Polynomial functions are another possible representation of the time trend. They allow for a smooth curve, but they are not flexible enough to conform adequately to the data because its mathematical expression only allows for terms considering the whole value range of the time variable. There is a third option: splines, which combine the best of dummy variable and polynomial representations, offering both smoothness and accuracy. There are two popular approaches to splines. Splines based on truncated power functions (TPFs) (Ruppert and Carroll 2000, Ruppert et al. 2003) and B-splines (Eilers and Marx 1996, 2010).

We use B-splines because it has been shown that they seem to have the better numerical characteristics (de Boor 2001).[4]

We compare the results of our B-spline regressions to those of the dummy variable regressions in order to explore the differences of both methods.

In the absence of adequate records about British height requirements and their application, we explored the MHR, by graphic inspection of the height distributions in our samples.[5] We found that the MHRs changed considerably over time, and were influenced by sampling errors. Consequently, we used a number of plausible MHRs (64, and 65 inch) for sensitivity analysis. The MHR for marines was lower and there were fewer tall soldiers among them as well (Figures 1 and 2).

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[4] TP splines are based on truncated power functions and consists of two parts: a global polynomial $\gamma_1 z+\gamma_2 z^2+\ldots+\gamma_d z^d$ of degree d and an assemblage of m local polynomials $\gamma_{d+1}s(z-k_1)^d+\ldots+\gamma_{d+m}s(z-k_m)^d$, one for each of the m intervals, separated by the a priori defined equally spaced knots k (Ruppert et al. 2003).This is represented by the following function:

$$y_i= \gamma_0+ \gamma_1 z+ \gamma_2 z^2+\ldots+\gamma_d z^d + \gamma_{d+1}s(z-k_1)^d+\ldots+\gamma_{d+m}s(z-k_m)^d +\varepsilon_i$$

$$s(z-k_j)^d_+ =\begin{cases} (z-k_j)^d, & z \geq k_j \\ 0, & otherwise \end{cases}$$

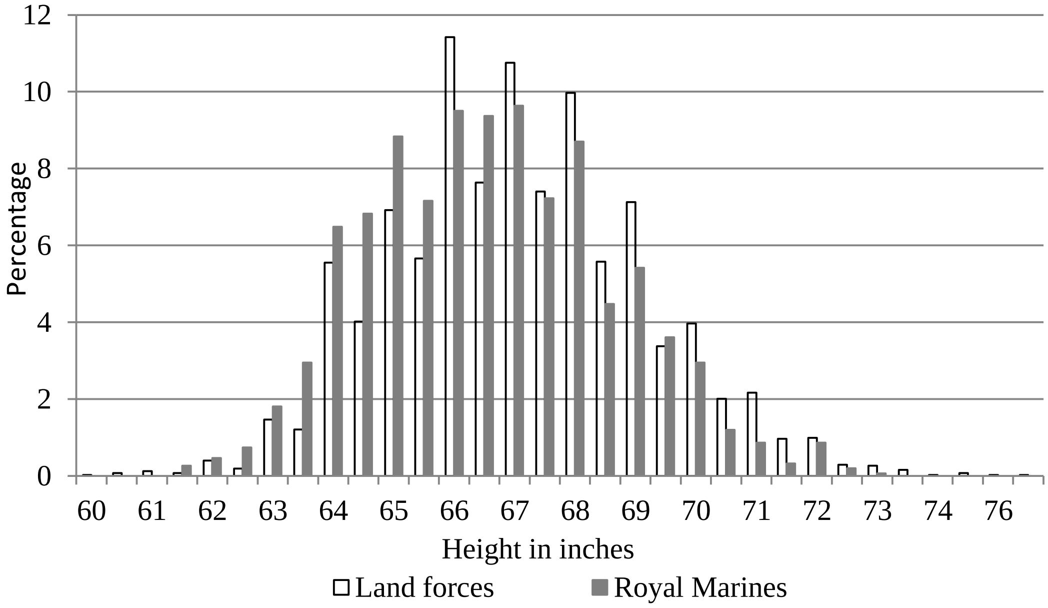
The vector z represents the time variable. The scalar k_j reflects the position of the j^th knot. The d-1 derivatives of the function $(z-k_j)^d_+$ are continuous. This guarantees smooth changes of the curve's slope. B-splines can be derived in terms of differences of the truncated power functions (Eilers and Marx 2010). In our case of equally-spaced knots, B-splines are defined by:

$$B_i(z, d) = (-1)^{d+1}+\Delta^{d+1}f_i(z,d)/(h^d d!)$$

The placeholder f represents the truncated power function of degree d as described above, and h describes the distance between the knots.

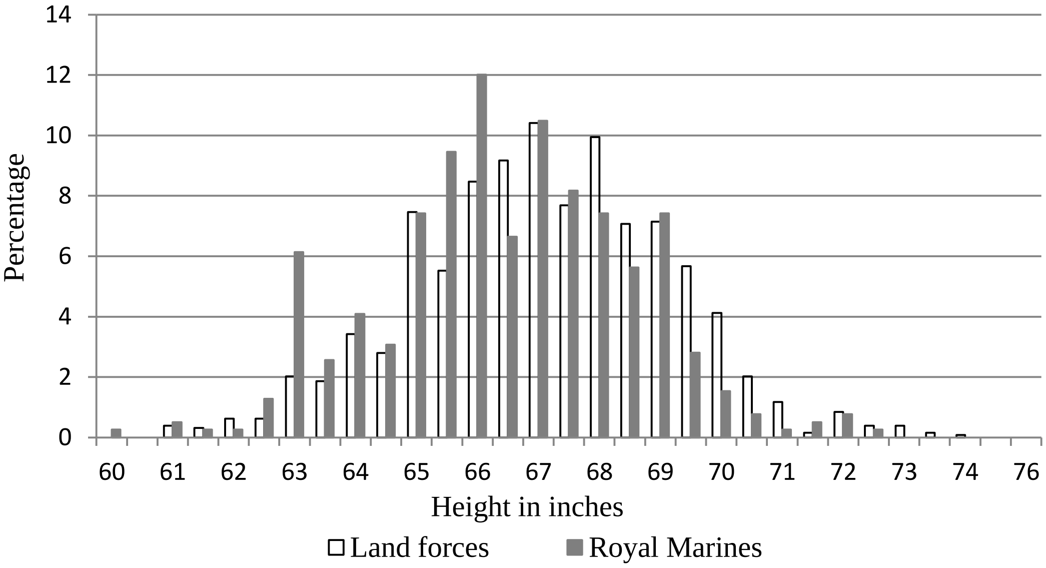
[5] The military has always relied on height as an indicator of physical strength. Military authorities assumed that a certain stature is necessary to be able to carry out all arising military tasks. Hence they only accepted recruits taller than a certain MHR. Exceptions have been made in the case of short recruits with particular skills that outweighed the fact that they did not meet the minimum height requirement; and on the other side of the equation, the Royal Marines had a maximum height requirement (on account of the living and working conditions unique to service onboard a ship), which could cause an additional right-side truncation of the height distribution.

Figure 1: Height distribution of Irish recruits aged 23-50: 1740 -1840.



N = 4,162 for British Army's Irish recruits and N = 1,071 for Royal Marines' Irish recruits.

Figure 2: Height distribution of Scottish recruits aged 23-50: 1740 -1840



N = 1,543 for British Army's Irish recruits and N = 445 for Royal Marines' Irish recruits.

There is another choice to be made which is specifically related to the fact that our sample is composed of land forces and marines. The fact that our data do not constitute a random sample of the British military poses a problem when it comes to estimating the height trend of the two forces combined, since the proportion of the two forces to each other in the sample does not reflect the actual proportion in the military. However, it is necessary to build our estimations upon the real composition of the military because marines were on average smaller than land forces (Figures 1 and 2). A disproportional high or low number of marines in the sample thus leads to a bias in the height trend. It is therefore necessary to use weights which adapt the sample to the true proportion of the two branches (Komlos and Küchenhoff 2012). We have calculated these weights based on information about the numbers of Irish and Scottish recruits to the British marines and land forces.

We control all regressions for county of birth and occupation prior to recruitment. In addition, our analyses contain dummies indicating the country of recruitment: England, Ireland, or Scotland. If region of birth differs from region of recruitment, the next question is whether the recruit left home recently, with the express aim of joining up far from home, or whether he left home before reaching recruitment age; in either case, one would like to determine the reasons (economic, political, or personal/familial) that he chose to do as he did. In the latter case -- more likely than the former one for at least two reasons: the British military's recruitment centers were so widespread that one had no need to travel far to find one; and it is unlikely that anyone intending to join up had the financial means to undertake such a journey -- then a recruit's maximal height is a function of both his birth region and his current place of residence. Abroad dummies are used to absorb these potentially biasing effects of a second environment on growth and for any correlation between such travel and height (for instance, a short man wishing to join up might choose a distant recruitment office if the recruitment officer in his region was reputed to be a stickler regarding the MHR).

1.4 Descriptive statistics

Ireland

The Irish sample consists of a total of 22,168 military recruits (83% in the Army, the remainder in the Royal Marines). There is a regional as well as a religious discrepancy between the two branches of the military: about 36% of the Marine recruits but only 27% of the Army recruits were born in northern Ireland, a Protestant stronghold since the 16th century and 58% of Irish Marines, as opposed to 13% of those who were in the Army, had moved to England by the time they enlisted. Only 4% of the recruits, Army and Marines combined, declared that they had had no previous occupation; the vast majority of the remaining 96% declared that they had been either laborers or craftsmen (Table 1). Since the military was the employer of last resort for young Irishmen from the lowest socio-economic stratum, the most plausible interpretation of this finding is that some of the 96% lied, lest the military reject them on account of their having had, in fact, no previous occupation.

Scotland

The Scottish subsample consists of 9,902 recruits born between 1740 and 1840. As was the case with the Irish subsample, 17% went into the Marines, 83% for the Army, and while the vast majority of the Scottish recruits described their occupational background as either laborer or craftsman, the proportion of craftsmen was significantly higher than in the case of the Irish (Table 2).

Table 1: Distribution of Irish soldiers born between 1740 and 1860.

	Army	Marines	All
County of birth:			
Antrim	0.05	0.05	0.05
Armagh	0.07	0.05	0.05
Carlow	0.04	0.05	0.05
Cavan	0.03	0.03	0.03
Clare	0.02	0.01	0.01
Cork	0.14	0.17	0.17
Donegal	0.02	0.02	0.02
Down	0.04	0.04	0.04
Dublin	0.06	0.05	0.05
Fermanagh	0.02	0.02	0.02
Galway	0.03	0.02	0.02
Kerry	0.01	0.02	0.02
Kildare	0.02	0.02	0.02
Kilkenny	0.02	0.04	0.04
Kings	0.02	0.02	0.02
Leitrim	0.01	0.01	0.01
Limerick	0.03	0.03	0.03
Londonderry	0.03	0.03	0.03
Longford	0.02	0.02	0.02
Louth	0.01	0.01	0.01
Mayo	0.02	0.02	0.02
Meath	0.02	0.02	0.02
Monaghan	0.02	0.02	0.02
Queens	0.03	0.04	0.04
Roscommon	0.02	0.02	0.02
Sligo	0.01	0.02	0.02
Tipperary	0.04	0.04	0.04
Tyrone	0.06	0.05	0.05
Waterford	0.01	0.01	0.01
Westmeath	0.02	0.02	0.02
Wexford	0.02	0.03	0.03
Wicklow	0.01	0.01	0.01
Occupation:			
Agriculture	0.01	0.02	0.01
Building	0.04	0.06	0.05
Dealing	0.01	0.02	0.01
Domestic	0.03	0.04	0.03
Laborers	0.48	0.49	0.48
Craftsmen	0.31	0.30	0.31
Mining	0.01	0.01	0.01
No occupation	0.05	0.01	0.04
Other	0.01	0.00	0.01

Service	0.02	0.02	0.02
Transport	0.00	0.01	0.00
Recruited in:			
England	0.13	0.58	0.21
Scotland	0.03	0.05	0.03
Observations:	**18,354**	**3,814**	**22,168**
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			

Table 2: Distribution of Scottish soldiers born between 1740 and 1860.

	Army	Marines	All
County of birth:			
Aberdeenshire	0.07	0.04	0.07
Argyle	0.01	0.02	0.01
Arran	0.00	0.00	0.00
Ayr	0.05	0.07	0.05
Banff	0.03	0.01	0.03
Berwick	0.03	0.02	0.03
Caithness	0.01	0.00	0.01
Clackmannan	0.00	0.00	0.00
Dumbarton	0.01	0.02	0.01
Dumfries	0.03	0.04	0.03
Fife	0.05	0.05	0.05
Forfar	0.05	0.07	0.06
Galloway	0.01	0.02	0.01
Haddington	0.05	0.01	0.04
Inverness	0.03	0.03	0.03
Kincardineshire	0.01	0.00	0.01
Kinrossshire	0.00	0.00	0.00
Kircudbrigdeshire	0.00	0.01	0.00
Lanark	0.16	0.20	0.17
Linlithgow	0.01	0.02	0.01
Lothian	0.12	0.15	0.13
Murray	0.03	0.01	0.03
Nairnshire	0.00	0.00	0.00
Orkney	0.00	0.00	0.00
Peeblesshire	0.00	0.00	0.00
Perth	0.05	0.05	0.05
Renfrew	0.05	0.07	0.05
Ross	0.02	0.01	0.02
Roxburgh	0.02	0.02	0.02

Selkirkshire	0.00	0.00	0.00
Shetland	0.00	0.00	0.00
Sterling	0.03	0.02	0.03
Sutherland	0.01	0.00	0.01
Wigtonshire	0.00	0.01	0.00
Occupation:			
Agriculture	0.04	0.03	0.04
Building	0.08	0.07	0.08
Dealing	0.02	0.02	0.02
Domestic	0.02	0.04	0.02
Laborers	0.25	0.25	0.25
Craftsmen	0.47	0.45	0.47
Mining	0.05	0.04	0.04
No occupation	0.02	0.01	0.02
Other	0.02	0.01	0.02
Service	0.01	0.07	0.02
Transport	0.01	0.01	0.01
Recruited in:			
England	0.13	0.42	0.18
Ireland	0.02	0.01	0.02
Observations:	**8,167**	**1,735**	**9,902**

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

1.5 Results

Ireland

We find that over the course of the 100-year period under consideration, 1740-1840, the average height of Irish recruits declined by between 0.6 and 3.8 cm depending on the choice of the subsample, the functional form of the time variable, and the inclusion of a Napoleonic war dummy variable (Figure 3).[6]

However, the downward tendency of the height trend was independent of the specifications of the regression. Further sensitivity analyses with a different MHR of 65 in., different MHRs to Army and Royal Marines recruits (Figure 4 and Table 3), and time-varying MHRs (not shown here) also confirmed the downward trend between 1740 and 1840.

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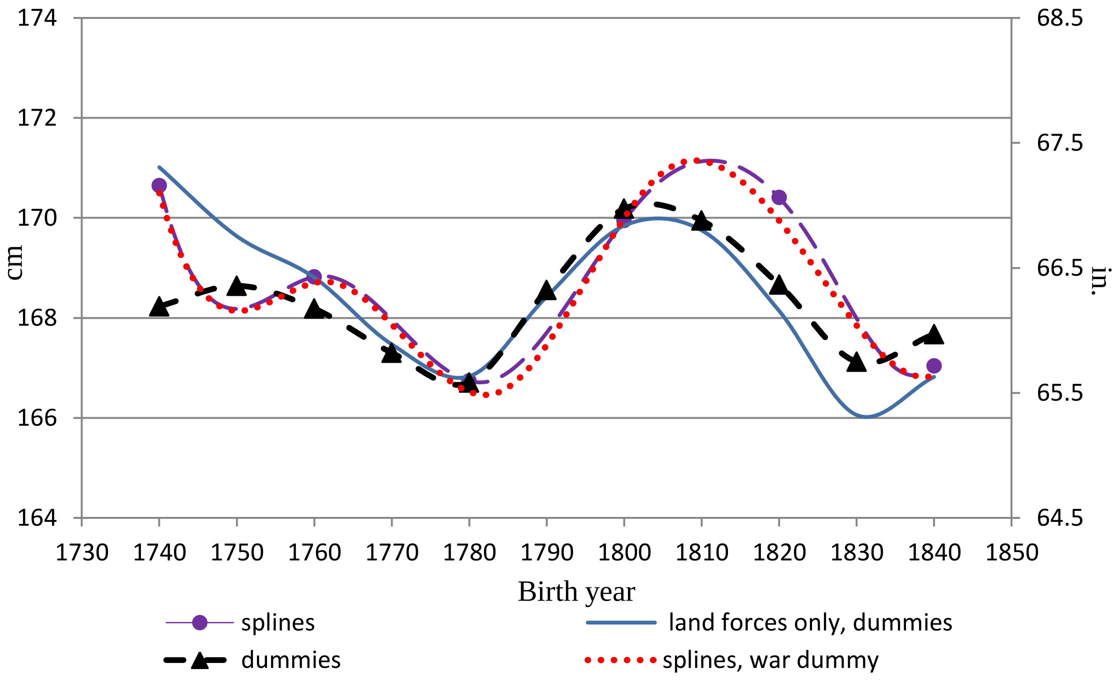
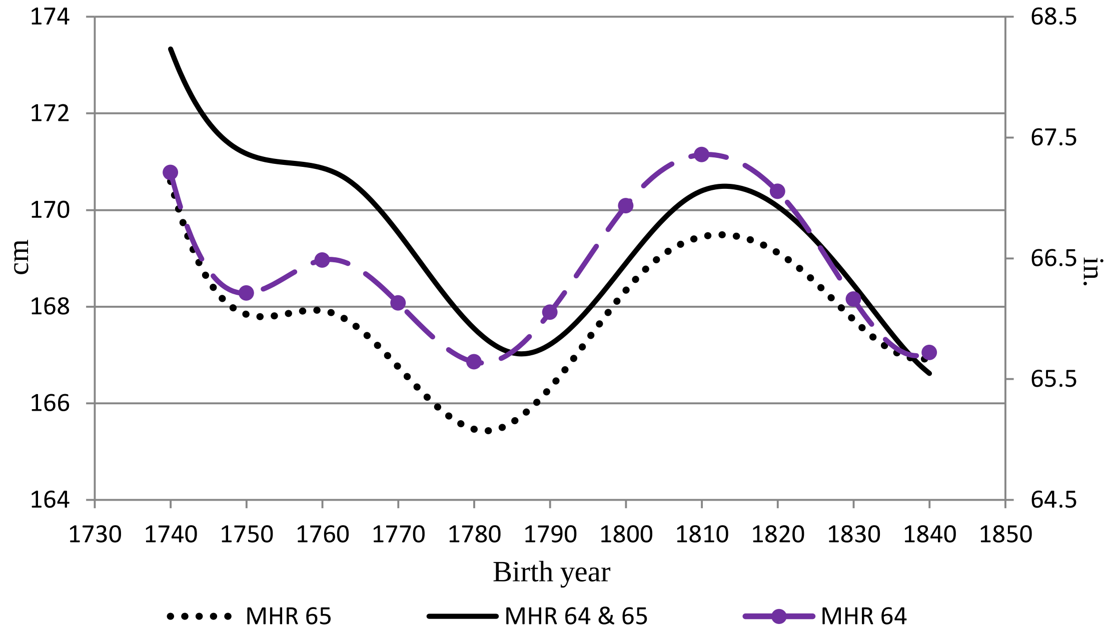
[6] By reestimating the secular height trend for the Army, without any proportional weight, we have been able to confirm that the estimated trend is not an artifact caused by inaccurate Army-versus-Marines weights. The introduction of a war dummy variable, as suggested by Cinnirella (2008), controls for potential changes in the recruitment process due to the upcoming war with France.

Figure 3: Estimated height of adult Irish recruits.



Note: N= 4,828 for "adults," and N= 3,974 for "adults, land forces only."
The MHR was set at 64 inch. Standard deviation for height was constrained to 2.7 in.

Figure 4: Estimated height of adult Irish recruits: Different MHRs.



Note: N = 5,456 for "MHR 63," N = 4,828 for "MHR 64," and N = 4,587 for "MHR 65." Standard deviation for height was constrained to 2.7 in.

The trend was not monotonous but was characterized by three periods: a decline in the second part of the 18th century, an intensive but short-lived rebound around the turn of the century, and another substantial decline after c. 1810/20. In the 18th century, the decrease in height from peak to trough was between 2.9 cm and 4.2 cm, dependent again on the chosen parameters of the regression (Table 3). The decline over the course of the whole observation period, 1740 – 1840, was between 0.6 cm and 6.7 cm.

Table 3: Change in Height (cm) of adult British Recruits.

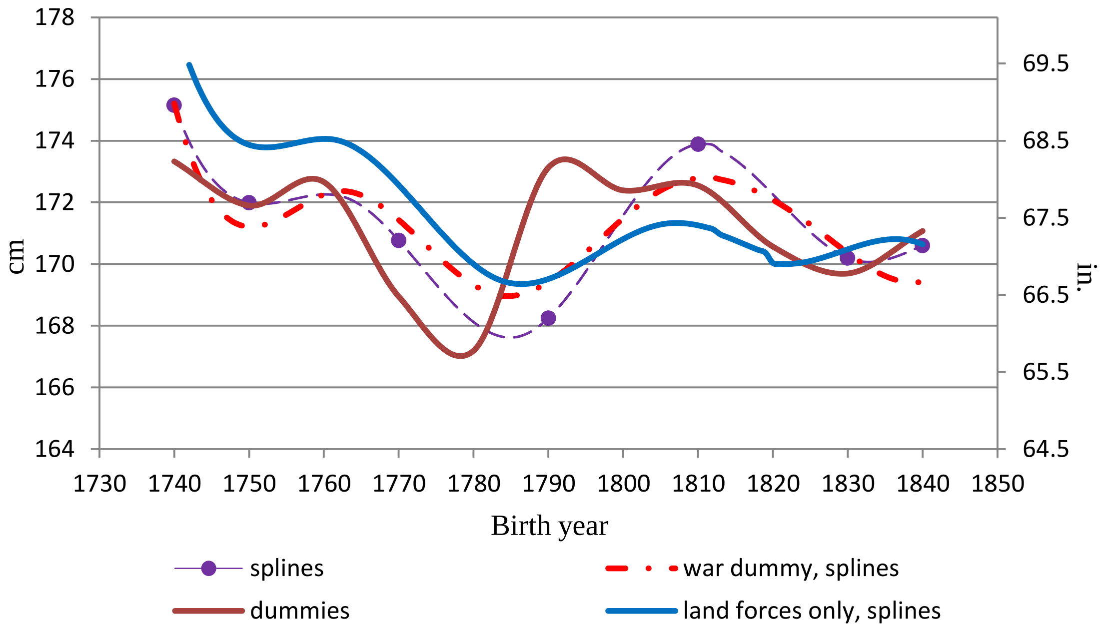
		Irish		Scottish	
MHR:	Period	Dummies	Splines	Dummies	Splines
From beginning to end:					
64	1740-1799	0.7	0.7	1.5	1.4
	1740-1840	-0.6	-3.8	-2.3	-4.6
65	1740-1799	-0.3	0.3	1.7	3.2
	1740-1840	-1.2	-3.7	-3.9	-7.3
64 & 65	1740-1799	1.0	1.1	1.0	2.1
	1740-1840	-6.3	-6.7	-3.8	-4.6
From peak to trough:					
64	1740-1799	-3.6	-4.2	-8.6	-9.1
	1740-1840	-3.5	-4.6	-6.2	-8.3
65	1740-1799	-2.9	-4.1	-9.7	-9.4
	1740-1840	-3.2	-5.1	-7.4	-9.1
64 & 65	1740-1799	-3.1	-4.2	-8.8	-8.8
	1740-1840	-6.3	-6.7	-7.1	-8.8

MHR: 64, 65, and 64 & 65 refer to the minimum height requirements used in the estimation.
Important: The numbers for the period 1740-1799 are based on independent estimations limited to the 18th century!

Scotland

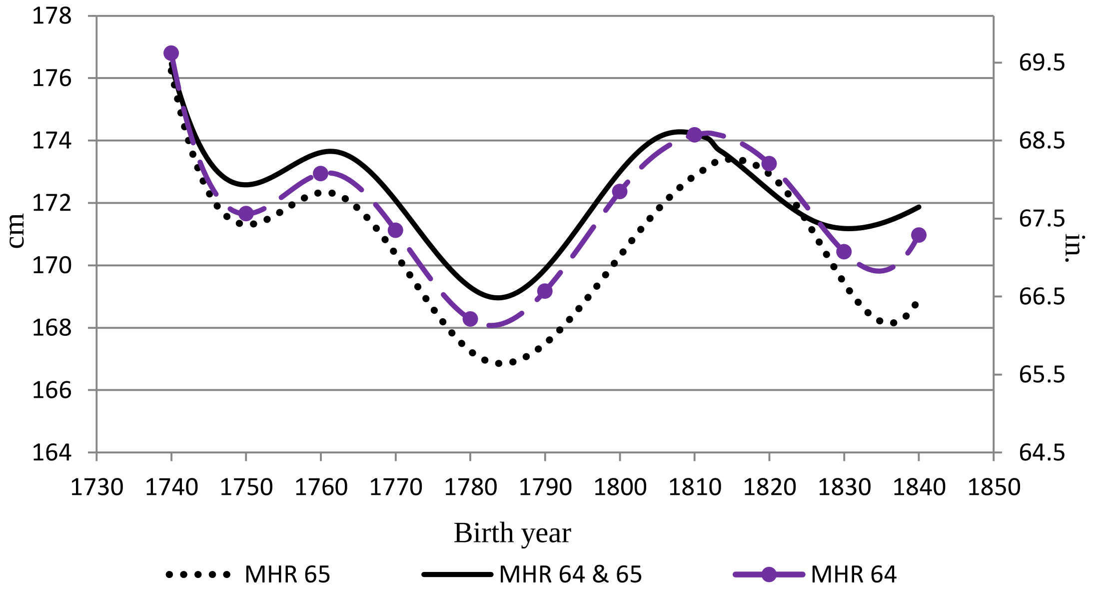
Average height of Scottish recruits to the British military declined over the course of the 100-year period. It decreased by between 2.3 and 6.0 cm depending on the specification of the regression (Figure 5). Although the magnitudes of the overall decrease are different, the Scottish secular pattern is similar to the Irish one: a decrease during the second half of the 18th century was followed by a short-term upturn at the turn of the century and then a second decline in the first half of the 19th century. Sensitivity analyses with different MHRs (Figure 6) and estimation of the height trend of land forces alone (Figure 5) confirm that average heights in 1840 were less than to the 1740 levels. This is also true for the estimation with the Napoleonic war dummy variable although the secular trend with the dummy variable is somewhat flatter in the period before and during the war (Figure 5).

Figure 5: Estimated height of adult Scottish recruits.



Note: N= 1,758 for "adults," and N= 1,505 for "adults, land forces only."
The MHR was set at 64 inch. Standard deviation for height was constrained to 2.7 in.

Figure 6: Estimated height of adult Scottish recruits: Different MHRs.

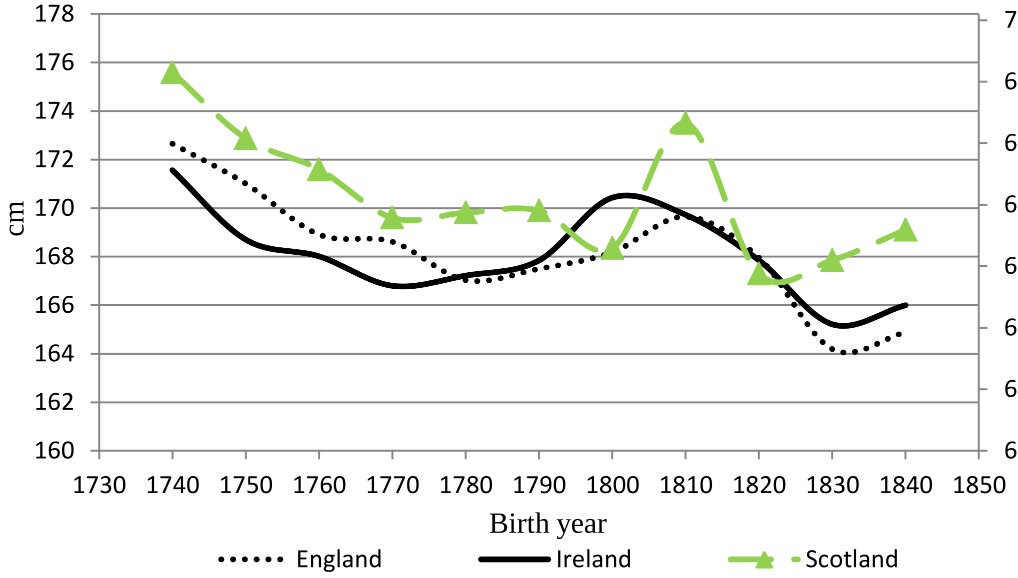


Note: N = 1,755 for "MHR 63," N = 1,758 for "MHR 64," and N = 1,636 for "MHR 65."
Standard deviation for height was constrained to 2.7 in.

Ireland, Scotland, and England: a comparison

The Irish, Scottish, and English height differed in their absolute height levels throughout the period under consideration but were similar in that the overall secular trend in all three cases was downward (Figure 7).

Figure 7: Height of adult soldiers in England, Scotland, and Ireland.

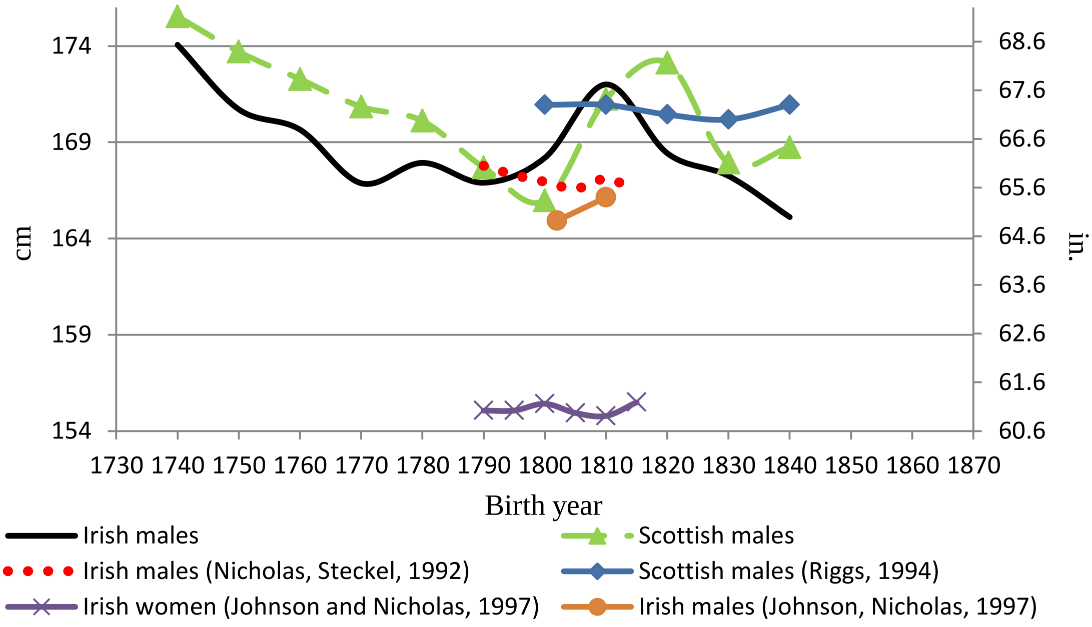


Note: N = 14,689 for England, N = 4,972 for Ireland, and N = 1,758 for Scotland. The MHR was set at 65 inch. Standard deviation for height was constrained to 2.7 in. Komlos's weight for the whole British Army as calculated in Komlos and Küchenhoff (2012) was applied for all estimations.

Our result that Scots were taller than their English and Irish counterparts is consistent with that of Nicholas and Steckel’s (1992), based on Scottish and English convict servants; with Oxley's study of women in pre-Famine Ireland (2004); and with the height differentials as calculated by Floud et al. (1990), all indicating that during the period under consideration here the Scottish people was taller than both the Irish and the English (Figure 8). Furthermore it is in line with Rigg’s (1994) that male prisoners born in Scotland were taller than Irish-born convicts. The Scottish height advantage is partly in line with Komlos (1993b) who found that after 1780 Scottish recruits tended to be taller than English ones but who did not confirm a clear Scottish height advantage over the Irish.

While the Scottish recruits, born between 1740 and 1840, were on average about 2.5 - 2.6 cm taller than their Irish and English counterparts, our results do not support the thesis that the Irish were consistently taller than the English. In fact, our estimates show that the Irish recruits were 1.3 cm shorter than the English between 1740 and 1780. However, they were on average 0.9 cm taller afterwards. This finding is not in line with Floud et al. (1990), Nicholas and Steckel (1992), Ó Grada (1996), Johnson and Nicholas (1997), Oxley (2004) who all concluded that the Irish consistently enjoyed a height premium over the English or were at least at parity. However, a prior analyses of late-18th-century British recruits (Steegmann 1985), and also early anthropometric research conducted by Beddoe (1870) and the Anthropometric Committee of the British Association for the Advancement of Science (Galton 1883) determined that during the 18th century Scotchmen were the tallest followed by the English and then by the Irish. Our finding is thus between the previous results in this respect. However, the more important finding of our analysis is that Scottish and Irish height declined between 1740 and 1840 in accordance with English height as found by Komlos and Küchenhoff most recently (2012).

Figure 8: Height in Scotland, and Ireland: comparison with previous findings.



Note: N=18,519 for "Irish", and N=8,291 for Scottish. The MHR was set at 65 inch. Standard deviation for height was constrained to 2.7 in.

Height and isolation: A geographical analysis of Ireland

The consensus among anthropometricians is that urban populations tended to be shorter than their rural contemporaries until the late 19th century. Cinnirella (2008) shows that during the 19th century urban living conditions had a significant negative impact, of about 1.5 cm, on the mean height of British recruits.

As for the Irish in particular, Nicholas and Steckel (1992) confirm that the Irish paid an urban height penalty, whereas Ó Gráda (1996) reaches a more nuanced conclusion: that "rurality consistently produced taller men early on," but "this premium had nearly vanished by the 1840s." Riggs (1994) finds height differentials that suggest that in Scotland industrialization (accompanied by urbanization) was associated with malnutrition.

The proximity to nutrition is commonly cited as one of the two chief reasons for the phenomenon of the rural height premium in general, including throughout Great Britain during the 19th century. Subsistence agriculture was still an important source of nutrition in these times. Peasant population had a more direct access to nutrition than townspeople. The fact that transportation systems were rudimentary meant that little in the way of perishable foodstuffs could be transported to markets in urban areas and that their price put it beyond the means of most urbanites (Komlos 1998). Moreover, in times of famine, farmers chose to keep their produce for their own consumption, rather than send any of it to distant markets.

The other factor adversely influencing the health and height of urban dwellers is epidemiological: there is a positive correlation between population density and the spread of diseases. Cities were a breeding ground for epidemics whereas the spread of diseases in the country was more difficult. This urban disadvantage is also reflected in the average height of urban dwellers.

To gauge the urban penalty, researchers usually use a dichotomous approach. A dummy variable identifies counties containing a relatively large proportion of urbanites.[7] Sunder (2011) defined the urban environment more precisely. He used proximity (measured as bee line distance) to a major city as a proxy for it. A dummy variable was set equal to one if the person was born within a 20-mile radius of the city. We, however, used the distance to the nearest town or port as an indicator of the extent of market integration.

Nearly a quarter (6,276) of the Irish recruits' files (a total of 22,405) identify the place of birth not just at the county level but in terms of a more precise locality (one of a total of 2,187); for technical reasons, we could identify and geocode only 4,212 of these 6,276 observations, and thus only 683 such localities, distributed quite evenly throughout the island (Figure 9).[8]

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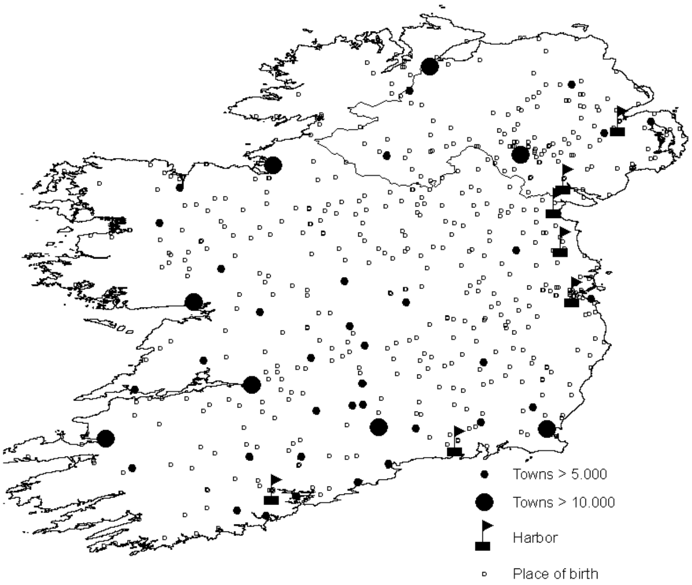
[7] In the case of counties that were also cities (that of Dublin, most notably), the share of urbanites was, in effect, 100%, but such all-urban counties were the exception; in most cases the city dummy variable was set at one, making for inaccuracy if, as was usually the case, the county included rural regions as well.

[8] The localities were identified and geocoded by means of the following procedure: a reference list of Irish localities (towns and villages), including the longitude and latitude of the center of each one, was assembled, and then our Irish subsample of Irish birth locations was merged with this list, by means of the "many to one" method, the key data for effecting this merger being the names of the birth locations. This merger could be achieved only in the case of those birthplace locations that were to be found in the reference list as located in one and the same county; we were thus obliged to exclude certain birthplace locations. There were two main reasons for any discrepancy between birthplace locations as they appeared in our subsample and the localities that composed the reference list, and hence for the exclusion of some birthplace locations: spelling errors, which we chose not to correct (with the exception of two-word locations spelled as one word, and vice versa); and the existence of two birthplace locations with identical names in a single county, rendering unique, unambiguous identification of each of the two locations impossible.

Figure 9: A map of Ireland identifying 683 places of origin of British Army recruits and towns and ports.



That there was a rural premium, thanks to proximity to food sources and hence to an affordable and nutritious diet, and that there was an urban penalty, due not only to poor nutrition but also to dire epidemiological conditions, is well established. Our geocoded data permit us to determine the extent to which the rural environments -- that is, the distance of a rural place of residence from an urban area -- is correlated with physical growth; more specifically, both the beeline and the road distance between the places of residence of recruits in our sample and the nearest larger town or port are used as proxies for market integration.[9] There existed three towns with more than 50,000 inhabitants, 15 with more than 10,000 inhabitants and

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[9] ArcMap 9.3.1 and road data available at http://www.diva-gis.org/gdata were used to calculate road distances. In the absence of data on 18th- and 19th-century roads, we use data that describe them as they exist today, confident that they offer a close approximation of what existed during the period under study, one marked by considerable construction of roads that remain in existence; in fact, by the beginning of this period many of today's roads had already been laid.

48 with more than 5,000 inhabitants in Ireland around this time.[10] Those small, medium, and large towns were chosen as urban areas. In addition, Dublin, Cork, Belfast, Waterford, Drogheda, and Dundalk were chosen as "destination" port towns because only they were busy ports.[11] Average beeline distance to the nearest port was 58 km, average road distance 64 km (Table 4). The correlation between the beeline and road distance is 0.93, 0.70, and 0.88 for port towns, towns > 10,000 inhabitants, and towns > 5,000 inhabitants, respectively. We find no statistically significant relationship between average height and any of the beeline distances (Table 5) but we find that 100 kilometers of road distance to the nearest medium-size town (pop. 5,000) is directly related to a 0.55 cm height increase: a finding that confirms the theory that a rural height premium existed.

That there is no significant effect when it comes to the nearest large town (pop. > 10,000) or port may be explained by the fact that the road distances to them were, on average, excessively large to make effective travel frequent (Table 4). Since this was a period when the expense and difficulty of traveling such a distance were prohibitive, it is not surprising to find no significant correlation between these road distances and the average height of the recruits.

Table 4: Characteristics of the "road distance" subsample.

	Harbor		Town > 10.000		Town > 5.000	
	Linear	Road	Linear	Road	Linear	Road
Minimum distance	0	0	0	0	0	0
Maximum distance	219	292	94	170	62	92
Average distance	58	64	29	30	12	13

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[10] All of the cities were categorized by size: Belfast, Cork, Dublin: population > 50,000; Armagh, Drogheda, Dundalk, Galway, Limerick, Londonderry, Newry, Sligo, Tralee, Wexford, Clonmel, Waterford : population > 10,000; Athlone, Ballina, Ballymena, Bandon, Birr, Carlow, Carrick, Cashel, Castlebar, Coleraine, Cove, Dungarvan, Ennis, Enniscorthy, Enniskillen, Fermoy, Killarney, Kilrush, Kingstown, Kinsale, Lisburn, Loighrea, Mallow, Navan, Nenagh, New Ross, Newtonards, Roscrea, Strabane, Thurles, Tipperary, Tuam, Tullamore : population > 5,000.

[11] They were chosen as "destination" port towns because toward the start of the hundred-year period under consideration (1753, to be precise) each one served as the home port to more than 100 ships (Edwards 2005).

Table 5: Influence of distance to next agglomeration in km on height in cm.

	Beeline distance	Road distance
Harbor	-0.0018	-0.00048
Town > 10.000	-0.0032	-0.00017
Town > 5.000	0.0013	**0.0055****

Note: **: Significant on the 5% level.

1.6 Discussion

The secular height trends of both Irish and Scottish recruits born between 1740 and 1840 were quite similar to one another as well as to that of England and the rest of Europe, consisting of an overall decline over the course of those hundred years, despite a brief recovery, in both cases, during the first two decades of the 19th century.

There may be a Malthusian explanation for the first stage of the Irish height decline: the combination of a population expansion with inefficient agricultural methods, with malnutrition and thus stunting was the inevitable result. Growing inequality may be a second reason because the increasing height of the already relatively rich getting richer cannot compensate for the declining height of the relatively poor getting poorer (Komlos 1998). It seems likely that this first height decline was at least partly due to a growing discrepancy in land distribution, resulting in a small Protestant landowning elite and a large landless Catholic underclass. In 1641 Protestants had owned 40% of the land; their share increased to 80% in 1688 and to 95% in 1778 (Edwards 2005) while they constituted only c. 27% of the population in the early 18th century (Cullen 1981). In addition, by the middle of the 18th century food exports, to England (wheat, oat, live cattle, etc.) were so considerable that they no doubt caused a further diminution of both the quality and the quantity of the foodstuffs available to all of the Irish -- with the exception of the Protestant elite (Komlos 1993a).

Ireland's second height decline coincided with the ongoing agricultural depression, the decline of cottage industries, and an unemployment crisis for the working class, due to the fact that the country was not yet sufficiently industrialized to cope with the population increase. Indeed, when it comes to the cause of the height decline, Komlos (1993b) mentions Malthusian population pressure, and Oxley (2004) pursues this line of reasoning, arguing that the pressure was felt at the microeconomic level, since the increasing number of newborns stretched family resources to, and often beyond, their limit. According to Komlos (1993b), the possible reason that average height reversed course around 1850 was that the Great Famine solved the overpopulation problem: newborns being few, they received adequate nutrition and thus became taller than did those whose growth years had coincided with the Famine.

Our Irish secular height trend is in line with the simple “Subjective Impoverishment Index” of Mokyr and Ó Grada (1988) in that it indicates that between 1815 and 1835 the living conditions of the Irish underclass deteriorated; in addition, it confirms the conclusion of Ó Gráda (1996) that there was no height increase between the end of the Napoleonic Wars, in 1815, and the late 1850s. In other words, after having undergone a height increase sandwiched between two significant height decreases, in 1840 the average height of the Irish was below where it had been a hundred years earlier.

The three phases of the Scottish height trend were parallel to those of the Irish one, but the height averages themselves were consistently greater, as one would expect, since the Scottish economy did not suffer from such severe stagnation.[12] In fact, Sabillon (2008) argues that during a part of the 18th century Scotland's GDP grew faster than England's; be that as it may, between 1740 and 1790 average height there did decline but less than English heights. One possible cause was the metamorphosis, in a span of just two generations of the Highlands' Gaelic culture from tribal to capitalist one; since the contracts governing clans were unwritten (Devine 2001), Highland clan chiefs had little practical difficulty in justifying their profiteering as commercial landlords, and -- just as the Irish underclass ate less well when the bulk of their agricultural output was exported to English markets --

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[12] Historians continue to debate the when and the why of Scotland's economic acceleration; Lenman (1977) dates it to the middle of the eighteenth century, specifically 1727-1780.

Scotland's Highlands population suffered economically and therefore physically when, having lost out to acquisitive landlords more interested in personal profit than in the welfare of their clan, were obliged to ship much of their agricultural output to urban markets, instead of consuming it locally.[13]

Adaptation to the market economy took somewhat longer in the Lowlands, mostly because tenant-landlord contracts were documented in writing, and therefore could not be annulled overnight (Devine 2001). Nonetheless, market pressure eventually made itself felt, primarily in the form of land-ownership concentration and regulation; no longer did tenants make a deal with a laborer in the form of land (rented, in turn, by the tenant, admittedly; but this was better than downright landlessness). As Devine (2001) puts it, "The latter eighteenth century ... brought dispossession on a truly unprecedented scale all over Gaeldom," Dispossession that, according to Komlos (1998), accounts for the subsequent decline in average height throughout both the Highlands and the Lowlands.[14]

The fact that average height in Scotland, as in Ireland, rose briefly at the turn of the 19th century may be due to the fact that, with wages outpacing prices, the standard of living rose -- briefly (Devine 2001). However, it is no mere coincidence that as the Scottish population soared, from 1.6 million in 1801 to 2.6 million in 1841 (Devine, 2001), average height once again declined. While Riggs (1994) finds evidence of serious overcrowding in Glasgow on the basis of the number of occupants per house, Scotland's overpopulation crisis did not come close to the Malthusian proportions of Ireland's. Scotland -- in contrast to Ireland -- experienced an agrarian revolution in the 18th century (Sabillon 2008), and did not export its entire nutritional surplus. It is therefore safe to say that Scotland's "balance of population to resources" was considerably better than Ireland's (Devine 1983). Nonetheless, urbanization meant an increase in the number of persons who had left

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[13] Thus, because the advent of capitalism -- that is, the market economy -- meant that it was now the market that determined both wage levels and food prices, it accounts for changes in nutritional intake, and hence changes in average height (Riggs 1994).

[14] Carson (Carson 2009) lends support to this argument with his analysis of how socio-economic inequality impinges on physical well-being.

subsistence agriculture behind and were now totally dependent on foodstuff brought to the cities. Riggs (1994) argues that the average height of Scotland's city dwellers declined because the agricultural and produce-transportation sectors could not keep pace with urban population growth; Scottish urbanization rate soared from 6.3% in 1700 to 36.6 % in 1800 (Malanima 2010). Although the food supply sufficed to keep city dwellers alive, the pre-industrial level of nutrition could not be sustained.

Also contributing to the decline in urban height during the Industrial Revolution was the increase in the child-labor rate and the average number of work hours (Voth 2003). In the words of Sabillon (2008), “Working children were only fed once a day, they labored in poorly lit rooms, without sanitation, frequently flooded with rain …” To make matters even worse, the Industrial Revolution devalued the skills of traditional craftsmen (Acemoglu 2002), who therefore found their economic status more precarious than ever before. It seems plausible that all these factors are represented in the significant decline in average height over the hundred-year period 1740-1840.

Comparison

The fact that at the beginning of the hundred-year period under consideration, 1740-1840, the Scottish recruits in our sample were on average taller than the English counterparts can be credited to their superior epidemiological situation (due to their relative isolation) and to their superior nutrition (due to subsistence agriculture). In 1750 17% of England's population lived in towns of 10,000 or more inhabitants, whereas only 9% of Scotland's did (Devine 2001). In addition, even the poorest laborer in Scotland had his parcel of land, guaranteeing food on the table (Riggs 1994); but this situation was soon to change, and with it the English-Scottish urban ratio (Malanima 2010). If the status quo in England had remained unchanged, there would have been an average-height convergence; but in England average height declined just as precipitously as it did in Scotland.

Since the two key advantages that the Scottish had over the English -- epidemiological insulation, thanks to geographical isolation, and adequate nutrition, thanks to a tradition of subsistence farming -- were enjoyed by the Irish as well as the Scottish, why did the latter enjoy a height premium over the former as well as over the English? Neither the nutrition provided by the diet nor the disease protection offered by their isolation could obviously compensate for the catastrophic collision of Ireland's primitive farming methods with absentee English landlords.

Adam Smith (1776) considered that the Irish were even worse off than their Scottish counterparts, and a French contemporary of his, Le Chevalier de La Tocnaye, reported that Scotland was richer than Ireland (1798; cited in Cullen 1983). There were other reasons, as well, for the Scottish height premium over the Irish. The Calvinist work ethic was coupled with an impressive system of universal education because the state forced the country's landlords to pay for education (Houston 1985), making for a 75% literacy rate as early as the middle of the 18th century (Herman 2003). Scotland's merchants had well-established international trade partners, due to its excellent trade-route location. The early introduction and implementation of modern agricultural methods such as crop rotation and enclosure which enabled farmers to maximize the potential of their lands helps to explain the fact that 18th-century Scotland suffered far fewer crop failures than did Ireland. Scotland's union with England in 1707 -- nearly a century earlier than Ireland's, in 1801 -- meant unlimited access to both England's domestic market and its colonial ones. In addition, its banking system was far more advanced than Ireland's, offering exceptional opportunities to new business enterprises, may have stimulated economic success as well. Perhaps even more important than these commercial advantages was the fact that the Scottish society was not fractured by widespread discontent, whereas Ireland’s society was chronically under pressure on account of deep-seated inequities, such as the Plantation-prompted land confiscations, and the profoundly anti-Catholic Penal Law (Devine and Dickson 1983).[15] Finally, Scotland had a superior system of charitable institutions (Cullen and Smout 1977) and maintained a tradition of treating their fellow-countrymen with an exceptional degree of generosity (Steven 2002). Taken all that factors together, it is no longer a

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[15] The Penal Laws were a series of laws imposed by the British to restrict the rights of the Irish natives.

mystery that Scotland's people were on average better nourished than Ireland's, and hence enjoyed a height premium.

On the other hand, it must not be forgotten that the average height of the Scottish as well as that of the Irish recruits in our sample declined significantly.[16] There is considerable evidence that a downward trend in average height was the pattern throughout Europe (Komlos 1993b, Cinnirella 2008, Komlos and Küchenhoff 2012), so optimists can take little comfort from our conclusions concerning the standard of living in the outlying regions of the United Kingdom during the hundred-year span that we chose to study and that spanned (not coincidentally) the first Industrial Revolution.

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[16] While the exact magnitude and time of the curvatures are difficult to determine, since they depend on the selected parameters of the regressions, sensitivity analyses show that the mentioned results are robust.

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The Biological Standard of Living in the Holy Roman Empire between 1735 and 1780

The paper analyzes the development of the biological standard of living, measured in terms of average physical stature, in the 18th century Holy Roman Empire and compares the result with trends in neighboring countries as well as with traditional welfare measures. Our main finding is that the height of German recruits decreased significantly between 1735 and 1780. This finding is consistent with both the development of monetary indicators and the height trends of all other European countries. We suggest that the decline in height can be explained by a combination of three factors: increasing socio-economic inequality, a Malthusian demographic regime that brought about a sharp increase in food prices throughout the continent, and, climatic conditions.

2.1 Introduction

The insights that we owe to the research on anthropometric history are undisputed.[1] It added a new, complementary perspective to the standard of living debate, which until then was primarily based on monetary indicators. Among the most striking advantages of height as an indicator of human welfare are its availability, reliability, and comparability. Data on height is available as early as the beginning of the 18th century, an era for which comprehensive monetary figures are scarce or nonexistent (Steckel 1995). Height is also not subject to problems associated with outliers because it reflects living conditions throughout the first c. 20 years of life rather than at a given reference date (Komlos and Kriwy 2002). Furthermore, height data lend themselves to comparison, even in the case of international analyses, obviating any need to convert them into a uniform measure as is the case with monetary measures (Koch 2012).

Given these favorable characteristics, it is not surprising that the number of publications in the field has increased substantially in recent decades.[2] However, few studies are available on the development of height in the Holy Roman Empire which constituted the core of Central Europe until its demise in 1806.[3] Studies in this region are limited to Bavaria, Saxony and parts of the Habsburg Monarchy.[4] This study aims to fill this gap by estimating the height trend based on an extensive data set of German recruits into the Habsburg infantry born between 1735 and 1780.

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[1] Among the most remarkable findings are the "early modern growth puzzle" (Komlos 1998), called "antebellum puzzle" in the American context (Komlos 1996). This refers to the insight that living conditions deteriorated in the U.S. at the onset of modern economic growth. A further important insight is that physical stature in the pre-revolutionary American colonies exceeded those in Europe (Komlos 2001), but the American height advantage disappeared in the second half of the 20th century (Komlos and Baur 2004).

[2] About 325 publications on height have been published in the social science between 1995 and 2005 (Steckel 2009).

[3] In the following we refer to the Holy Roman Empire as Germany and to its inhabitants as Germans in spite of the unhistorical nature of this abbreviation.

[4] The reason for the imbalance in the number of publications is that there exist more height data for the 19th than the 18th century. Furthermore the Industrial Revolution is still one of the most attractive topics in economic history and, therefore, much attention -- also in anthropometric history -- is aimed at 18th and 19th century England.

The Holy Roman Empire was a suprastate entity which in the 18th century consisted of more than 300 political units (principalities, duchies, kingdoms, bishopsrics, and free cities) inhabited by a population of c. 25 million (Duffy 2000, Hartmann 1995). Its territory varied significantly over the course of time but the German-speaking area was always the heartland of the Empire. In addition its territory included parts of what are today France, the Czech Republic, Poland, Austria, Lichtenstein, Switzerland, and the Benelux states. This federation was held together by a few empire-wide institutions such as the Imperial Diet. Apart from that, the regions were largely independent. This political fragmentation led to considerable regional differences in socio-economic development. Trading was mostly regionally limited as tariffs, different currencies, and different crafts codes complicated long-distance trade (Hartmann 2005). Reflecting this heterogeneity Fremdling (1988) came to the conclusion that it is complicated to derive German income figures before 1850. It is therefore even more important to consider alternative ways of measuring welfare in this suprastate.

The concept of the biological standard of living as first formulated by Komlos in 1989 “captures the relevant biological components of life” and, therefore, “indicates generally how well the human organism thrives in its socio-economic environment" (Komlos and Snowdon 2005). It is a valuable complement to traditional welfare measures and enables us to gain insights into trends in welfare that would otherwise elude us. Height is -- besides mortality and morbidity -- a common proxy for physical wellbeing.

The political fragmentation also limited research on German anthropometric history of the 18th-century: hitherto only Bavarian, Saxon, Bohemian, and Austrian data have been collected. Baten (2002) analyzed the height of Bavarian soldiers and found that average height increased in the second quarter of the 18th century but declined in the third quarter (Table 1). Cinnirella (2008) reported that the physical stature of Saxon soldiers declined by c. 1 cm between 1695-1785. Komlos (1989) analyzed the height of 18th century Habsburg soldiers and found that the average stature of soldiers from Lower Austria decreased significantly between 1740 and 1790. The same is true for soldiers from Bohemia. The negative trend was a universal phenomenon in Europe. Between 1740 and 1800 average height of English soldiers to the British military decreased at a rate of c. 1.6 cm per decade (Komlos and Küchenhoff 2012). The physical stature of Scottish soldiers to the British military decreased by 4.0 cm in the same period and Irish height decreased by 2.4 cm (Koch 2012). In the province of Orleans (France) average height of militia decreased by c. 1.6 cm between 1715 and 1760 (Schubert and Koch 2011). Swedish height also slightly decreased in the second part of the 18th century (Heintel et al. 1998) as did Northern Italian height (A'Hearn 2003).

Table 1: Height trends in 18th century Germany and Europe (cm).

	1700s	1710s	1720s	1730s	1740s	1750s	1760s	1770s	1780s	1790s	Peak to trough
Bavaria				2.0	0.6	-0.3	-1.7				-3.5
L.Austria[1]						-4.5	1.0	-3.8	1.8	-2.4	-7.9
Saxony	0.6	-1.3	.14	-3.9	2.7	-1.0	1.2	-1.0			-4.0
Bohemia[1]					0.1	-1.2	0.3	-2.0	-0.9	-0.6	-4.4
England					1.1	-2.4	-0.2	-2.4	-2.4		-9.9
Orleans		-0.5	-0.7	-0.3	0.4	-0.5	0.5	-0.5			-1.6
France		-0.2	-1.2	2.3	1.0	-1.5	-0.1				-7.8
Moravia[1]					2.4	-2.8	0.8	-3.8	0.1	1.5	-5.8
Ireland					-1.9	0.7	-2.8	-1.0	-1.0	2.4	-6.0
Lombard								1.5	-0.9	-2.3	-5.5
Hungary					2.6	-3.5	0.2	-2.4	-0.2	-0.9	-2.0
Scotland					1.1	-0.5	0.4	-6.0	2.9	-0.8	-5.2
Sweden					1.0	-1.3	-0.2	-1.0	-0.3	1.1	-1.6
Russia									-2.41		-2.41

Note: Change in cm compared to the period before. Both the heights and the accompanying annual figures may be not perfectly precise, since they sometimes had to be red directly from the graphs.

[1] Figures for Lower Austria, Bohemia, Moravia, and Hungary are taken from Komlos (1989) and reflect his QBE results. As he states the trend in physical stature and not the height change from decade to decade is decisive because the QBE routine is subject to a certain amount of error.

Sources: Baten (2002), Komlos (1989), Cinnirella (2008), Komlos and Küchenhoff (2012), Schubert and Koch (2011), Komlos (2003), Koch (2012), A’Hearn (2003), Heintel et al. (1995), Mironov, A’Hearn (2006).

2.2 Determinants of height

Final human stature is the result of a complex growth process and thus reflects numerous influences and interactions between them. Two main factors influence the human stature. The individual genetic predisposition of a person defines his height potential and the environmental conditions experienced in the womb, during childhood, and adolescence determine how much of this potential will, in fact, be realized.[5] While genes explain height differences between individuals or different populations, they cannot account for fluctuations in average height of a society given that the genetic composition of it did not change significantly over time.[6] That is, secular variations in the average height of a society with stable genetic composition are by implication the result of sustained changes in the epidemiological and/ or economic situation. Intra-societal shifts in the distribution of the available resources are the third possible environmental reason of height variations.

There were no major inter-country migration streams to 18th century Germany; that is average height variations in our sample exclusively reflect changes in environmental conditions during that period.[7] The epidemiological, economic, and social environment influences height insofar as it affects the nutritional status -- defined as the balance of nutritional input and output -- of a person. The input is determined by the quantity, quality, and balance of the ingested food. The output is the sum of the energy needed by the human body for growth, maintenance, repair,

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[5] Silventoinen (2003) estimated that about 20 percent of individual height variation is the result of environmental conditions. Mc Evoy and Visscher (2009) confirmed this ratio.

[6] There is not even a consensus among scientists that genetic predisposition is a cause of different average heights between populations (e.g.: Bogin 2001, Malcolm 1974, Mascie-Taylor and Bogin 1995, Clark 2007). Human beings have a long reproduction cycle of c. 25 years from generation to generation. Genetic mutation, therefore, occurs only over the course of centuries or millennia rather than decades. Thus, we can also exclude genetic adaptation over time as a cause of height variations in our sample.

[7] Komlos (1998) divides the environmental factors which affect height into endogenous and exogenous variables. According to him, changes in the income distribution, income variability, population growth, and relative prices are endogenous factors of height variations. Weather is an exogenous influence factor and the disease environment is both, an endogenous and exogenous determinant.

and work (Bogin 2001). Height represents the nutritional residual which is left after the body's realization of the other basal metabolic tasks.

Economic status and height

Nutritional intake is decisively influenced by the purchasing power available to the family.[8] A household's spending power was thus, ceteris paribus, reflected in the final height of its children because most of income was spent on food prior to the 20th century (Cipolla 1994); that is income variations inevitably affected the food consumption possibilities of the population. At the aggregate level height is thus a reflection of the economic situation, ceteris paribus.[9] However, average height is not a linear measure of a society's income. As both the income elasticity of demand for food and the marginal return of food to human growth are less than one, a shift in income from the lower to the upper social strata means that average height declines (Steckel 1983, Komlos 1998, 2007). Stature, thus, does not simply reflect the level of income but also captures the distribution of income. Everything else being equal, more egalitarian societies are on average taller than relatively unequal ones.[10]

Warm and tall or hot and short: How weather influences height

Income is not the only variable that influenced average height. Climatic conditions also affected a population's standard of living in pre-industrial agricultural societies. Baten (2002) for example attributed the 18th century European decline in nutritional status to the deterioration of European climate. According to Komlos (2002) there

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[8] Usually the father was the main earner in the family but it was not unusual that the wife and the older children also contributed to the family income.

[9] Diet is also influenced by the distribution of income between food and other goods. The allocation of resources within different foodstuffs but also between articles of food and non-food is affected by shifts in relative prices. An increase in food prices relative to non-food item might well lead to a decline in nutritional stature or nutrient intake.

[10] To be precise: Distributional justice does not only matter on the aggregated level but also on the household level. The diet is not only influenced by the distribution of wealth and thus food within a society but it also depends on the distribution of nutrients between family members. It might have been perfectly rational to provide the head of household the most food so that he did not fail as a bread-winner. As a consequence, his wife and children had to get along with the remaining food available to the household.

are several direct or indirect mechanisms through which climate or weather changes could affect height: the effect of the ambient temperature on the energy consumption of the metabolism of humans, the effect of sunlight on hormone release related to human growth, and the effect of average temperature and rainfall on harvest.

The average ambient temperature influences the body's requirement for calories because the colder it is the more energy is needed to maintain body temperature at 37 Celsius. The calorie demand by the human body mainly depends on four interrelated variables: the basal metabolic rate, physical activity, age, and ecological factors (Costa 1977). The body's daily energy expenditure can be described in simplified terms as basal metabolical rate (BMR) times the physical activity level (PAL) per day:

$$\text{DEE(kcal/day)} = \text{BMR(kcal/day)}*\text{PAL}$$

(Froehle 2008). The BMR is the amount of energy -- measured in kcal per day -- needed by the body for maintenance when at rest. The BMR level is not only influenced by individual characteristics such as age, sex, height and body weight but also by the prevalent ambient temperature. An increase of the daily temperature by one degree Celsius leads, ceteris paribus, to a c. 4-5 kcal/day decrease in BMR (Froehle 2008). However, a boy aged 12-14 with normal weight requires on average c. 1,460 kcal/day for basal metabolism (WHO 1991). The annual temperature in Europe varied by little more than one degree Celsius in the 18th century. The summer of 1757 for example was the hottest summer between 1500 and 2000 and still deviated by only 1.08 degrees Celsius upwards (Mauelshagen 2010). That is, the effect of the ambient temperature on the basal nutritional requirement is rather negligible.[11]

The effect of sunlight on hormones (vitamin D2) affecting final height is

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[11] To be sure: We only refer to the influence of annual temperature fluctuations on the energy consumption of the body and the question whether disproportional hot or cold periods might have had an influence on height by leaving more or less energy for growth. We do not discuss the potential effect of temperature on the average height by the way of evolutionary selection. Evolution might prefer taller humans in hotter regions and smaller humans in colder areas according to thermoregulatory rules. For a discussion on the consequences of latitude on body shape, see Ruff (1994).

more complicated. Carson (2008, 2009, 2011) evaluated the effect of sunlight on vitamin D2 production of the body and its influence on height. He concludes that greater insolation is in general associated with significantly taller average stature.[12] However, the relatively constant average temperature in the 18th century indicates that the secular variation in insolation must have been minor within this period. Hence, we suppose that changes in the body's vitamin D2 production were not responsible for secular changes in average physical stature.

The influence of rainfall and temperature on harvest and thus availability and prices of food is more significant as the weather had a major impact on the size of the harvest. However, there are no extensive data on average weather conditions or on quantities of harvests in 18th century Germany.

Physical activity and calorie consumption

As seen above, the daily energy expenditure of the body follows from multiplying the basal metabolical rate by the physical activity level. The magnitude of the activity level depended on how the individual spent his day. Sleeping has a PAR (Physical activity ratio) of 1, normal walking of 3.2, and heavy work such as felling a tree has a PAR of 7.5 (Floud 2011). The average PAL (Physical activity level) per day is the weighted sum of these daily activities:

$$PAL = \sum_{hour=1}^{24} \frac{number\ of\ hours\ \ x\ \ PAR\ of\ respective\ activity}{24}.$$

However, we do not know comprehensively the extent to which the daily routine and thus the calorie consumption of German youth changed in the 18th century.

One known event that did influence the average number of working days -- and thus serves us as example to evaluate the possible influence of changes in the work habits on height -- was the abolition of several catholic holidays in the 18th century Habsburg Empire.[13] We want to quantify the possible effect of the increase in annual working hours on calorie consumption as consequence of the fewer

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[12] Insolation is the solar radiation striking earth.

[13] See Komlos (1989), Komlos and Ritschl (1995), and Voth (1995, 1996) for an extensive discussion about the effect of the reduction of Holy Days on average height.

holidays. Komlos and Voth argued about the consequences of the abolishment of c. 14 holidays. What would have been the additional caloric demand if German youth worked 14 more days per annum? The PAL of a person enjoying a full day of leisure on a holiday is c. 1.3. The daily PAL of a person working in the fields for ten hours is c. 1.7. Thus, a 14 year old boy needs c. additional 600 kcal for each day he works (given the above mentioned basal need of c. 1,460 kcal/day). Based on those assumptions, 14 abolished holidays increase the boy's yearly calorie requirements by only c. one percentage point.[14] Calculations with consumption figures for older adolescent and different occupations confirm the magnitude of the result. Hence, we consider the "holiday discussion" as a minor aspect when it comes to explaining the German height trend and conclude that changes in the work habits at most explain slight changes in average stature.

Survival of the tallest: Diseases and height

It is well known that any infectious disease adversely influences the nutritional status of the affected person (Scrimshaw 2003). Thus "it is not surprising that severe or prolonged illness has an adverse effect on growth and maturation, especially when a child is already malnourished" (Scrimshaw et al. 1968).[15] A deterioration in the epidemiological environment would have increased the number and severity of diseases and thus led to a decline in the net nutritional status. However, there is a second and opposite effect of disease on height. Diseases kill weak and small (malnourished) children with a higher probability leading to a biased sample of taller and healthier survivors. The question is which of the two effects dominates?

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[14] Calculation: $(1.7*1460-1.3*1460)*14/((6*1.7*1460+1.3*1460)*56)= 0.00869 \approx 0.01$
Estimated difference in daily energy consumption between a working day and a holyday, times 14 days, divided by the estimated energy needed within a year (assuming 6 working days a week). The figures used to derive the PAL values are taken from: http://www.fao.org/DOCREP/003/AA040E/AA040E00.HTM, 20.01.2012.

[15] Some diseases force the human body to use considerable energy to combat the pathogen which is then lost for the growth process; other medical conditions reduce the food intake by regulating the appetite (Bogin 2001). Diseases involving the gastrointestinal tract also reduce the absorption of nutrients (Rotberg 1986).

According to Deaton (2007) the selection effect is likely to dominate when infant and child mortality is very high, while the "nutritional theft" argument predominates in low-mortality settings. Bozzoli and Deaton (2009) confirmed that finding by showing that at high mortality levels, the selection effect can dominate the stunting effect.

Plague was no longer endemic on a large scale in 1720 and cholera did not emerge in 18th century Western Europe yet (Hays 2005). Measles, rubella, diphtheria, and influenza were occasionally epidemic. Typhus and dysentery also emerged locally from time to time; spread by passing troops (Kohn 1995).[16] The universal scourge in these times, and thus the single most decisive disease for our analysis, was smallpox. Highly contagious (95 in 100 persons who get in contact with the pathogen get infected), smallpox killed many. Those who survived were often marked for life. Social status did not protect from infection (Vasold 1999). Scientist eagerly searched for a cure. First immunizations took place in Germany around 1721 (Fischer 1965). In the second half of the century, variolation (an early form of immunization) expanded in Germany (Vasold 1999). Bengtsson (2009) concluded that the European disease pattern decisively changed throughout the 18th century. Various diseases became less prevalent (e.g. malaria) or less virulent (smallpox) in this period.

Voth and Leunig (1996) estimated that smallpox reduced average height by c. one inch and that its eradication was therefore responsible for at least one-third of the rise in height found in their data. Razzell (1998) criticized that Voth and Leunig draw the wrong conclusions mainly because of bad data with many boys who actually had suffered smallpox not identified as such. Heintel and Baten (1998) criticized that Voth and Leunig used the wrong estimation strategy and therefore overestimated the effect. However, Leunig and Voth (1998, 2001) refuted both

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[16] There was a typhus epidemic over wide areas of Germany in 1734. In the period between 1741 and 1743 there were typhus, typhoid, and dysentery epidemics in Bavaria, Thuringia, Hesse-Homburg, Bohemia , Silesia and the Main area (Kohn 1995).

arguments. They rejected Razzel's argument by presenting descriptive statistics of their sample. Those statistics revealed that the miscoding rate in their data was very minor and did not affect their results. Leunig and Voth also declined Heintel and Baten's criticism by showing that they had misread their paper and used too small subsamples for their counter-analysis. Therefore, we deem it as empirically proven that historical heights were influenced by smallpox.

To summarize: A changing disease environment can have a significant influence on average height and it is possible that the virulence of the most devastating contagious disease in 18th century Germany, smallpox, declined because of successful immunization efforts. However, we do not know the direction and dimension of the inferred effect.

2.3 Data

The muster roles of the Habsburg Infantry Regiments are the source of our data.[17]

The Waldstein's system of voluntary recruitment, introduced in 1625, did not attract enough soldiers to the Habsburg Army and Vienna therefore established a supplementary system of regional quotas within the Habsburg dominion in 1749 ("Landrekrutenstellung"). The army subsequently consisted of volunteers recruited by the individual regiments and by conscripts provided by the regional sovereign. The hiring of the troops was based on contracts of individual duration and bounty (Komlos 1989, Wrede 1901).[18] Voluntary recruitment and conscription had in common that only the able-bodied poor would be recruited (Hochedlinger 2000). The main catchment areas of the recruiting officers were the Habsburg territories

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[17] Muster roles of the regiments 22, 25, 41, and 46 -- with recruitment dates between 1767 and 1820 -- were used in this study. Regiments' numbers 22 and 25 were raised in the whole Holy Roman Empire, number 41 mainly in Bavaria and Franconia, and number 46 in Tyrol and the southwestern Empire.

[18] Pröve (1995) defines three different motives why men voluntarily enlisted: The first includes motives such as thirst for adventure, curiosity, and cockiness. The second group of men uses the army as way out of a personal hardship and the third group consists of men who regard the military as serious economic and social alternative to civil life especially because the military offered a possibility to -- at least temporarily -- earn one's living in an overpopulated agrarian society.

and the contiguous German areas (Duffy 1977).[19] By then the army had to raise one-third of its men in the German Empire -- at least during peace times (Allmayer-Beck 1983). The most profound change of the recruiting system took place after 1770. It included the introduction of Prussian-style cantonal conscription of males in the Hereditary Lands. It was based on the principle that every citizen was obliged to serve in the military. However, it was possible to pay a ransom or send a substitute to avoid service (Wrede 1901). Thenceforward the new recruiting-regime co-existed with the regimental recruiting and the enlistment of volunteers (Duffy 1977). These adaptations in recruitment over time also affected the regiments under consideration.

The 18th century military was usually the employer of last resort only attracting volunteers from the low social strata. General conscription, however, also forced men from higher social strata into service. The gradual introduction of conscription in Austria, therefore, could have led to an improvement in the average socio-economic composition of the sample over time.[20] However, the evidence suggests that the socio-demographic shifts in the Austro military as a result of the reform were minor. Komlos (1989) stated that the expansion of the 18th century Habsburg Army did not explain variations in height.[21] Furthermore the descriptive statistics of our sample indicate that the occupations of the soldiers did not change

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[19] In areas of the Holy Roman Empire, the recruiter needed the permission of the reigning ruler to hire soldiers.

[20] A shift in the average socio-economic background of the recruits is not the only possible reason that might change the socio-demographic composition of the sample. War is another example. Armed conflicts certainly affected the recruitment process but they might also have had an effect on the motivation of the potential recruits (patriotism) and thus influenced the composition of the sample. Urbanization is a somewhat different example. Urban dwellers were on average shorter than people living in the countryside because of a worse epidemiological environment and a worse supply of food. Periods of large rural exodus to towns influenced the composition of the data and this might have led to a decline in the secular height trend. But there is a difference between these two examples: Changes in the recruitment process are exogenous events which only affect the composition of the sample but do not influence the underlying population. Urbanization affects the general population and the changes in the sample only reflect this social trend. Therefore the effect of urbanization on height should be represented in the data as it is a cause of the evolution of average height -- at least as long as the effect of urbanization is not overrepresented in the compositional shifts of the data.

[21] Walton (1991) also found little empirical evidence for a significant change in the sociological composition of the third Infantry Regiment between 1740 and 1790.

significantly over time and thus support the notion of socio-economic stasis in the 18th century Habsburg military.

The Minimum Height Requirement (MHR)

The military has always used height as an indicator of physical strength. Hence it only accepted recruits taller than a certain MHR. This threshold value, however, changed depending on the demand for recruits. In addition, the official MHR was not always implemented consistently. Exceptions were always made. The MHR led to left truncated height distributions of military samples.

Written information on the varying standards for the Habsburg infantry throughout the 18th century is not entirely available and sometimes inconsistent.[22] It is, however, also possible to retrieve the MHR from the sample itself. We graphically inspected the height distributions of our sample and clearly identified the truncation point at 63 inch (165.9 cm). Graphical inspection also revealed that the MHR was constant over the observation period (Figure 1 and 2). Our finding is consistent with the existing written information and is, therefore, applied in the following in order to correct for the truncated height distribution. By doing this, we are able to estimate the correct height level for the underlying German population and not only the upward biased level of the recruits.

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[22] Duffy (1977) wrote that Habsburg officers usually did not accept recruits shorter than 165.1cm but it is not exactly clear to which period he refers. Komlos (1989) mentioned more specific requirements. According to him the MHR for the reserve infantry, introduced in 1753 as additional “part-time” national defense, was 165.8 cm. The MHR for the regular infantry was 163.1 cm in 1756 but was raised to 165.8 cm in 1758. Wrede (1901) mentions a MHR of 171cm for the reserve and 165 cm for the regular infantry. From 1760 onwards the MHR was enforced more flexibly (Komlos 1989).

Figure 1. Distribution of adult height by year of recruitment: 1771-1781.

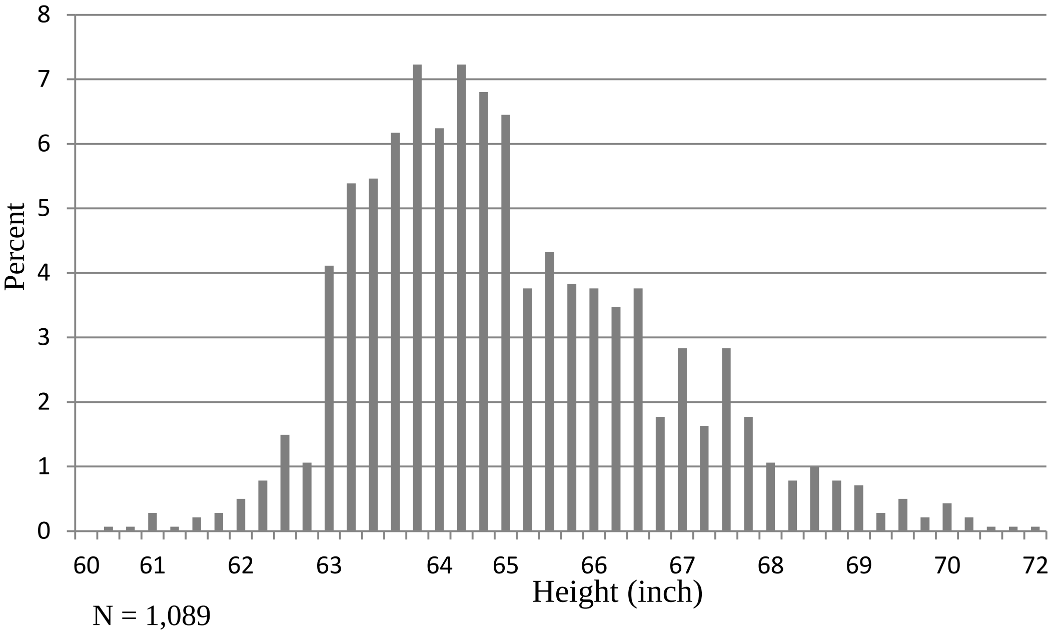
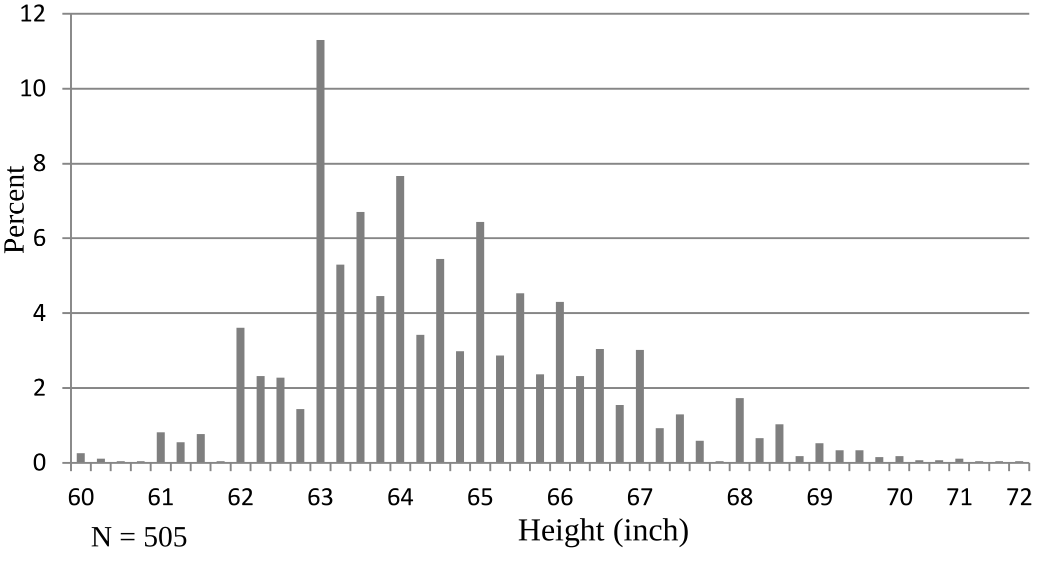


Figure 2. Distribution of adult height by year of recruitment: 1805-1808.



2.4 Method

We use the truncated maximum likelihood estimator (truncated MLE) with constrained variance to analyze the data. The truncated MLE provides consistent estimates for a whole underlying population even when a part of its distribution is missing. OLS would overestimate the average height with MHR. It is furthermore possible to increase the efficiency of the truncated MLE if the standard deviation of the distribution is constrained to a predefined value (A'Hearn 2004). We use to choose this option because the standard deviation of height distributions is constant and well documented.

Most anthropometric studies use a dummy-representation of year of birth to explore non-linearities in the time trend.[23] We estimate a quinquennial dummy variable representation as a reference model. Furthermore we estimate a trend based on splines as described by Ruppert et al. (2003). The advantage of the splines-based representation compared to dummy variables is that splines allow for both flexibility and smoothness at the same time.

2.5 Descriptive statistics

Our sample is restricted to soldiers born within the borders of the Holy Roman Empire. We create an “adults-only” and an “adult plus youth” subsample. The adults sample consists of 17,912 recruits aged 23 to 50. The adults plus youth data contain 23,649 soldiers between 16 and 50 years of age. The vast majority of the recruits came from either the Habsburg controlled territories and the Swabian Imperial Circle (Table 2).[24] The regional composition of the sample varied considerably over time. The share of recruits from Austrian possessions and Swabia increased markedly in the course of the 18th century while the percentage of recruits born in the Rhine-area declined significantly (Figure 3).

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[23] An exception is Komlos and Küchenhoff (2012) who were the first to apply splines to height data.

[24] The low share of Bavarians -- although a neighbor of the Habsburg dominions -- is probably a consequence of the close relationship between Bavaria and France during the 18th century.

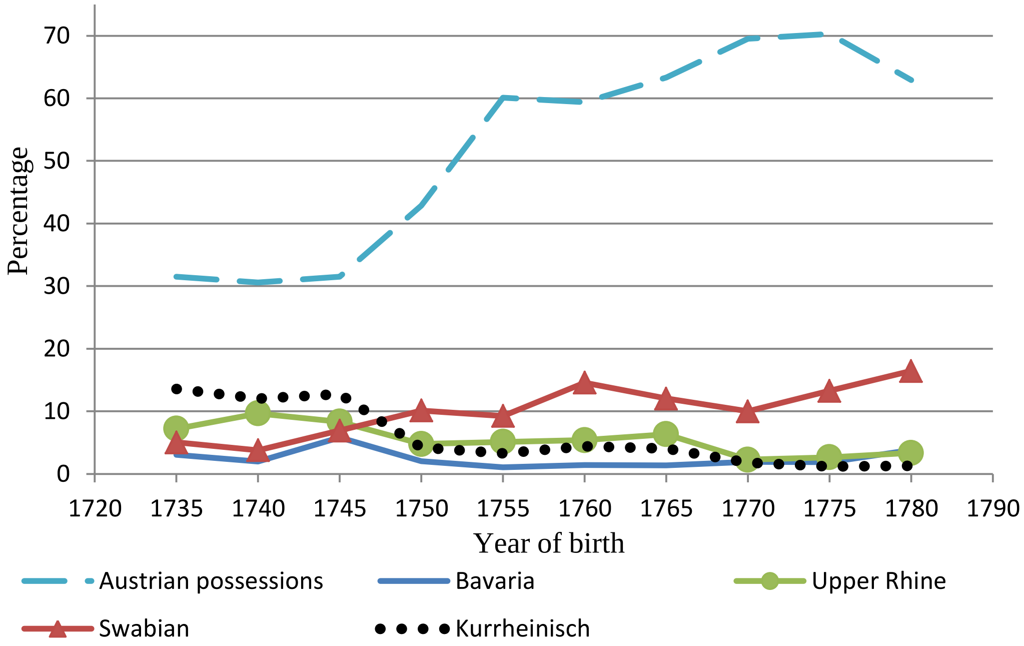
Table 2: Descriptive statistics of the Habsburg soldiers born within the Holy Roman Empire.

	Adults plus Youth		Adults	
	Number	Share (%)	Number	Share (%)
Birthplace				
Austrian possessions[1]	11,435	58.36	9,169	58.88
Bavaria	375	1.91	303	1.95
Burgundia	199	1.02	154	0.99
Franconia	443	2.26	355	2.28
Kurrheinischer	831	4.24	600	3.85
Lower Saxonia	175	0.89	147	0.94
Swabia	2,217	11.32	1,666	10.70
Other[2]	2,324	11.86	1,950	12.53
Upper Rhine	980	5.00	711	4.57
Upper Saxonia	452	2.31	387	2.49
Westphalia	162	0.83	129	0.83
Birth Decade				
1735-39	457	2.33	457	2.93
1740-44	713	3.64	713	4.58
1745-49	996	5.08	845	5.43
1750-54	1,759	8.98	1,701	10.92
1755-59	3,127	15.96	2,977	19.12
1760-64	4,193	21.40	3,062	19.66
1765-69	2,956	15.09	1,282	8.23
1770-74	1,708	8.72	1,344	8.63
1775-80	3,684	18.80	3,190	20.49
Occupation				
Professional	206	1.05	154	0.99
Service	147	0.75	115	0.74
Agricultural	85	0.43	65	0.42
Laborer	5,934	30.29	4,697	30.17
N.A.	13,221	67.46	10,540	67.66
Religion:				
Catholic	17,904	91.46	14,243	91.57
Protestant	1,353	6.91	1,083	6.96
Other	319	1.63	229	1.47

[1] This category includes the recruits born in the Austrian Circle, Bohemia or Salzburg.

[2] This category contains the observations which could not be related to a specific Imperial Circle but it was sufficiently clear that they come from within the Empire.

Figure 3: Provenance of recruits in our sample.



The occupational information was coded according to the "History of Work Information System" (Hisco). In the absence of information regarding the occupation of the recruit's parents, we have to refer to the conscript's own occupation as proxy for the socio-economic environment in which the adolescent grew up, thus assuming a low degree of intergenerational mobility.[25] Occupation is a useful indicator for the access to resources because the poorer part of the population, from which the recruits came, used most of its income for alimentation.

Specific information on the soldier's occupational status was only available for c. 33 percent of the sample.[26] The overwhelming majority of the soldiers (c. 30 percent) reported that they were production workers, haulers, or laborers (Table 2). In contrast, the religion is known for all soldiers. Catholics represent the absolute majority with c. 90 percent. It is striking that the geographical, occupational, and religious proportions are almost identical for both the "adults plus youth" and the

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[25] It has been shown that in the historical context one's own occupation is a fairly good proxy for the occupation of the parents (Zehetmayer 2010, Lantsch and Schuster 2009).

[26] There must have been many conscripts who had no prior occupation to report. On the one hand it is possible that they were so rich that they did not work, on the other hand it is possible that they were unemployed (Corvisier 1979).

"adults" sub-sample.[27]

2.6 Results

The estimated height of adult recruits born within the Holy Roman Empire decreased significantly between 1735 and 1780 (Figure 4 and Tables 3 and 4). It declined by c. 1.6 cm according to a constrained spline regression with four knots and by c. 2.0 cm according to a constrained dummy variable regression.[28]

Recruits born around 1735 were on average c. 166.3 cm tall while those born in the 1780s were only c. 164.7 cm tall.[29] The secular height trend was more pronounced for those recruits born in the Habsburg territories of the Empire than among those born in other parts of the Empire. Height there decreased by c. 2.8 cm from 167.5 cm to 164.7 cm between 1735 and 1780 (Figure 4 and Table 4). The Seven Years' War (1756 - 1763) had no obvious influence on the height trend. The modern North-South gradient in height existed already in the German Empire of the 18th century. Northerners and recruits born in the middle of the Empire were on average slightly taller than those born in the south (Figure 5).[30] Coppola (2010) confirmed this German North-South divide for the subsequent period from 1815 to 1840. These findings are also in line with Pfister (2010) who stated that Germany consisted of a north-west region characterized by favorable welfare conditions because of the proximity to the oceans and a better man-land ratio and an inland area where real incomes remained on a lower level and there the population was more dependent on the local climate. Stature in central Germany decreased by c. 1.9 cm between 1735 and 1780 while the physical stature of southerners declined by c. 5.1 cm (Figure 5 and Table 4).

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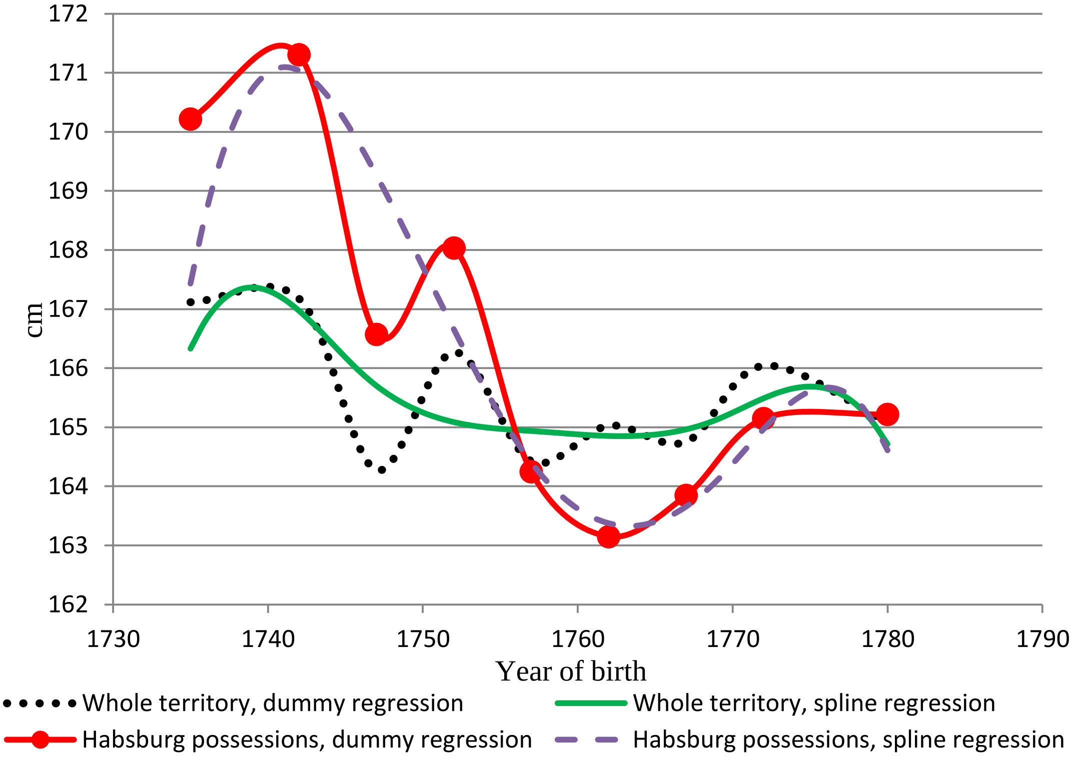
[27] Furthermore, the occupational composition of those soldiers born within the Habsburg territories of the Empire is almost identical to the main sample (not shown here).

[28] Unconstrained estimations reveal the same secular height trend but on a lower height level.

[29] All results were calculated at the mean of the sample. We subsequently refer to the results of the spline regressions if not stated otherwise.

[30] The Northern trend is not shown in the figure because there were only relatively few subjects from the north.

Figure 4: Estimated height of soldiers born within the Holy Roman Empire.



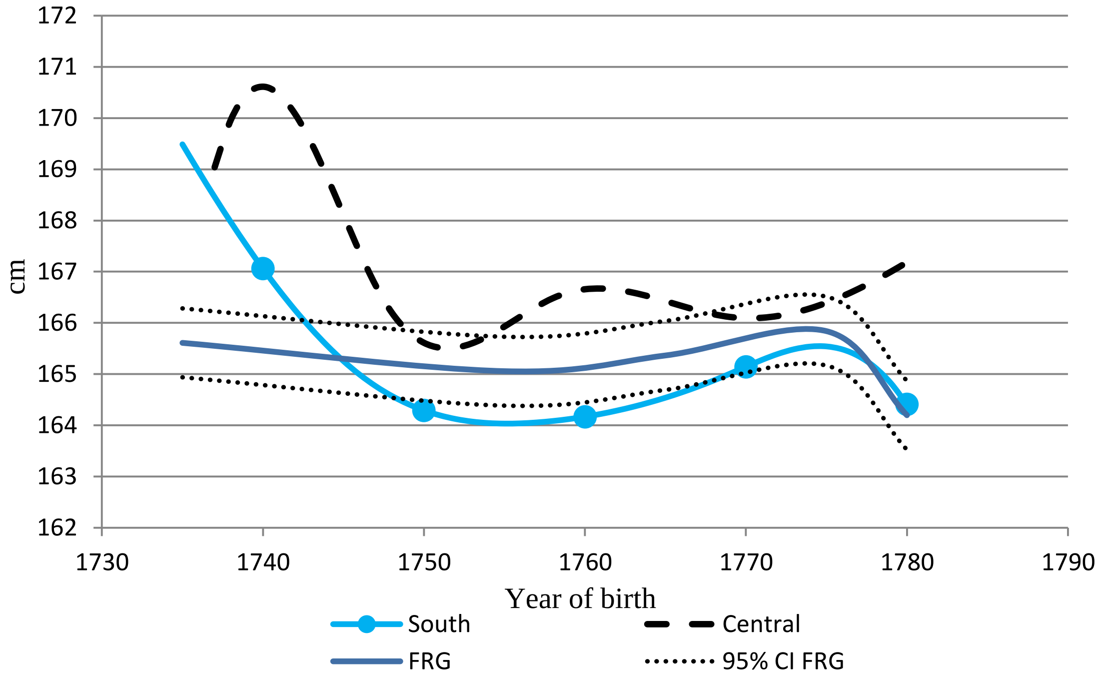
Note: The samples consists of adults and youth. N = 19,589 for "Whole territory", and N = 4,899 for "Habsburg possessions". MHR was set to 62.99 zoll. Standard deviation of height was constrained to 2.6 zoll. The height level refers to the sample mean. The covariates are the same as in table 3.

Table 3: Regression results (cm): Adult soldiers born within the borders of the Holy Roman Empire.		
	Coefficient:	Significance:
Birthplace		
Austrian possessions	0.21	
Bavaria	Reference	
Burgundia	0.00	
Franconia	0.32	
Kurrheinischer	1.24	*
Lower Saxonia	2.40	**
Swabia	0.90	
Other[1]	0.18	
Upper Rhine	0.42	
Upper Saxonia	0.42	
Westphalia	2.71	***
Birth Decade		
1735-39	Reference	
1740-44	0.05	
1745-49	-2.92	***
1750-54	-1.24	**
1755-59	-2.84	***
1760-64	-2.24	***
1765-69	-2.63	***
1770-74	-1.34	**
1775-80	-1.98	***
Occupation		
Professional	0.76	***
Service	0.93	***
Agricultural	0.11	
Laborer	Reference	
N.A.	-0.15	**
Religion:		
Catholic	Reference	
Protest	0.95	***
Other	1.05	
Age:		
16	-0.84	
17	0.55	
18	-1.79	***
19	-1.84	***
20	-0.76	*
21	-0.71	*
22	0.66	*
Constant:	166.73	***
N:	19,589	

Notes: MHR was set to 62.99 zoll. Standard deviation of height was constrained to 2.6 zoll. Results were estimated in zoll and subsequently converted to centimeters. Significance at: *: 10 %, **: 5% , ***: 1%.

[1] This category contains the observations which could not be related to a specific Imperial Circle but it was sufficiently clear that they come from within the Empire.

Figure 5: Estimated height of soldiers born in the south, central, and within the borders of today's Germany (FRG).



Note: The sample consists of both adults and youth. "South" consists of Bavaria, Austria, and Swabia. "Central" conists of Franconia, "Kurrheinischer", and Bohemia. N = 13,169 for "South", N = 2,483 for "Central", and N = 14,741 for "FRG". MHR was set to 62.99 zoll. Standard deviation of height was constrained to 2.6 zoll. The height level refers to the sample mean. The covariates are the same as in table 3 except for origin.

We repeat the trend estimations of physical stature based on a division according to today's national borders instead of historical boundaries. Again we apply a constrained truncated maximum likelihood estimator using splines.[31] The height of recruits aged 16 to 50 and born within the territory of the Federal Republic of Germany (FRG) declined by c. 1.4 cm between 1735 and 1780 (Figure 5 and

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[31] The covariates are the regions of Germany (north, central, south), occupation, religion, and age. The height level refers to the sample mean.

Table 4). Adult height also decreased by c. 1.4 cm in the same period.

Table 4: Decline in height 1735-1780 (cm).

			1735-1780		Peak to trough	
			Adults	Adults + Youth	Adults	Adults + Youth
Holy Roman Empire		Dummy	2.2	2.0	2.2	2.1
		Splines	2.3	1.6	3.8	2.6
Austrian dominion		Dummy	n.a.	5.0	n.a.	6.1
		Splines	n.a.	2.8	n.a.	7.7
Region of the Holy Roman Empire	North[1]	Dummy	n.a.	1.5	n.a.	6.5
		Splines	n.a.	4.6	n.a.	6.0
	Central[1]	Dummy	n.a.	1.0	n.a.	5.5
		Splines	n.a.	1.9	n.a.	5.1
	South	Dummy	n.a.	1.7	n.a.	5.1
		Splines	n.a.	5.1	n.a.	5.4
Germany (FRG)		Dummy	1.4	1.4	3.5	2.4
		Splines	1.4	1.4	3.0	2.4

[1] The trends for Northern and Southern Germany were calculated from 1737 onwards because of few observations in the years 1735 and 1736. Results for the adults sample are not available in some cases because of too few observations.

In a further analysis we compare the height of those soldiers born within today's territory of Germany to the stature of those recruits in our sample born in what is today Austria, France, Poland, Russia or Switzerland.[32] It is striking that the German and French height trends are highly correlated (Figure 6). A further finding is that all national height trends declined over time even though the timing of the decline varied by a few years. Most heights converged (between 165 and 166 cm) around 1775 - no matter how far apart they were in the beginning. However, one should keep in mind that the number of observations is relatively small for some of the estimated height trends (Russia: N = 144, and Switzerland: N = 89) and thus, the validity of those results is limited.

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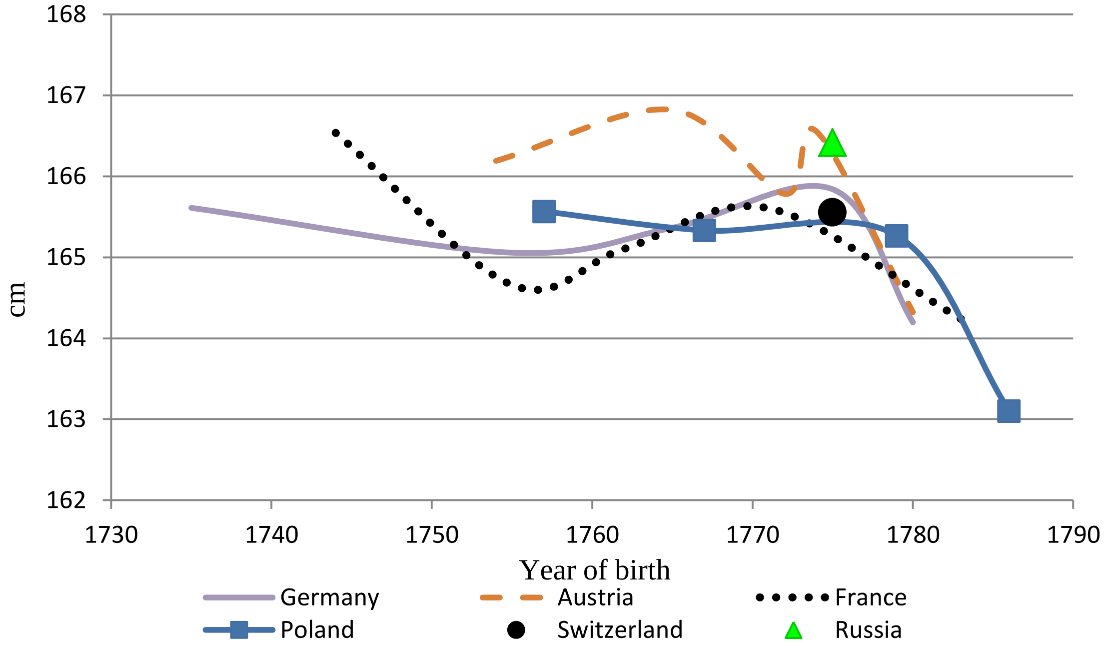
[32] Most but not all of these recruits were born in those areas of Austria, France, Poland, Russia or Switzerland which were previously a part of the Holy Roman Empire or areas bordering the Empire. Therefore, the subsamples are not representative of the respective countries with today's borders.

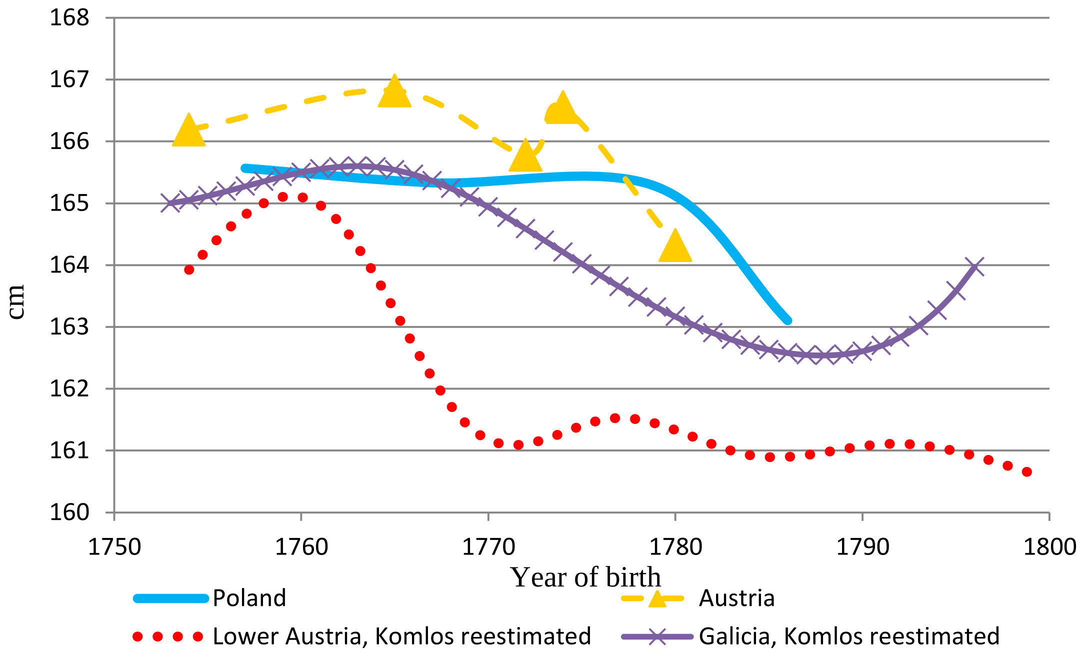
Figure 6: Estimated height of German soldiers in international comparison I.



Note: The subsamples contain adolscents and adults aged 16 to 50. N = 14,871 for Germany, N = 2,245 for Austria, N = 1,251 for France, N = 837 for Poland, N = 89 for Switzerland, and N = 144 for Russia. MHR was set to 62.99 zoll. Standard deviation of height was constrained to 2.6 zoll. The height level refers to the sample mean.

The comparison of the estimated heights of these “foreign” recruits to the Habsburg Army with estimates of previous studies reveals differences in the level of height but corresponds to the direction of the trend. The Russian recruits from our sample were on average taller than adult Russians from the province of Saratov born between 1780 and 1794 who were only 159.69 cm tall (Mironov and A'Hearn 2008). By contrast, the Swiss recruits to the Habsburg Army born in the 1770s were on average shorter than Swiss mercenaries to the British Army born between 1815 and 1819 (167.23 cm) (Kuess 2007). The secular trend of height of Polish recruits in this sample, however, is in line estimates of the height of Polish soldiers from Galicia originally studied by Komlos in 1989. Both height trends clearly decline in the second half of the 18th century (Figure 7). Our estimation for Austria also corresponds with Komlos results for Lower Austria. The trends both decline as well.[33]

Figure 7: Estimated height of German soldiers in international comparison II.



Note: The subsamples contain adolscents and adults aged 16 to 50. N = 837 for Poland, N = 2,245 for Austria. MHR was set to 62.99 zoll. Standard deviation of height was constrained to 2.6 zoll. Sources: reestimation of Komlos (1989).

In a third "international" comparison we contrast our German height estimate with other 18th century European height trends as found by previous research. We find that our decline is consistent with the trends in England, Ireland, Scotland, and France (Figure 8). There was a general decline in physical stature during the 18th century in all of these countries without exception. Nonetheless, substantial differences exist in the initial levels of height: recruits from the English-speaking countries were significantly taller than German and French recruits. This might be a legacy of the 30 Years War which left the European continent devastated. This finding is in line with Komlos and Cinnirella's (2005) indication that 18th century German men were relatively short by contemporary standards. The extent of the

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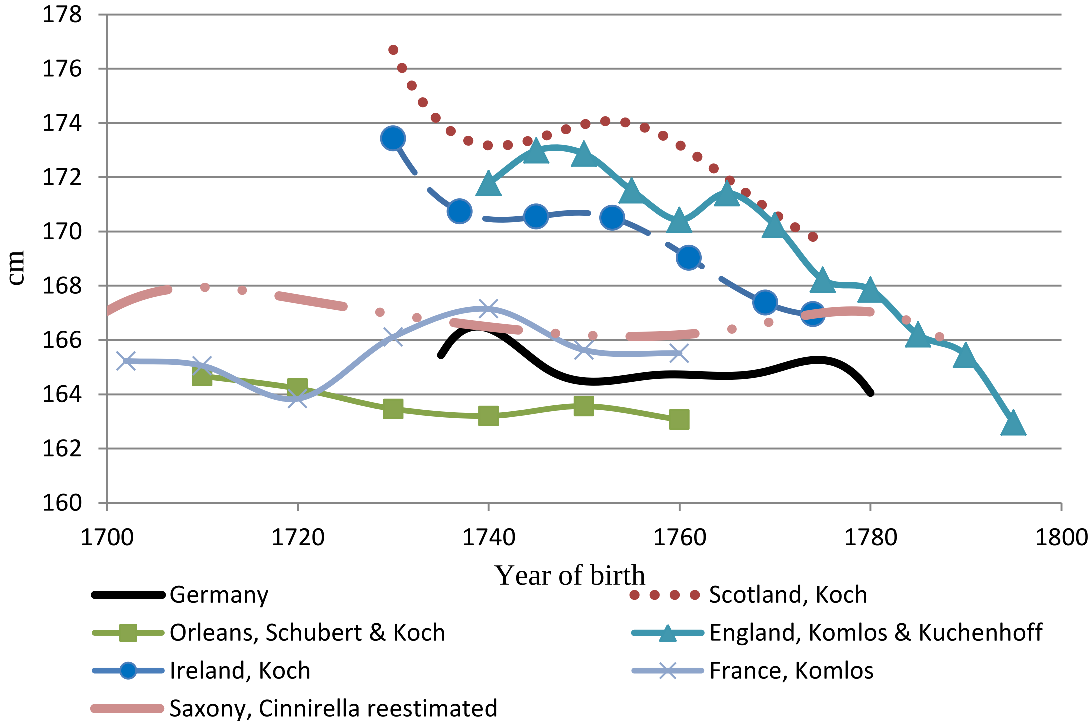
[33] The results of our reestimations of the Komlos data are very similar to his original findings based on dummy variables.

height decline also reveals an international North-South divide. The decline of the Anglo-Saxon countries was far steeper than that of the continental countries Germany and France. As a result the height levels converged in the course of the 18th century (Table 5).

Figure 8: Estimated height of German soldiers in international comparison III.



Sources: Koch (2012), Komlos (2003), Schubert and Koch (2011), and reestimation of Cinnirella (2008).

Table 5: Height of European countries (cm).

	1740:	**Trough after 1740:**
Germany	166.4	164.0 (1780)
England	171.8	163.0 (1795)
France	167.1	165.5 (1760)
Ireland	170.5	167.0 (1774)
Orleans	163.2	163.1 (1760)
Saxony	166.5	165.3 (1790)
Scotland	173.2	169.8 (1774)

Sources as in figure 9.

Cinnirella (2008) analyzed the stature of Saxon soldiers born between 1695 and 1785. He used dummy variables to estimate the trend. We have repeated his estimation but used splines instead to depict the secular development (Figure 8). The result is a downward height trend which corresponds very well to Cinnirella's original finding. The only difference is that our estimate is a slightly smoother than the dummy variable based variant. The decline in Saxon height further supports our finding of a declining biological standard of living in 18th century Germany.

2.7 Conclusion and discussion

We have found that the average stature of recruits born within the borders of the Holy Roman Empire decreased by c. 1.6 cm between 1735 and 1780 and we showed that this secular development is consistent with other European height trends which declined by between c. 3.9 cm (France) and 6.5 cm (Ireland) in the same period (Figure 8). German heights were at the low end of the European spectrum -- both at the beginning and at the end of the 18th century. Only soldiers from Orleans were smaller (Figure 8). This might have been a legacy of the 30 Years War which left Germany devastated.

Although human stature is the result of a complex growth process and reflects numerous variables and the interaction between them, it is possible to derive insightful conclusions from this height trend regarding the development of living conditions in Germany. There is no evidence that 18th century Germany experienced a significant and long-lasting deterioration in the epidemiological environment. In contrast, if there was any significant change in the general disease environment, it was for the better. Thus, changes in the disease incidence cannot explain the decline in average height during the period under consideration, given that we do not attribute much importance to the possible positive impact of the selection bias of diseases on height. It is far more probable that the decline in average physical stature was mainly the result of changes in the general economic condition throughout

Europe and in Germany in particular.[34]

The German economy probably grew in the course of the 18th century although from a relatively low level on account of the devastations of the 17th century. Sabillon (2008) estimated that it expanded on average by 0.4 percent p.a. while Gagliardo (1991) suggested that GNP grew modestly throughout the century but that the growth accelerated after 1740 as it did elsewhere on the continent. Pfister (2011) offered an estimate of the 18th century German per capita GDP based on estimates of food consumption. He calculated that the German GDP per capita grew by about 0.2 percent p.a. during the first half of the 18th century.

However, the economic growth in the 18th century was probably accompanied by an increase in social inequality. Gagliardo (1991) for example maintained that the number of the poor increased consistently both in the countryside and in the towns during that time. Increasing inequality in wealth, however, is related to decreasing heights because the increasing height of the already relatively rich becoming richer does not compensate for the declining height of the relatively poor getting poorer (Komlos 1998). Thus, increasing inequality might be one of the explanations of the estimated height trend.

A second explanation for the trend is a general decline in real wages brought about by increases in food prices and the beginning of the demographic revolution. A rising GDP and falling real wages are no contradiction and have been found in other economies as well. Van Zanden (1999) found that there was a negative link between economic development and the level of real wages in preindustrial Europe.[35] Empirical evidence indeed suggests that real wages were declining in 18th century Germany. Comparing the German height trend with Pfister's (2011) real wage index -- calculated as the fraction of the wage of an unskilled laborer in terms of grams of silver to a cost of living index -- reveals a significant correlation of 0.68:

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[34] North America did not experience such a height decline in the 18th century (Komlos 2001).

[35] De Vries (1994), however, suggests that the decline in wages was compensated to some extent by a higher labor market participation rate of the other household members, namely wife and children.

Both trends clearly declined between 1735 and 1780 (Figure 9). The regional differences in average stature also have their equivalent in Pfister's wage data. The recruits born in the north of the Empire were not only taller than in the south but the average wage was also higher there thanks to a lower land-man ratio and the integration into the maritime trading system (Pfister 2010). Allen's estimates (2001) of declining real wages for Augsburg and Leipzig further substantiate the interaction between decreasing wages and height in 18th century Germany .

But why did real wages decline? One answer is the demographic revolution. The price of food depends on the balance between demand and supply. The demand side was affected by the growing population in Germany from 17.5 to 22 million inhabitants in the second half of the 18th century (Baten 2002). The supply side was mainly determined by annual weather conditions and regional levels of market integration as there was little technological change in the German agricultural sector at this time.[36]

Weather conditions were another factor affecting food availability. Scientists draw conclusions regarding historical weather conditions by using biological and physical proxy data such as tree rings or water levels (Rösener 2010). Simulations suggest that European winter mean temperature declined by up to one degree between c. 1740 and 1780 (Luterbacher 2004, Riedwyl 2008). European summer mean temperature also declined in the second half of the 18th century. Reliable information about the average rainfall is scarce but it is known that the 1740s were dry and that periods of drought also occurred in the subsequent decades (Glaser 2001). That is to say a growing population size met with worsening climatic conditions for agriculture and, therefore, a declining food supply. Calculations show that the price of grain for example increased by c. 30% given a ten percent decline in production (Bengtsson 2009). This would have led to a significant decline in real wages. Wheat and rye prices for example increased significantly in the second half

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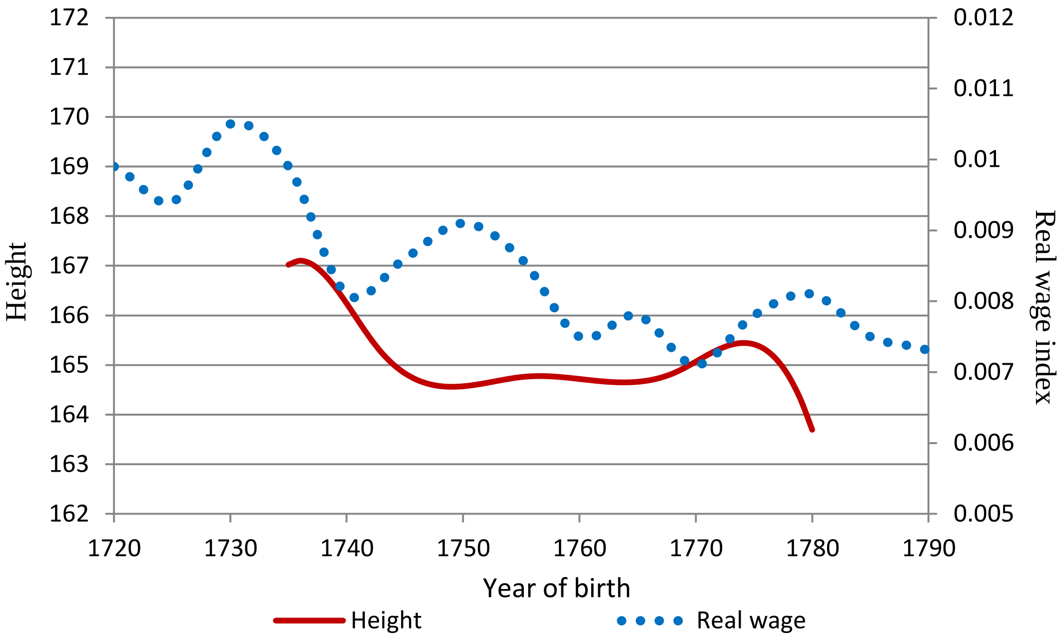
[36] The rapid spread of new crops such as maize, potatoes, peas, or beans throughout Europe from the 17th century onwards also had an impact on food supply and eating habits (Livi Bacci 1991). However, the "crop expansion" did not necessarily improve the general food supply due to the simultaneous rapid demographic expansion (Langer 1975).

of the 18th century, whereas nominal wages did not increase accordingly, leading to declining real wages (Abel 1966, 1986). As the purchasing power of much of the population declined, height decreased subsequently.[37] This was a Europe-wide phenomenon in which Germany was an integral part.

Figure 9: Height vs. a German real wage index.



Source: Pfister (2010).

In sum, our German height trend adds another piece of evidence to the discussion about the development of the biological standard of living in central Europe and clearly supports the notion of a worsening standard of living.

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[37] The decline can also be interpreted from a Malthusian perspective. Under the assumptions of limited arable land in Germany, no or little technological advance, and market competition in the 18th century, population growth led to a decline in labor productivity and, thus, in wages.

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Spatial aspects of the decline in physical stature in the Antebellum United States

We analyze the physical stature of Union Army recruits born between 1823 and 1860 in order to explore the development of the biological standard of living in Antebellum U.S. on the basis of a newly compiled sample. We use geographical weighted regression, adapted for truncated height data, to examine whether the relationship between the explanatory variables and stature depends on the provenance of the soldiers. We confirm the Antebellum Puzzle and its nutrition-based explanation. Average height of native white recruits decreased by c. two inches in the second quarter of the 19th century. Immediate access to food, vicinity to transportation, and the epidemiological environment affected average stature. The influences of those variables on height were, however, varied across regions. Spatial analyses reveal geographic patterns in the relationship between the explanatory variables and height. Being a farmer was related to a significant height advantage in the Dairy Belt but only to a minor one in the Cotton Belt. Access to transportation offered a height advantage in the more densely populated areas in the east but a height penalty in the rural western areas.

3.1 Introduction

The Antebellum U.S. was a heterogeneous country. Various regions specialized in different products such as cotton, grain, or dairy. Belt names bear witness to differences in the agricultural priorities of different regions which evolved over time. The southern areas mainly grew cotton, the Midwest predominantly cultivated grain, and the northern region (from Minnesota to Maine) mainly focused on dairy farming. In addition, there were also climatic, economic, and cultural differences which should be taken into account in any empirical research of U.S. economic history.

Until recently this spatial heterogeneity was modeled by adding regional dummy variables to regressions analyzing height data. However, this approach is not sufficient to fully capture the spatial heterogeneity at the local level. Yoo (2012) has recently made this point by using geographical weighted regression (GWR) for the first time in anthropometric history and, by doing so, he demonstrated that the relationship between an explanatory variable and height may vary greatly spatially within the U.S.. Access to transport for example influenced physical stature differently in areas that were importing food like in the Northeast -- where it had a less negative (or even positive) impact -- than in areas in the Midwest that were exporting food -- where it had an clearly adverse impact. Traditional regression analysis, however, only estimates a global coefficient for the whole country which does not reflect these potential spatial differences in the relationship.[1]

In this paper we adapt GWR to the special issues of historical height data in order to further analyze spatial patterns in physical stature of men recruited into the Union army before and after the Civil War.[2] We apply the program to new data from

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[1] To be fair: Some studies have used interaction terms between dummy variables reflecting geography and further explanatory variables in order to reveal spatial differences in the relationship between a variable and height. This approach is, however, a rather inflexible method which is only feasible if one has a-priori assumptions about the prevailing regional patterns.

[2] GWR as it exists today is based on the Ordinary Least Squares method (OLS). OLS is, however, not appropriate for truncated data such as our height data. Therefore, we have combined the idea of GWR with truncated maximum likelihood estimation which is the common approach to analyze truncated height data.

the American antebellum period. The work on this period has concentrated on those soldiers who fought during the Civil War of 1861-1865. We expend this work by analyzing the height of soldiers recruited before and after that date in order to ascertain the extent to which recruitment during the War might have affected the type of soldiers who were drawn into the military. Height data from this era is particularly interesting because of a conundrum called the Antebellum Puzzle. Fogel et al. (1979) were the first to discover a contradictory development of American average stature and traditional economic indicators in the period prior to the Civil War. They found that average height of Union Army recruits declined although per capita GDP and long run real wage grew significantly between 1820 to 1860 (Johnston and Williamson 2011, Margo 2000).[3] This contradiction was later named Antebellum Puzzle. Komlos (1987) was among the first to corroborate this decrease in average American stature: height declined by c. 1.4 cm for native born West Point cadets and by c. 2.1 cm for regular army recruits between the 1820s and 1860s. Komlos attributed the differences in the decline to the fact that West Point cadets had a higher socio-economic background than ordinary recruits. A'Hearn (1998), on the basis of a sample first analyzed by Margo and Steckel in 1983, found a decline in the average stature of white American in the 1830s. He attributed the decline to increased food prices.[4] This is in accordance with Komlos (1987) who argued that the birth cohorts of the 1830s were the ones primarily affected by the Antebellum Puzzle. A general but not monotonic or universal decline in height for Pennsylvania recruits to the Union Army, born between 1815 and 1845 was revealed by Cuff (1998). He stressed that the time profile remained when economic development is

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[3] However, the growth in real wage was not continuous between 1820 and 1860. The wage series of Johnston and Williamson (2011), Margo (2000), Williamson-Lindert (1980), and David and Solar (1977) all revealed that there were temporary subperiods of stagnation or even decline in real wages within that 40 years. Johnston and Williamson (2011), Margo (2000), and David and Solar (1977) for example identified a period of decreasing or constant American real wages in the late 1830s. Margo (2000), in addition, found that real wages declined from the late 1840s to the mid/late 1850s. He attributed the short-term erratic behavior of real wages to shocks such as a sharp increase in immigration caused by the Irish Great Famine (1845-1852).

[4] Margo and Steckel (1983) themselves had not found clear evidence for a height decline but that result was due to the use of the wrong estimation method.

considered. In the same year Haines (1998) also found evidence of a decline in the biological standard of living for Union Army recruits born after 1830.[5]

There also was a decline in the average height of free blacks throughout the antebellum period. Komlos (1992) estimated that there was a decrease in the physical stature of free blacks from Maryland by c. 1.3 cm between the 1820s and 1840s. Haines et al. (2011) analyzed the height trend of c. 8.500 adult black male recruits who served the United States Colored Troops. Their results showed evidence for a height decline from the 1820s onwards. Carson (2011) recently analyzed the height of black prisoners mainly from the South. He found that their physical stature declined by c. 0.5 cm between the 1830s and 1860s. The average height of slaves, however, did not decrease in the pre-war period (Komlos and Coclanis 1997). This was because they were not allowed to substitute manufactured goods for food in their consumption as the free population -- white or black -- was (Komlos and Alecke 1996). Profit-maximizing masters had an incentive to secure or even improve their slaves' diet in times of rising cotton prices during the antebellum period (Rees et al. 2003).

The wealthier were also not affected by declining heights. Sunder (2007, 2011) showed that the height of male and female passport applicants did not decline in the pre-war period and thus reinforced the argument made by Komlos (1987, 1996) that the decline was caused by changes in relative prices of food products. Tennessee convicts were a third group unaffected by the antebellum decline. Sunder (2004) used c. 2,500 prisoners born between 1830 and 1859 for a Bayesian analysis of the antebellum period. He found that the height of both white and black convicts was relatively constant and even might have increased in the late 1830s. He argued that the specific situation in Tennessee with a high degree of self-sufficiency in protein production protected all classes from the biological decline. Native Americans are the fourth group which was found yet to have not experienced a

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[5] Independent of the pre-war height decline, Americans had a significant height advantage compared to Northern and Western Europeans in the middle of the 19th century (Komlos and Baur 2004).

decline in height in the antebellum period (Komlos and Carlson 2012). The fact that all these disparate groups were exempt from the Antebellum Puzzle is an indication that the diminution of heights was not brought about by a deterioration in the disease environment, because that would have affected all segments of the society in an epoch in which medical technology was rather rudimentary.

Furthermore, heights did not continue to decline after the end of the Civil War. Zehetmayer's (2011) analysis of c. 58,000 Union Army recruits revealed that height continued to decline during the war by c. 0.4 in., stagnated thereafter, and increased towards the end of the century. Additional evidence of a temporary (but earlier) height increase is given by Hiermeyer (Hiermeyer 2010) who found that West Point cadets born in the 1880s were about 1.5 cm taller than those born in the 1860s. The chronology was somewhat different for cadets to The Citadel, the Military College of South Carolina. Coclanis and Komlos (1995) found that their average stature basically stagnated throughout the end of the 19th century which reflected the difficulties the Southern economy encountered after the Civil War.

3.2 Data

> *"In America, conscription is unknown; men are enlisted for payment. Compulsory recruitment is so alien to the ideas and so foreign to the customs of the people of the United States that I doubt whether they would ever dare to introduce it into their law."*
>
> (de Tocqueville)

Alexis de Tocqueville was wrong, however. The Civil War did bring conscription to America. In the first half of the 19th century, however, the U.S. relied on a small, volunteer army, supplemented in times of war by the militia and by the U.S. Volunteers. As a result our military data are not representative of the 19th century

U.S. population.[6] We use the available information regarding the recruits' occupation prior to recruitment in order to control for possible changes in the socio-economic composition of our sample over time.

Occupational information

The data regarding the recruits' occupations prior to enlistment are given in the form of job titles. Only 46 of 23,651 observations did not contain any information. We linked the job titles to the five-digit hierarchical scheme supplied by the History of Work Information System (HISCO). Entries with obvious spelling errors were subsequently classified by hand. Thus it was possible to classify the occupations of 22,982 soldiers. The 193 identifiable different job titles were subsequently classified into the seven major categories suggested by HISCO.

We use the occupation categories as a proxy for the socio-economic environment in which the recruit grew up because we do not know the occupation of the recruit's parents or anything else about the individual economic situation during his growing years. Zehetmayer (2010) has shown that the recruit's occupation is a fairly good proxy for the occupation of the parents because of a low degree of intergenerational mobility in the 19th century United States. The ooccupation of the breadwinner of the family in turn is a good indicator of the financial situation of the family.[7]

Geographical information

The data contain information on the soldiers' location of birth as well as the location of their enlistment. All but 63 observations contain the state of birth which we use to assign the observation to their census division of birth, the geographical unit used in the basic trend estimation. In addition, all but 574 entries contain further spatial information regarding the place of birth. Those observations were geocoded with

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[6] Candey (2000) writes: "Historically, the quality of men who would sign up with the army, in a country of expanding economic opportunities, was poor."

[7] Cuff (1993) has shown that the danger of a self-selection bias in the variable "occupation" is low.

latitude and longitude by merging our data with an extensive data base of c. 130,000 American location names from the U.S. Board on Geographic Names. Further 1,091 observations were manually geocoded, after having corrected spelling errors in the location names. All told, we could geocode 15,135 of the 23,651 observations with latitude and longitude from 1,722 different places. The remaining observations could not be identified, either because the location name existed more than once within a state or because the spelling error was not obvious.

Additional census information

Nutrition and disease are well known factors influencing height. In order to evaluate the influence of these two variables on the physical stature of soldiers, we merged our observations with county-level data from the census of 1840 as published by the National Historical Geographic Information System (NHGIS).[8] By doing so, we are able to create a variable “Self-sufficiency” which describes whether a county was able to feed its population or not. The variable equals one if the quantity of calories produced within the given county in the course of a year equals or exceeds the average yearly calorie consumption of the county’s population. We calculate the calorie balance of a county by using the produced quantities of food (crops, dairy products, meat) as given in the census of 1840, consider for the probable quantities used as livestock supplementary or seed, convert the number to calories, aggregate the figures and divide it by the estimated total energy requirement of the county’s population. This total calorie requirement is estimated by multiplying the number of people with the calorie consumption of an average human being. The sex and age

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[8] Minnesota Population Center. *National Historical Geographic Information System: Version 2.0.* Minneapolis, MN: University of Minnesota 2011.

structure of the population was thereby considered.[9]

While we use the information about the available calories per county to proxy food supply in the immediate vicinity, we calculate the age-specific death rate stratified by gender per county in 1840 to consider the epidemiological environment. Similar to Zehetmayer (2010) or Haines et al. (2003) we therefore resort to the number of deaths as stated in the census of 1840. Contrary to them, we adapt these figures according to the age and sex structure of the county in order to consider the different demographical composition of the counties.

Transportation is a further variable which might influence height indirectly by facilitating the spread of diseases or the access to food markets. The existence of navigable waterways in a county is an often used proxy for access to transportation because information about it is available in the census. We also use this dummy variable because it captures the degree of market integration. Nonetheless, this variable also has disadvantages insofar as the access to waterways could also be provided to contiguous counties.[10] We also created another variable in order to

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[9] Alternatively we use the quality of the soil with regard to the suitability for crop cultivation in order to measure the immediate food supply. Soil quality as proxy for immediate access to nutrition has three advantages. First, the character of the soil is certainly an exogenous variable. Second, the census data regarding agricultural output are snapshot data and can vary significantly, annually. The quality of the soil, however, is a relatively time-constant variable. Third, it is even more precise than the county-level calorie data. Grid cell size of the data is 30 arc second (c. 900 meter). Information about the soil was taken from the Harmonized World Soil Quality Database created by the Land Use Change and Agriculture Program of the *International Institute for Applied Systems Analysis* and the Food and Agriculture Organization of the United Nations. Data are taken from: Fischer, G., F. Nachtergaele, S. Prieler, H.T. van Velthuizen, L. Verelst, D. Wiberg, 2008. *Global Agro-ecological Zones Assessment for Agriculture (GAEZ 2008).* IIASA, Laxenburg, Austria and FAO, Rome, Italy.

The correlation coefficients between the produced quantities of food (measured in calories) within a country and its average soil quality are 0.25 for the best soil, -0.26 for the second best, and -0.39 for the third and worst quality.

[10] Let’s assume that there are two neighboring counties A and B. A has access to navigable waterways and the dummy variable is therefore set equal to one. County B does not have direct access to navigable waterways and as consequence the variable is set equal to zero. However, depending on the specific geographical position of the waterway within county A, it is possible that the inhabitants of county B have -- on average -- better access to the waterway than those people from county A. In such a case, the dummy variable does not reflect the true situation because county borders are no natural barriers which exclude the neighbors from the use of its infrastructure.

capture the degree of urbanization in the vicinity of the recruit's birthplace. In this period there was an urban penalty in height, people in towns tended to be shorter because the disease pool was more extensive in urban areas and because urban populations had to pay higher prices for food than rural ones. The variable "Town" is a dummy variable set equal to one if the recruit was born in a town with more than 5,000 inhabitants. The variable "Town nearby" is a dummy variable set equal to one if there is a town with more than 5,000 inhabitants within 20 km of the recruit's birthplace. Distance is calculated as road distance and not bee-line distance. Distances were calculated with ArcMap 10 and the use of freely available shapefiles reflecting the major road connections in the United States.[11]

3.3 Descriptive statistics

The main sample consists of 23,443 recruits, born between 1823 and 1848.[12] Years of recruitment were 1866 to 1870 and, thus an advantage of this data set is that it is not affected by Civil War recruiting as the entire sample pertains to those who entered the military in peace time. Mean age at time of measurement was 22.9 years for all recruits and 25.7 years for adult recruits older than 21. The 12,419 recruits younger than 21 years at time of recruitment are included in the all-age sample.[13] Graphical inspection of the height distribution of the adult sample reveals that the Minimum Height Requirement (MHR) was 65 in. (Figure 1).

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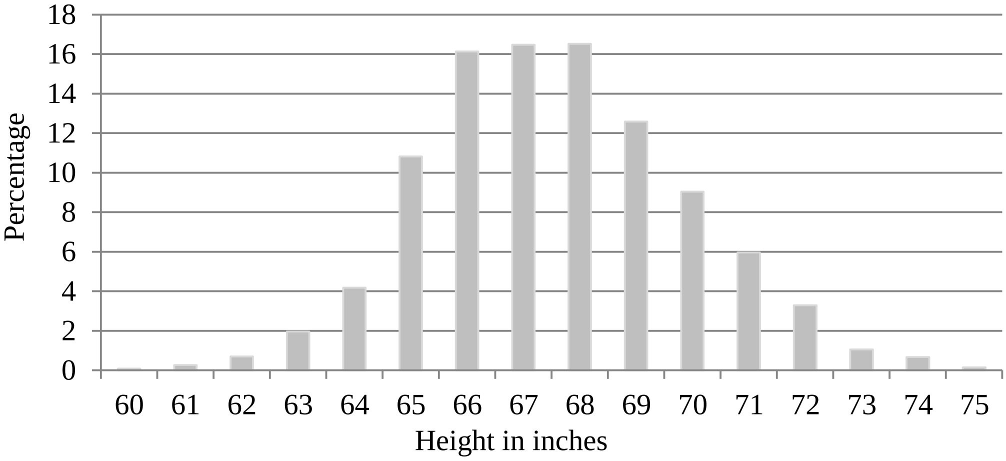
[11] As there was no freely available digital information on historical roads of the 18th century, we had to rely on 20th century major road information.

[12] The characteristics of the height data for the years 1849 to 1860 are rather particular. Therefore, they are considered separately. More details are given in the fifth chapter.

[13] We had to exclude 666 observations because of missing basic information such as age.

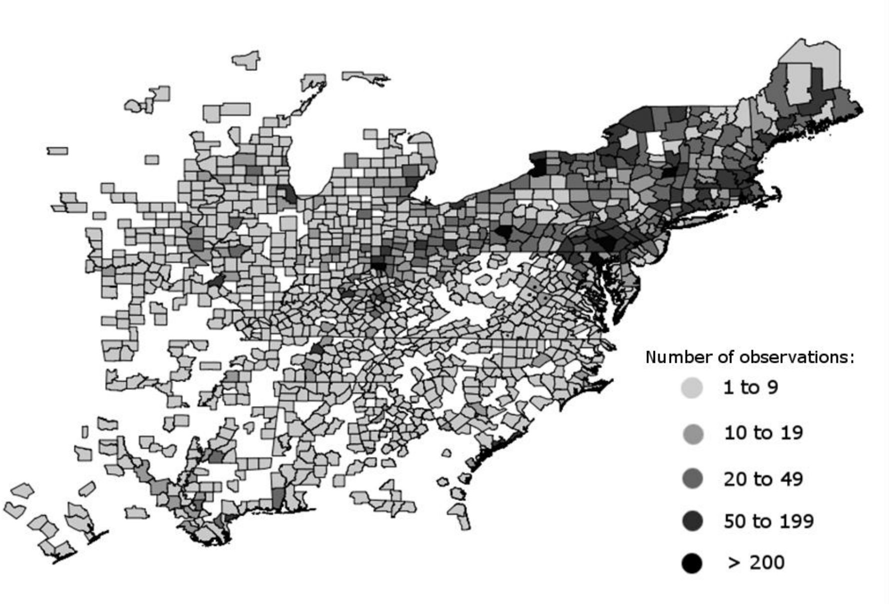
Figure 1: Height distribution of adult American recruits: 1823- 1848.



N = 10,358.

The spatial distribution of the sample is uneven (Figure 2). Most observations stem from the Middle Atlantic region including New York, New Jersey, and Pennsylvania (Table 1). Many observations are from the Northeast, the Midwest, and the South Atlantic region. Few recruits are from West North Central, East South Central or West South Central, and no soldiers were from the Mountain or Pacific census division. The regional composition of the sample is about the same for adults and adults plus youth. Furthermore, two out of three recruits were recruited in another state than their state of birth. We refer to them as "movers" (Table 1).

Figure 2: Spatial distribution of the sample.



The figure shows the counties in the United States. The darker a county the more observations were born within its borders.

Table 1: Descriptive statistics of the American soldiers recruited 1866-1870.

	Adults plus Youth		Adults	
Birth cohort:	Observations	%	Observations	%
<1829	233	1.0	233	1.9
1830 – 1834	793	3.4	793	6.5
1835 – 1839	1,251	5.3	1,251	10.2
1840 – 1844	6,193	26.5	6,193	50.6
1845 – 1848	13,265	56.6	3,198	26.1
Birthplace:				
New England	3,214	13.7	1,665	13.6
Middle Atlantic	10,050	42.9	5,602	45.8
East North Central	4,194	17.9	1,843	15.1
West North Central	597	2.6	291	2.4
South Atlantic	3,202	13.7	1,737	14.2
East South Central	1,548	6.6	818	6.7
West South Central	568	2.4	262	2.1
Mountain	3	0.0	2	0.0
Pacific	27	0.1	11	0.1
Occupation:				
Professional	1,139	5.0	590	5.0
Managerial workers	27	0.1	10	0.1
Clerical worker	1,414	6.2	938	7.9
Sales	277	1.2	150	1.3
Service	3,897	17.1	2,693	22.6
Agricultural	5,191	22.8	1,884	15.8
Laborer	10,843	47.6	5,648	47.4
Military branch:				
Infantry	12,311	52.6	5,913	48.3
Artillery	2,532	10.8	1,506	12.3
Cavalry	6,073	25.9	3,338	27.3
Unknown	2,415	10.3	1,439	11.8
Mover:	15,075	64.4	8,741	71.4

The occupational structure of the sample is unevenly distributed as well. Many of the adult soldiers were formerly engaged in service (22.6%), or agriculture (15.8%), but most of them (47.4%) were former laborers employed in production or transport. The only major difference in the occupational composition of the two subsamples "adults" and "adults plus youth" is the fact that the younger soldiers were more often engaged in agriculture than in the service sector.

Of the 646 counties in the sample 430 produced sufficient calories for the nutritional needs of all of its inhabitants, plus its livestock. Precisely 39 percent of the recruits were born in a self-sufficient county, (Table 2). The age-specific death rate stratified by gender is 18 deaths per 1,000. The range is from 5.28 deaths per 1,000 inhabitants in Porter/ Michigan to 28.09 in New Orleans/ Louisiana. Many recruits (54% and 58%) were born near a town, 12 % were born in a town with more than 5,000 inhabitants. Almost all subjects (89% and 91%) were born in a county with access to navigable waterways.

Table 2: Descriptive statistics II.

	Adults plus Youth			Adults		
	Mean	Min	Max	Mean	Min	Max
Self-sufficiency	0.39	0	1	0.36	0	1
Death rate[1]	18.23	5.28	28.09	18.58	5.28	28.09
Town nearby	0.54	0	1	0.58	0	1
Town	0.12	0	1	0.12	0	1
Waterway	0.89	0	1	0.91	0	1

[1] Death rate refers to age-specific death rate stratified by gender.

3.4 Method

Since the beginning of research in the field of anthropometric history three decades ago, the statistical methods have become more sophisticated: Nowadays, truncated regression is employed to consider when height data is truncated, (penalized) splines are used to estimate smooth height trends, and constraints on the variance are imposed to increase the efficiency of the estimator.[14] One important issue, however, has been addressed only recently: the “globality assumption”. Common models assume that the relationship between an explanatory variable and stature is the same within the whole sample and do not allow for variations in the coefficient corresponding to distinct characteristics of the observations. Researchers thus implicitly assume that their estimated coefficients hold globally across the entire sample.[15] Yoo (2012), however, argued convincingly that there are reasons to believe that the relationship between some variables such as transport and height might well vary depending on the geographic location of the observation. More specifically, he assumed that the influence of a variable such as access to transportation on height might vary by location because the effect should be theoretically different in exporting and importing regions. Heights should benefit from food imports but height should diminish in food exporting regions. Hence, the effect of transportation on height should vary spatially. As a consequence he introduced geographical weighted regression (GWR) to the field of anthropometric history. GWR enables one to estimate spatially varying coefficients and, thus, helps to detect and depict spatial patterns in the relationship between an explanatory variable such as access to transport and physical stature.

In this paper we adapt GWR to the special challenges of height regressions, namely truncated data, and also restrict the influence of outliers on the result.

The idea behind GWR is the assumption that the influence of a covariate on the dependent variable may depend on the location of the observations given as latitude and longitude. Using Ordinary Least Squares would lead to one coefficient reflecting the global average but not the true spatial-dependent causal

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[14] We apply splines based on truncated power functions for all regressions here but do not explain their role as they are extensively described elsewhere in the dissertation. We also use a truncated maximum likelihood estimator with constrained variance here but we do neither explain its functioning as it a standard approach.

[15] Some regression models use interaction terms to improve the “globality assumption” to some extent. However, this is only a rudimentary approach and requires that the structure of the variation is known. In this case we would have to use 675 interaction terms in order to capture the spatial effect on the county level.

relationships.[16] GWR, however, captures these spatial effects by calculating 676 local coefficients (one for each county) which can be drawn in a map thereafter.[17]

To be more precise: GWR estimates one relationship $y_i = \alpha_i + \beta_i X + \varepsilon_i$ for every (spatially-unique) observation i instead of just estimating a global model $y = \alpha + \beta X + \varepsilon$. The appropriate estimator can be written as:

$$\hat{a}(u) = (X'W(u)X)^{-1}X'W(u)y.$$

where W is the weighting matrix containing the observation-specific weights w_i. It corresponds to a weighted least squares estimator with the feature that the weight of the observations depends on its distance from the respective reference location/ observation i. It has been shown that the precise configuration of the weight does not matter as long as it depends upon the distance (Fotheringham et al. 2010). We apply the most common weighting formula:

$$w_i(u) = \left(1 - \left(\frac{d_i(u)}{h}\right)^2\right)^2$$

where d_i represents the distance between the observation i and the reference point, h the bandwidth and w_i the corresponding weight. The bandwidth h determines the

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[16] The following figure, taken from Fowler (2011), elucidates the idea of spatial variation. Even if the true β depends on the location of the observations:

$$\begin{array}{ccccc} .9 & .8 & .8 & .7 & .5 \\ .8 & .7 & .6 & .5 & .4 \\ .7 & .6 & .5 & .4 & .4 \\ .6 & .5 & .4 & .3 & .2 \\ .5 & .4 & .3 & .2 & .1 \end{array},$$

the coefficient estimated by OLS is nonetheless global:

$$\begin{array}{ccccc} .5 & .5 & .5 & .5 & .5 \\ .5 & .5 & .5 & .5 & .5 \\ .5 & .5 & .5 & .5 & .5 \\ .5 & .5 & .5 & .5 & .5 \\ .5 & .5 & .5 & .5 & .5 \end{array},$$

leading to spatially-dependent residuals:

$$\begin{array}{ccccc} + & + & + & + & 0 \\ + & + & + & 0 & - \\ + & + & 0 & - & - \\ + & 0 & - & - & - \\ 0 & - & - & - & - \end{array}.$$

[17] The geographically weighted regression is extensively discussed in a book by Fotheringham et al. (2010). There are also short introductions into the topic, e.g.: Brunsdon et al. (1996) or Wheeler and Pàez (2010).

radius around the reference observation within which observations are considered and weighted with the above-mentioned distance-based weight. Beyond the bandwidth distance observations are considered with a weight of zero and thus not represented in the local regression. There are two ways to determine the bandwidth. The first possibility is to use a fixed bandwidth which is the same for all observations. The second possibility is to use an adaptive bandwidth which varies by locality. The difference is that in the first case different local regressions contain different numbers of weighted observations depending on the spatial distribution of the sample. The second method, adaptive bandwidths, avoids that by individually choosing the bandwidth for each regression in such a way that there is always the same number of observations. The chosen bandwidth is small if the reference observation is located within a crowded area. The bandwidth is large if the reference is located in a sparsely populated area. We apply adaptive bandwidths because of the rather irregular spatial distribution of the observations in our sample (Figure 2). The optimal number of observations is usually determined by leave-one-out cross-validation. The cross-validation score is found by the following formula:

$$CV = \sum_{i=1}^{n} (y_i - \widehat{y_{\neq i}}(u))^2$$

where the cv-score for a given bandwidth u is the sum over all n squared deviations of the left out reference height minus the estimated height for the left-out observation. Mathematically, the cross validation procedure creates a n x k matrix which contains the n squared residuals for a given bandwidth on the columns and the sum over one column yields to the cv-score for the given bandwidth. Each column represents one of the k tested bandwidths.[18]

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[18] n corresponds to the number of observations, and k corresponds to the number of tested bandwidths.

n x k matrix of residuals:

$$\begin{array}{l c c c}
 & \mathbf{1} & \cdot\ \cdot\ \cdot & \mathbf{k} \\
\mathbf{1} & (y_1 - \widehat{y_{\neq 1}}(u_1))^2 & & (y_1 - \widehat{y_{\neq 1}}(u_k))^2 \\
\cdot & \cdot & \cdot\ \cdot\ \cdot & \cdot \\
\cdot & \cdot & \cdot\ \cdot\ \cdot & \cdot \\
\cdot & \cdot & \cdot\ \cdot\ \cdot & \cdot \\
\mathbf{n} & (y_n - \widehat{y_{\neq n}}(u_1))^2 & \cdot\ \cdot\ \cdot & (y_n - \widehat{y_{\neq n}}(u_k))^2 \\
\hline
 & \sum_{i=1}^{n}(y_i - \widehat{y_{\neq i}}(u_1))^2 & & \sum_{i=1}^{n}(y_i - \widehat{y_{\neq i}}(u_k))^2 \\
 & \uparrow & & \uparrow \\
 & \text{cv-score for first bandwidth} & & \text{cv-score for k}^{\text{th}}\text{ bandwidth}
\end{array}$$

There exist (user-written) add-ons for R, STATA, and ArcGIS, as well as specialized stand-alone software which enable the user to apply GWR. However, we have written our own GWR procedure in STATA 11.1 for two reasons. First, existing GWR software -- as the one used in Yoo (2012) -- or user-written commands for statistical software are all based on the least squares routine. Military data, however, is usually truncated and, generally requires a truncated maximum likelihood estimation approach to avoid biased results. The same is true with respect to the geographic analyses. Results of ordinary GWR could be biased if the minimum height requirement were not controlled adequately in the estimation. Therefore, it is important to use GWR based on a truncated maximum likelihood estimator. The only difference of our adapted GWR as compared to the ‘standard’ GWR is that we use a weighted truncated maximum likelihood estimator instead of a weighted least squares estimator. The second advantage of our self-written approach is that it enables us to adapt the cross-validation routine used to determine the optimal bandwidth h. Farber and Pàez (2007) have shown that the traditional cross-validation score (and thus the chosen bandwidth) is disproportionately influenced by few observations with unrepresentative characteristics.[19] There exist several methods to limit the influence of these ‘outliers’. We use the so-called row-standardization procedure suggested by Farber and Pàez (2007). Row-standardization means that

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[19] In our sample the largest residual is c. 370 times larger than the average residual. This would mean that this single observation influences the optimization procedure 370 times more than an average observation.

each residual in the above shown n x k matrix is divided by its respective row-sum before being aggregated to the cv-score. This approach restricts the influence of single outliers on the cv-score as they are thereby standardized to a value between zero and one.

3.5 Results

3.5.1 Time trend

We use the truncated maximum likelihood estimator (truncated MLE) with constrained and unconstrained standard deviation to analyze the data. Splines with four knots are used to allow for a flexible and smooth representation of the trend. The secular height trend is estimated with only few explanatory variables (age, state of birth, occupation, and military branch) in order to not reduce sample size due to missing information. The height levels as shown in our figures refer to the sample mean. Physical stature clearly declined over time as in prior samples. Height decreased by 2.15 in. (5.5 cm) between 1823 and 1848 (Figure 3).[20] 95% confidence bands confirm that the downward trend is significant. Several sensitivity analyses were conducted in order to evaluate the influence of different numbers of knots, or the inclusion of the year of enlistment into the regression (not shown here). Furthermore, we analyzed the height trend by various subsamples such as occupation or region of birth (Figure 4 and 5). All these additional regressions confirm the downward height trend.

Additional data taken from a large data set analyzed by Zehetmayer (2010) reveal that the trend declined after 1848 as well (Figure 3). The 758 recruits born between 1849 and 1860 are considered separately from our main trend because they were longer serving recruits and, therefore had special characteristics. Nonetheless, average height also declined in these additional eleven years under observation. Physical stature decreased by c. 0.60 in. (1.51 cm) from 67.1 to 66.5 in. The higher average height level in Zehetmayer’s data set compared to our main sample is due to the fact that the subjects were re-enlistees and they were also older. Hence, they

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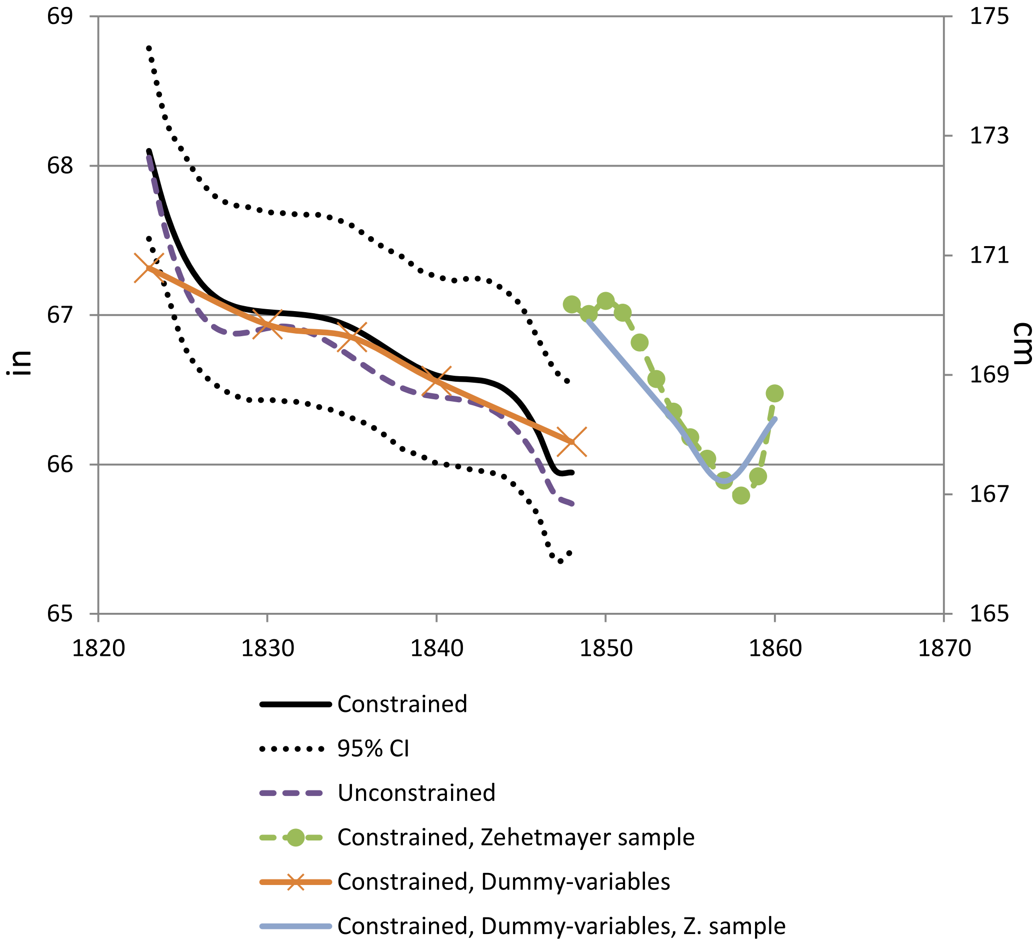
[20] The height trend remains the same if we restrict our sample to adults, aged 22 to 50.

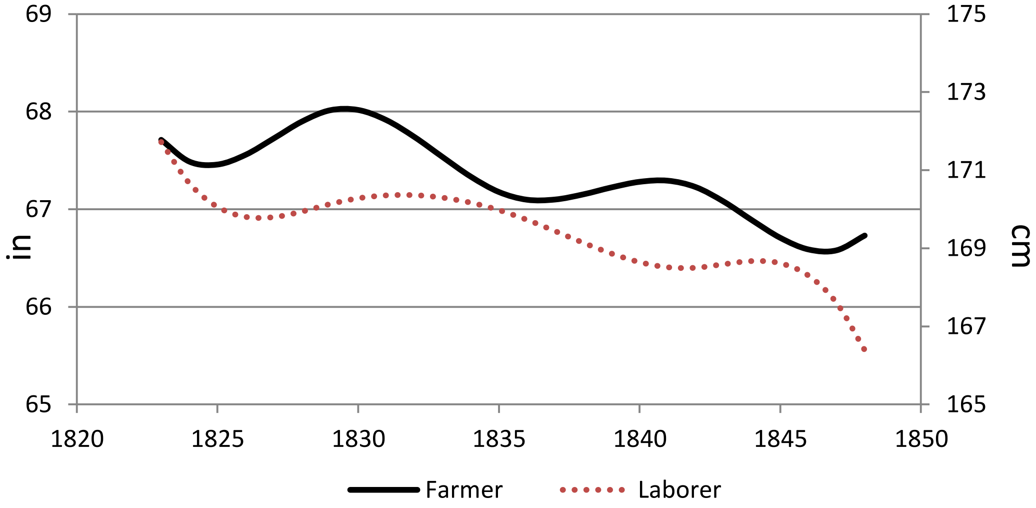
might have been taller also because of the survivor bias, which means that shorter people die younger leaving the older people taller than average.

Figure 3: Height of adult American soldiers.



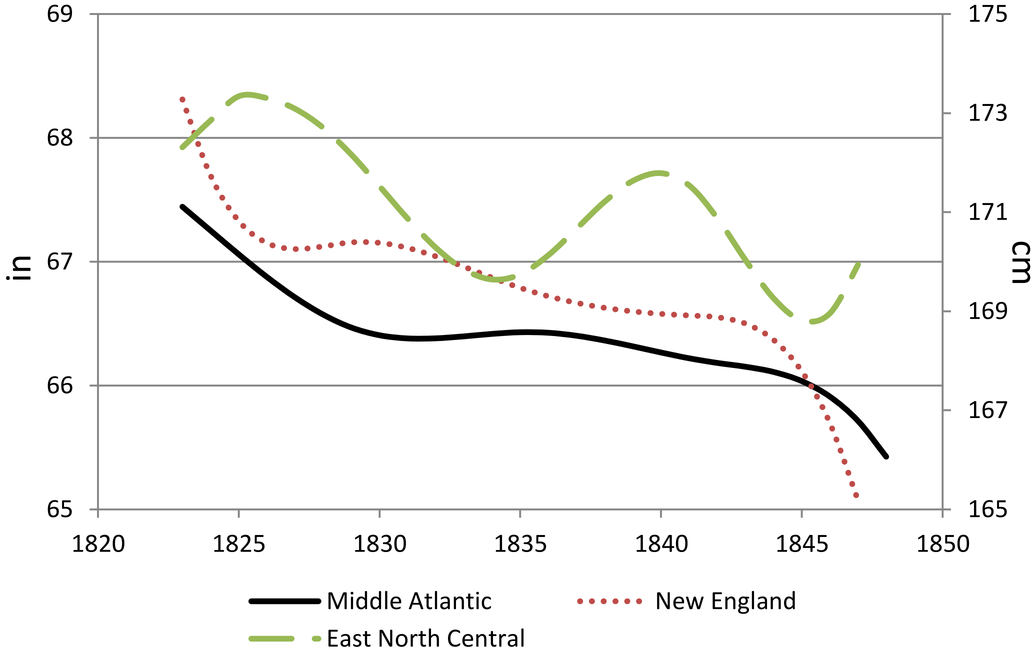
Note: N = 10,358. Covariates of the respective regression are state of birth, and military branch. The MHR was set at 64.99 inch. The height levels refer to the sample mean. CI refers to the constrained estimation with splines.

Figure 4: Subsample analysis by occupation.



Note: N = 1,884 for adult farmers and farm-related workers, N = 5,648 for adult laborer
Covariates of the respective regression are state of birth, and military branch.
The MHR was set at 64.99 inch. The height levels refer to the sample mean.

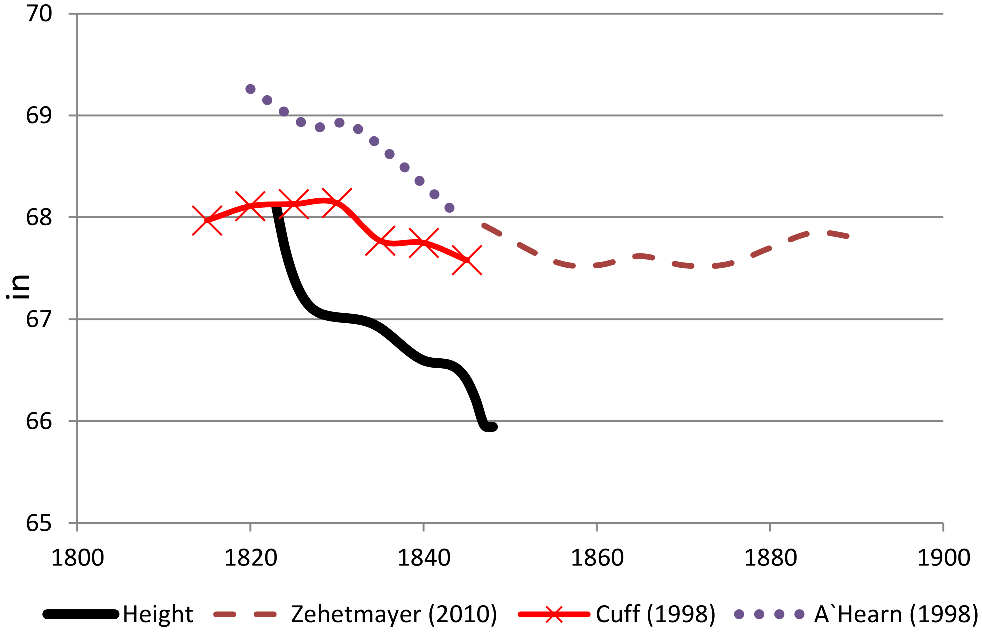
Figure 5: Subsample analysis by Census division.



Note: N = 5,602 for Middle Atlantic, N = 1,665 for New England, and N = 1,843 for East North Central. Covariates of the respective regression are occupation, and military branch. The MHR was set at 64.99 inch. The height levels refer to the sample mean.

Our downward trend is consistent with the Antebellum Puzzle (Figure 6). Average height of Cuff's (1998) recruits from Pennsylvania declined by 0.53 in (1.34 cm) between the 1820s and 1845. Komlos (1996) found a decrease by 0.22 in. (0.56 cm) from 1820 to 1840. Heights of recruits from the East-North-Central region also clearly declined in the same period (A'Hearn 1998).

Figure 6: Height of adult Union Army soldiers in comparison.



Note: N = 10,358. Our height as in figure 1. Zehetmayer's data refer to "common" American recruits. A'Hearns recruits were adult and from East-North-Central. Cuff's trend refers to 22 years old unskilled recruits from Pennsylvania.

While the existence of the Antebellum Puzzle was quickly and unanimously acknowledged by the scientific community, the possible reasons for that pre-war development were discussed intensively throughout the last quarter-century. There are, however, good indications that the decline in height was related to a change in the average diet rather than ascribed to a worsening epidemiological environment. Komlos (1987, 2012) argued that the agricultural productivity did not keep up with the rapid population growth and urbanization in the pre-Civil War period. There was an imbalance between food supply and demand and this consequently led to increased food prices relative to industrial goods and caused a deterioration of diet quality. Numerous data support this line of reasoning. Total population nearly doubled from 9.6 million in 1820 to 17.1 million in 1840 and, at the same time, the urbanization rate climbed from 7.2 percent to 10.8 percent (Carter et al. 2006). This development was accompanied by a significant decrease in the relative labor force employed in agriculture (Weiss 1986, 1992).[21] Furthermore, in 1820 still 71% of the Northern population lived on farms, whereas 40 years later the rural population only represented 41% of the total population (Atack and Bateman 1987). Relative prices of food rose because productivity gains in the agricultural sector were not sufficient to compensate for the increased demand for food driven by the population boom (Komlos 1987). Weiss (1993) estimated that the average annualized rate of farm output per worker rose by only 0.14 % between 1800 and 1820, and by 0.44 % between 1820 and 1840.[22] Beib-Gundersen and Zahrt (1996) reviewed the productivity estimations and obtained the same figures. The productivity gains were low because little was known about capital-intensive, scientific farming in the pre-Civil War period and technological advances were still in their infancy (Atack 2000). The first harvesters were patented in 1833 and 1834, respectively, but few were sold till 1850; mechanical threshers were also introduced in the 1830s and 1840s but were oversized and too expensive for individual farmers in the first decades to have a sustainable impact on production (Atack 2000). Danhof (1969) also concluded that agricultural productivity gains were not substantial until after 1840 and further stated that even in 1850 only few farmers had taken the chance and fully adapted to the new technical possibilities. There were also no major advances in plant breeding because the necessary biological knowledge did not exist yet (Atack and Passell 1994). In sum, there were no catalysts for a distinct increase in agricultural productivity in the 30s and 40s and in the 50s they were perhaps available but not broadly applied yet.

As a result per capita production declined and food prices rose. Cuff (1992)

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[21] Urbanization itself and the consequent shift in the demographic composition are also often mentioned as a cause of the height decline because of both the worse epidemiological environment and the adverse supply situation in the towns compared to the countryside.

[22] One of the few other estimates of agricultural labor productivity exists for 19th century Massachusetts. Rothenberg (1992) estimated that labor productivity increased by c. 15% between 1820 and 1850 or at an annual rate of c. 0.45 %.

offered decadal estimates of the daily per capita pork availability and found that protein and calorie supply decreased between 1849 and 1859. Sunder (2007) presented scattered price data which supported the thesis of rising relative prices in the period under observation and Haines (2004) found -- on the basis of Philadelphia prices -- that agricultural to industrial prices rose by c. 40% in the U.S. over the period 1800 - 1861. This price rises led to substitution and, as consequence, to a decline in average calorie and protein intake.

The analyses of height trends of different socio-economic strata confirm this chain of reasoning. The decline in pre-war height was found in the lower but not in the middle and higher social classes. Passport applicants and middle-class West Point cadets, both relatively wealthy persons, did not experience a height decline prior to the Civil War (Sunder 2004, Komlos 1987). The reason is that the higher strata of society were able to compensate for the relatively higher food prices and they, therefore, could maintain an adequate diet even during hard times when poorer classes of population could not. A sustained decline in the health environment, however, would have affected all Americans because pathogens did not stop at social borders. The height trend of slaves further supports Komlos's argument. Height of slaves did not decline in the antebellum period either (Sunder 2004), which can be explained by the nutrition- but not the disease- based argument. A worsening epidemiological environment would have affected slaves as everyone else because there was no efficient defense against the invisible danger in those days. The "danger" of increasing relative food prices, however, could be managed by the slaves' owners. In fact the profit-maximizing masters even had an incentive to improve the diet of their slaves in the antebellum period with rising cotton prices (Rees et al. 2003). Thus, the trend of slaves' height again supports the nutrition-based explanation.

Another reason that possibly contributed to the decreasing height trend was the growing economic imbalance in the pre-Civil War period. Rising inequality is, ceteris paribus, related to decreasing average height because the increasing height of the relatively rich getting richer is not sufficient to compensate for the decreasing stature of the relatively poor getting poorer (Komlos 1998). There are many fragmented sources which, taken together, support the conclusion that the first half of the 19th century was characterized by increasing economic inequality. Williamson and Lindert (1980) for example wrote: "It now appears that the main epoch of increasing inequality was the last four decades before the Civil War." Shammas (1993) estimated that the Gini-coefficient for free men plus unmarried women grew from 0.72 in 1774 to 0.83 in 1860. Steckel (1994) calculated the decadal development of wealth distribution for the states of Massachusetts and Ohio based on data from tax records and federal census manuscripts and found that the Gini-coefficient increased from 0.68 in 1820 to 0.81 in 1860. But it was not only the distribution of wealth that changed. Margo (1998) compared long-run growth rates of real wages for common laborers, artisans, and white collar workers. He found that the wage premium for white collar work compared to blue collar work surged between 1820 and 1860.[23] Kiesling and Margo (1997) analyzed census data and found that the number of persons receiving public assistance rose by 76% between 1850 and 1860. This indicates that it was not only the rich getting richer in the course of the economic development but it reveals that there was at the same time an adverse development in the lower parts of society.[24]

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[23]

Long-Run Growth Rates of Real Wages, 1820-1860 (Percent p.a.):

	Common labor	White colar
Northeast	1.26	1.57
Midwest	0.72	0.80
South Atlantic	0.75	1.27
South Central	0.83	1.56

Source: (Margo 1998)

The figures are, however, values averaged over time. Margo himself noted that the growth of real wage was erratic over certain subperiods. In the mid-to late 1830s and the late 40s real wages did not grow or even declined.

[24] Among the possible causes of the increasing inequality in the pre-war period are immigration and urbanization because immigrants were poorer than natives, and farmers were richer than non-farmers (Pope 2000). Industrialization also increases inequality (see: Kuznets 1955).

3.5.2 Factors of influence

Average height did not only change over the course of time but also varied depending on characteristics of the recruits. Members of artillery regiments were significantly taller than those in infantry regiments because of the selection bias whereas there was no significant height advantage of the cavalry compared to the infantry (Table 3). Men recruited in another state than their state of birth (mover) were taller than those who enlisted in their home state (Table 3, columns 1 and 3) but this effect disappears when our county specific variables self-sufficiency, death rate, distance to town, and access to waterways are entered in the regression (Table 3, columns 2 and 4). There were also differences in height depending on the origin of the recruits. Those born in New England, East North Central, South Atlantic, and East South Central were significantly taller than those born and raised in the Middle Atlantic.[25] There was, however, no clear North-South or East-West pattern in height in this sample. There were also some differences in height according to the prior occupation of the recruit. Men who were formerly employed in office work (professional and clerical worker) had a height advantage compared to laborers. Former farmers or farm laborers were clearly taller at the 1 percent level but only in the basic regressions without the additional environmental covariates (Table 3, columns 1 and 3).[26] The effect again disappears in the extended regressions (Table 3, columns 2 and 4). The explanation for this contradiction is the correlation of working in the agricultural sector with our variables “self-sufficiency” and “distance to the next town”. The chance of being a farmer or farm laborer is positively correlated with “self-sufficiency” (correlation coefficient: 0.17) and negatively with “living in a town” (-0.20).

Recruits from self-sufficient counties were on average 0.41 and 0.38 in. taller (Table 3, columns 2 and 4). The reason is that expenditures for transportation were

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[25] The division variable controls for the different population densities in the different areas and all other division-specific characteristics. It is thus difficult to interpret these variables.

[26] It should be mentioned that not every rural person was a farmer or farm laborer since the rural population also included “traders, craftsmen, government official, and clergy as well as those engaged in cottage or small-scale enterprises at the beginning of the IR” (Johnson 1997).

substantial in those times (although the costs of transport were sharply decreasing because of the transportation revolution in progress) and distance from producer to consumer influenced food availability, quality, and prices profoundly. Thus, proximity to nutrition was an advantage as diet tended to be cheaper next to the site of production. Proximity to food production is proxied by our variable “Self-sufficiency”.[27]

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[27] The quality of soil as an alternative measure of the availability of nutrients was not statistically significant.

Table 3: Regression analyses: Height (in.) of American soldiers recruited 1866-70.

	Adults + Youth:				**Adults:**			
Column:	**1**		**2**		**3**		**4**	
Regiment:								
Infantry	Reference							
Artillery	0.43	***	0.43	***	0.43	***	0.42	***
Cavalry	0.21		0.20		0.21		0.17	
Unidentified	0.43	***	0.37	**	0.6	***	0.55	***
Mover	0.31	**	0.23		0.38	**	0.26	
Occupation:								
Professional	-0.41	**	-0.43	**	-0.27		-0.34	
Managerial	-1.78		-0.88		-1.52		-0.19	
Clerical worker	0.39	***	0.44	***	0.29	*	0.35	**
Sales	-0.15		-0.12		-0.16		-0.18	
Service	0.15		0.18		0.19		0.23	
Agricultural	0.40	***	0.17		0.45	***	0.27	*
Laborer	Reference							
Birthplace:								
New England	0.41	**	0.49	***	0.42	**	0.45	***
Middle Atlantic	Reference							
East North Central	0.83	***	0.50	***	0.42	**	0.49	***
West North Central	0.16		-0.12		0.14		0.15	
South Atlantic	0.51	***	0.83	***	0.82	***	0.80	***
East South Central	0.57	**	0.33	*	0.33		0.53	**
West South Central	-0.07		0.07		0.51	***	0.38	*
Environment:								
Self-sufficiency			0.41	***			0.38	*
Death rate			-0.03	*			-0.03	*
Town			-0.25				-0.06	
Town nearby			-0.18				0.06	
Waterway			-0.36	**			-0.65	***
Age:								
16	-14		-14					
17	-5.55	***	-6.39	***				
18	-1.71	***	-1.78	***				
19	-0.86	***	-0.85	***				
20	-0.40	*	-0.41	**				
21	-0.37	***	-0.45	***				
Constant	67.1	**	67.7	***	67.1	***	67.8	***
Observation	12,175		10,417		7,113		6,015	

Notes: Occupation is coded according to the “History Of Work Information

System." Our different categories correspond to the seven major groups defined by HISCO. The origin- dummies are coded according to the Census Divisions with Division 1 & 2 referring to the American Northeast, 3 & 4 to the Midwest, and 5, 6 & 7 to the South. "Self-sufficiency" is a dummy variable being one if the production of calories within a county could feed its population. "CDR" is the county's age specific death rate, adjusted for the county's composition by sex. "Town nearby" is a dummy variable which equals one if a town with more than 5.000 inhabitants is within a range of 20 kilometers. "Waterway" is a dummy variable which indicates whether the county has direct access to navigable waters.

The death rate adapted for the counties' composition by age and sex serves as a measure of the epidemiological environment. The disease environment affects height negatively because any infectious disease adversely affects nutritional status and thus possibly the height of the sick child or adolescent (Scrimshaw et al. 1968). Diseases force the body to use up energy combating the pathogen which reduces the calories available for the growth process. Some diseases also reduce the food intake by regulating the appetite or by lowering the nutrient value of the digested food (Bogin 2001). Thus, it is not surprising that recruits born in disease-stricken areas are on average smaller than those soldiers born in relatively disease free counties (Table 3, columns 2 and 4).

Navigable waterways within the county of birth led to significantly smaller recruits. Recruits from counties with access to waterways were on average 0.36 to 0.65 in. smaller, than those born in countries without access to navigable waterways. Our second measure of market integration, being born in a town or within 20 km distance of a town, however, does not affect height adversely. The insignificance of the latter variable remains if the threshold value is reduced to five or even three kilometers. Removing, the death rate and self-sufficiency variables from the regression, however, leads to a highly significant and negative effect of living in a town on height (-0.44 in.) (not shown here). Then the variable captures the effect of the urban height penalty. Living near a town (20 km radius) is also significant in this setting. People living in the sphere of influence of a town are on average 0.37 in.

smaller than those living in remote areas.[28]

3.5.3 Spatial variation in the coefficients

The analysis above revealed that former farmers were on average 0.40 and 0.45 in. taller than production laborers (Table 3, columns 1 and 3). GWR, however, reveals that there is a spatial pattern regarding the effect of working in the agricultural sector on physical stature.[29] Being a farmer or farm laborer is associated with taller average height compared to laborers in every county. The positive influence is greatest in New England (Figure 7). Farm-related work led to a height advantage of more than 0.45 in. in Maine, Vermont, Connecticut, New Hampshire, and Massachusetts. Working in agriculture was related to a height advantage of 0.30 to 0.44 in. in parts of New York, Pennsylvania, and New Jersey, as well as in Michigan, Ohio, and Indiana. In the remaining part of the country, former farmers were between 0.15 and 0.29 in. taller than production laborers with the exception of south-east Pennsylvania and the east of North Carolina where former farmers had only a slight height advantage of up to 0.14 in. It is conspicuous that the effect of working in agriculture on height is roughly in line with the borders of the agricultural belts. Being a farmer or farm laborer has the most positive effect on height in the Diary Belt and less effect in the Cotton Belt and Grazing Belt. Perhaps the cotton farmers did no longer lead a self-sustaining life in the 30th and 40th due to specialization and they were, therefore, depended on the food market as everyone else. The regional distribution of self-sufficient counties in our data supports this thesis insofar as almost all self-sufficient counties lie north of Arkansas, Mississippi, Alabama, Georgia, South Carolina, and North Carolina, the traditional Cotton Belt states. Douglas North (1961) stressed the Midwest to South axis in trade of food which enabled the South

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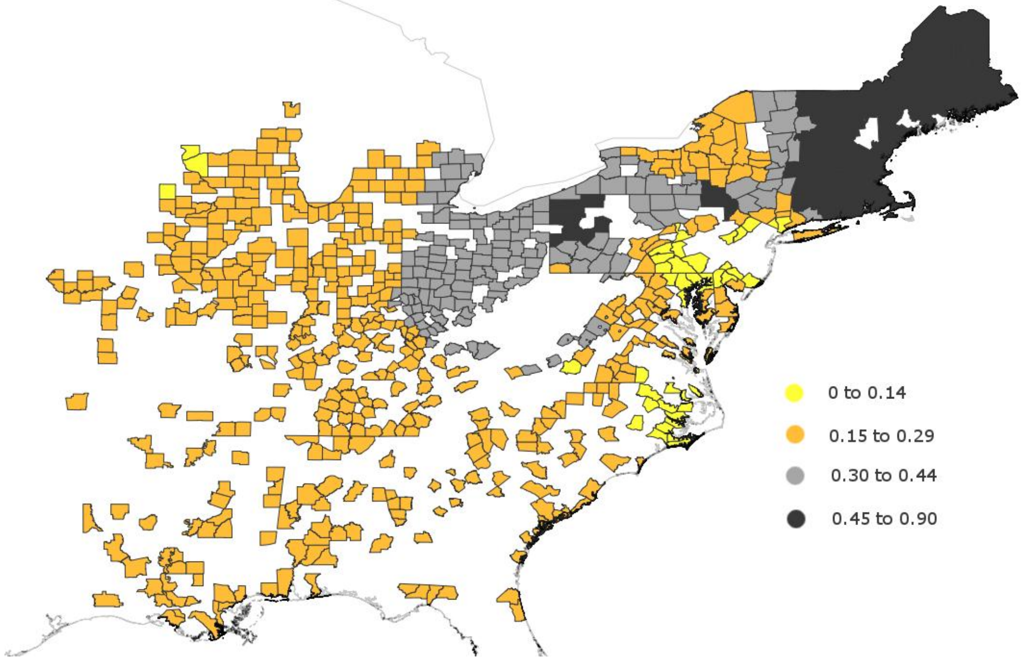
[28] We have tested additional explanatory variables such as the number of libraries or newspapers available in a county to proxy for the influence of knowledge/information on average height. They did not exert any influence, however, and are thus not reported in this paper.

[29] The setting of the GWR-model equals the regression in Table 3, columns 3, that is we used recruits, 16 to 50 years old as sample and regiment, occupation, age, and quinquennial dummy variables reflecting the year of birth as covariates.

to dedicate even more time and money to the cultivation of cotton.[30] Horatio Seymour, then the president of the New York State Agricultural Society, stated more generally in the 1850s that farmers no longer found it profitable to do everything themselves (Danhof 1969). A further rough indication of the declining self-sufficiency is the development of manufactured goods between 1840 and 1860. As Atack and Bateman (1987), based on information from Tryon (1917) and the U.S census of manufacturing show home-made products declined sharply. Dependency on the market, by implication, grew.

Figure 7: The effect of being a farmer on height in the Antebellum United States.



Notes: The coefficient "farmer" was separately calculated for each individual location determined by latitude and longitude. The coefficients were then weighted by the number of observations living on the respective location and county mean values were determined from these. We used recruits, 16 to 50 years old as data and regiment, occupation, age, and quinquennial dummy variables reflecting the year of birth as covariates.

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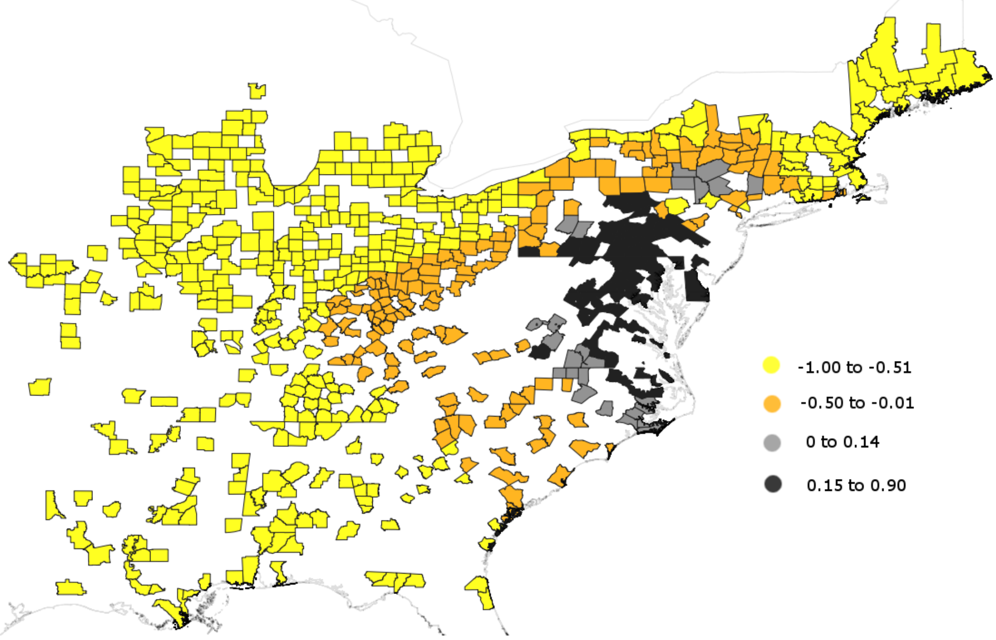
[30] Other authors, however, have questioned North thesis of a Midwest-South tangent in food trade and argued that the South was self-sufficient in food production. For an overview see: Atack and Bateman (1984).

The relationship between access to transport and height also varies spatially. Access to navigable waterways within a county has a positive influence on average physical stature in parts of Maryland, Virginia, Pennsylvania, New York, and North Carolina (Figure 8). Inland navigation, however, affects average stature negatively in all remaining states. The adverse effect of access to transport on height is relatively small (-0.50 to -0.01 in.) in the areas immediately surrounding the regions gaining from inland waterways (northern part of New York, western part of Pennsylvania, southern part of North Carolina, Kentucky, and Ohio). The negative effect is greater (-1.00 to -0.51 in.) in all areas in the west and south-west of Kentucky as well as in the New England region. The pattern is similar to the spatial distribution of population density at the time (Figure 9). Areas with a relatively high density of population mainly gained from the access to waterways while counties with low densities lost on average. That's because low-density areas were mainly agrarian areas and farmers used the access to waterways to exploit more distant markets and, subsequently carried food away while farmers in counties without access to transport were confined to local markets to sell their food. The different market potential for the farmers, thus, influenced the prices and food for local customers in the agrarian counties. Access to distant markets, ceteris paribus, worsened the food supply for locals and as consequence average height was lower than in farming counties without navigable waterways. Relatively urbanized counties, however, gained from access to inland waterways because it improved their average food supply.

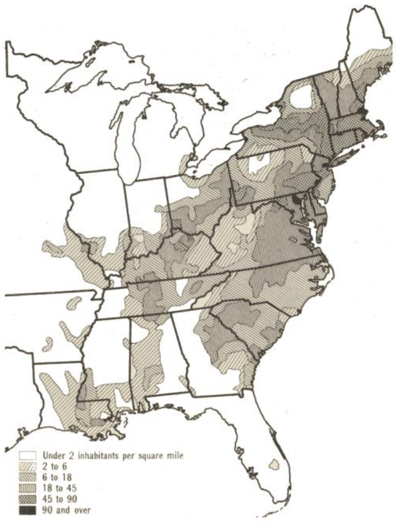
In contrast to our result, Yoo (2012) found that the influence of access to navigable waterways on height was almost universally negative. There is a clear southwest to northeast pattern in his spatial pattern. The adverse effect of access to transport was greatest in the southwestern regions of the U.S. and smallest in the New England region. The state of New York represents the only exception from this pattern with the relationship being zero or slightly positive. The fact that our pattern differs from his may be due to the fact that his height data are from birth cohorts 1838 to 1842 whereas ours comprises a considerable longer period. The transportation system improved a lot in the 1820th and 30th and thus, this improvement might have had an effect on the pattern.

Figure 8: The effect of navigable waterways on height in Antebellum United States.



Notes: The coefficient "navigable waterways" was separately calculated for each individual location determined by latitude and longitude. The coefficients were then weighted by the number of observations living on the respective location and county mean values were determined from these. We used recruits, 16 to 50 years old as data and regiment, occupation, age, and quinquennial dummy variables reflecting the year of birth as covariates. The fact that this figure contains fewer counties than figure 7 is due to multicollinearity. Some local regression in the GWR could not identify the local influence of the variable "navigable waterways" on height because of multicollinearity between the variable and the constant.

Figure 9: Density of U.S. population, 1820.



Source: Paullin (1932); slightly edited by the author to improve quality.

3.6 Conclusion

This study analyzed three aspects of U.S. physical stature between 1823 and 1860. First, we estimated the secular height trend based on splines. Average height declined monotonically by c. two inches during the observation period.[31] This result once again confirms the Antebellum Puzzle that is the conundrum that American average height declined while the economy grew significantly. Komlos first solved this puzzle in 1987 when he showed that the decline of physical stature was the result of a worsening nutritional situation in the antebellum period. Second, we examined the influence of county-specific variables such as death rate, county-wide production of nutrients, and market integration on average stature. We found that death rate and market integration had a negative influence on height but self-sufficiency had a positive one. We found that immediate access to nutrition for individuals as measured by the occupational category farmer is no longer that important when one controls for the nutritional situation in the county. This is reasonable as the local price was the key to the food consumption of the local

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[31] The magnitude of the decrease is partly due to the fact that the physical stature of the birth cohorts after 1840 was affected by the Civil War.

population and the price of food depended on its availability. Third, we evaluated the spatial aspects of the relationship between explanatory variables and height. We did so by using geographical weighted regression (GWR) as suggested by Fotheringham et al. (2010) and introduced to anthropometric history by Yoo (2012) but adapted the method to the special requirements of height data. Adapted GWR revealed that the effect of the tested explanatory variables on height is spatially heterogeneous. The specific spatial pattern differs for the two variables “farmer” and “access to transport” but conforms, in the main, to the logic of interregional trade: regions which exported grain became shorter while those that imported food gained from access to waterways. The influence of transportation on height is dependent on the population density. We hypothesize that access to transport is advantageous to populated areas while it has a negative impact on relatively unpopulated regions. Insofar as transportation revolution facilitated interregional trade it decreased the price of agricultural products in urban areas and decreased the price of manufactured products in rural regions. As a consequence, it induced the substitution of one sector’s products for that of the other in their respective destinations. Regarding individual characteristics of the recruits, we analyzed the spatially-varying effects of being a farmer or farm laborer on height. The effect of being a farmer or farm laborer on height seems to be guided by the borders of the agricultural belts. We found that it had a positive effect on physical stature in both the Diary Belt and the Corn Belt but a slightly adverse effect in the Cotton Belt region.

In sum, the main contribution of this paper to anthropometric history is the confirmation of Yoo’s (2012) recent argument that it is important to consider the spatial heterogeneity in the analysis of height data and the adaptation of GWR to the special challenges of truncated height data. Furthermore, we confirm the Antebellum Puzzle and the importance of the easy access to food products for the improvement of the average height of a population.

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Waaler revisited: The anthropometrics of mortality[1]

Although many studies have been written about the relationship between BMI and human height on the one hand and mortality on the other, the issue of socio-economic status (SES) as confounding variable has been at times less emphasized. This study analyzes the influence of education and income on the relationship between BMI and mortality and between height and mortality. It is based on data collected between 1963 and 1975 by the Norwegian National Health Screening Service. 1.7 million subjects were recorded. The Norwegian statistics bureau linked these data to the national death records and to socio-economic information. We apply Cox proportional hazards regressions in order to determine whether adding income and education as covariates affects the relations among BMI, height, and mortality. Previous findings and insights are either not present or ambiguous.

We conclude that the omission of SES does not significantly bias the effect of BMI on most causes of death, with one exception: type 2 diabetes mellitus, where the effect of BMI is substantially lower for both adults and adolescents when adjusted for education.

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[1] This chapter of the thesis was already published as paper: Koch, D. (2010). Waaler revisited: The anthropometrics of mortality. *Economics and Human Biology* 9 (1), 106–117.

4.1 Introduction

The relationship between anthropometric measures such as BMI and physical stature on the one hand and mortality on the other has been often investigated. One of the first to do so was Hans Th. Waaler (1984), who, on the basis of a large Norwegian data set, found a robust negative association between height and mortality and a "U"-shaped relationship between BMI and mortality. Since then the issue has been taken up by many other researchers (Allebeck and Bergh 1992, Andres et al. 1985, Engeland et al. 2003, Meyer et al. 2002, Mikkelsen et al. 1999, or Song et al. 2003). While these papers' study designs and underlying samples differed, one can safely conclude that the empirical evidence regarding the negative influence of overweight and obesity on mortality is unambiguous.

Researchers also explored the effect of obesity on cause-specific risk of death and found that it is associated with type-2 diabetes, hypertension, cardiovascular diseases, and stroke (Field et al. 2001). Previous findings and insights regarding the question whether adding income and education as covariates affects the relations among BMI, and mortality are either not present or not specific.

There is considerably less research on the relation between height and mortality. Waaler (1984) found a positive association between height and longevity -- for both sexes and all age-groups -- with the very tall being the only exception. Engeland et al. (2003) found that among men there is a negative linear relation between height and the risk of death, whereas among women the risk decreases up to a height of 160-164 cm and then increases again. Peck and Vagerö (1989) concluded that the shortest group runs a risk of death about 20% higher than that of the tallest group: a discrepancy that is reduced but not eliminated when information about the socio-economic status of the subjects is considered. Allebeck and Bergh (1992) also analyzed the effects of height on mortality and confirm the inverse association between height and mortality. However, contrary to Peck and Vagerö (1989), they concluded that the inverse association can be accounted for when data on social and behavioral characteristics of the subjects are included in the regression.

The current study is an extension of a series of Norwegian studies that began with Waaler (1984) and continues up to Bjorge et al. (2008). However, none of these papers examined the confounding effects of socio-economic status on either the BMI-mortality or the height-mortality relationship. Using the same data as these studies, we examine whether socio-economic status, as measured by education and income, affects the relation between BMI, height and mortality.

There is a general robust positive correlation between socio-economic status and health. Socio-economic status can be defined in terms of four variables: financial resources, education, social rank, and ethnicity (Cutler and Lleras-Muney 2008). Wilkinson and Pickett (2006) reviewed the findings on the relationship between a society's income distribution and population health. They concluded that the income distribution as a measure of the scale of social class differences is related to population health and that this association is positive in most of the analyzed studies.

A common explanation for the fact that education affects health is that well-educated people know better than others what foods are healthy, and generally how to live a healthy life. In addition education is positively correlated with income and therefore also picks up some of the effect of income on health.[2]

Therefore, omitting socio-economic status from the explanatory variables could lead to biased regression coefficients. A young person's nutritional intake depends on family real income, because income determines food consumption, and eating habits, and not only the quantity but also the quality of food influences the growth process.[3] Her eating habits are presumably also influenced by his educational attainment as well as that of her parents.

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[2] While there is a clear negative relationship between education and weight for women, it is ambiguous for men (Leigh et al. 1992). For an extensive overview regarding the effect of socio-economic status on obesity, see McLaren (2007).

[3] This seems plausible as physical stature is not only the result of genetic disposition but also of net nutritional intake, which is defined as nutritional intake net of the claims of disease and physical labor (Komlos 1993). Studies estimate that about 40 to 70 % of the variation in obesity-related phenotypes can be explained by genes (Comuzzie 1998). The remainder is influenced by food consumption and energy expenditure (Hill 1998).

4.2 Data

The main data source is a compulsory Norwegian tuberculosis screening program. Mass x-ray screenings including measurement of height and weight were carried out from 1963 until 1975. All persons aged 15 years or older were invited. About 80% or 1.9 million people attended the screenings. Persons below 15 were also invited if tuberculosis was present in their surroundings. Height was measured to the nearest cm without shoes and weight was measured with the subjects wearing light clothing to the nearest half kg. Those measured under unusual circumstances, such as measurements with shoes, pregnancy, bent knees were excluded. This study adds to the literature by analyzing anthropometric data that were linked to death files and socio-economic attributes of the individuals by Statistics Norway.[4] Therefore, we can explore the extent to which the relationship between BMI and mortality was influenced by socio-economic linkages working independently of human biology. Socio-economic status is represented by highest education achieved during the observation period as well as family income adjusted by the number of household members.[5]

Causes of death are coded according to the European short list classification for causes of death. Persons in the sample were followed longitudinally until they passed away.[6]

The sample is stratified into two subsamples because the younger participants of the study were still growing at the time of measurement. Those in the adolescent sub-sample are from 14 to 19 years of age while the adult sub-sample comprises all those older than 19. Consequently BMI and height are used in terms of percentile categories calculated according to the CDC 2000 Growth Charts in the "adolescent regressions." BMI and height were used as simple categorical variables

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[4] Statistics Norway, Kongens gt. 6, NO-0033 Oslo, http://www.ssb.no/en/

[5] We are aware that our representation of SES is oversimplified. Nonetheless it is the only information we could retrieve from the data. Furthermore we are convinced that despite some minor technical limitations (such as the time of measurement of income, …) of the SES variables, they still provide some valuable insights.

[6] Person accrued observation years from date of measurement until date of death, date of emigration or 31. Dec. 2006.

in the "adult regressions."

Adolescent sample

The adolescent subsample contains observations on 114,015 boys and 109,352 girls who were observed for an average of 37.1 years for a total of 8,281,068 person-years. Age at entry into the study is quite uniformly distributed between 14 and 19 (Table 1). A total of 6,228 males and 3,498 females died during the observation period.

Table 1: Distribution of the adolescent sample by age at time of measurement in percentage.

	Age					
	14	**15**	**16**	**17**	**18**	**19**
Boys	12.66	13.76	20.83	19.29	17.68	15.78
Girls	12.92	14.04	20.88	19.57	17.19	15.40

Most adolescents graduated at least from high school during observation period (Table 2).

Table 2: Distribution of subjects according to highest education achieved during observation period in percentage.

		Boys:	Girls:
Middle school	(<=9 years)	15.79	17.15
High school	(10 years)	22.44	36.64
High school	(11 or 12 years)	30.88	17.89
University degree	(13+ years)	30.89	28.32

Adult sample

734,040 men and 829,634 women were observed for an average of 28.3 years, making for a total of 44.3 million person-years of observation. Altogether 446,952 men and 429,619 women died during the observation period. 11% of the men and 7% of the women graduated from university (Table 3).

Table 3: Distribution of subjects according to highest education achieved during observation period in percentage.

		Men:	Women:
Middle school	(<=9 years)	54.46	57.13
High school	(10 years)	20.18	29.24
High school	(11 or 12 years)	18.25	6.10
University degree	(13+ years)	11.11	7.53

4.3 Method

As Engeland et al. (2003) we use the semi-parametric Cox proportional hazards (Cox-PH) model to depict the relationship between human stature and mortality or BMI and mortality, respectively.

For those who died during the observation period, the time-at-risk variable was defined as the time span between the medical examination and death; for all others duration was defined as the time span between the medical examination and the last date of observation.[7] A dichotomous variable was generated which reflected whether a subject passed away during the observation period or just dropped out of the data set.

The Cox-PH model describes the individual hazard rate as $h_j(t)=h_0(t)e^{(ß0+\mathbf{x}j\boldsymbol{\beta})}$. The fact that the individual hazard h_j is multiplicatively proportional to the baseline hazard h_0 reflects the model's basic assumption that the hazards of the subjects are proportional to each other and that the proportionality constant is independent of time. This proportional hazard assumption is a considerable conjecture and must be tested before the Cox-PH model can be used. In order to test the validity of this model interactions between covariates such as education and different functional

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[7] Korn et al. (1997) argue that one should use age instead of time-on-study as the time-scale variable, because presumably it has the largest influence on the hazard with Cox-PH models. In the case of mortality analysis, this seems plausible. However, they also argue that the difference between the two specifications should be minimal. Since most studies use time-on-study as the underlying time variable, we have chosen to do the same. Additional regression with age as time-scale variable confirm that the differences are indeed minimal.

forms of time (t) such as t^2 or log(t) are created and tested against the null hypothesis that these interacted variables are not different from zero. Our test indicates that the PH-specification cannot be rejected and therefore will be used in the subsequent analysis.

4.4 Results

4.4.1 Adolescents

The effect of BMI on mortality

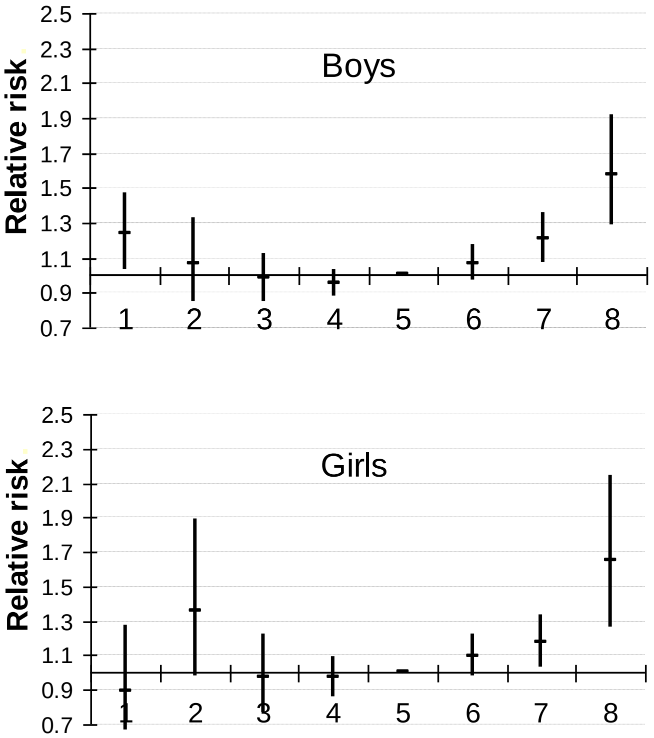
Comparison with the American CDC 2000 Growth Charts shows that few Norwegian girls and boys have extreme BMI values (Table 4).

Table 4: Distribution by BMI percentiles (%) in comparison to the CDC 2000 Growth Charts.

	BMI percentiles			
	<25th	**25th-74th**	**75th-84th**	**>85th**
Boys	22.75	63.69	8.03	5.51
Girls	15.73	64.47	11.53	8.26

Baseline results of a Cox-PH model controlled for age at the time of measurement, birth cohort and education clearly show a "U"-shaped effect of BMI on relative risk of dying (Figure 1). That is, adolescents with a relatively low or high BMI at time of measurement have a higher relative risk of dying than the reference group within the 75th -to- 84th BMI percentile category. Results are by and large consistent with Engeland's (2003) findings.

Figure 1: Relative risk of dying of adolescents 14 to 19 years of age at time of measurement as a function of the BMI percentile categories.



Note: X-coordinate represents the eight BMI groups as specified below:

Number:	1	2	3	4	5	6	7	8
Percentile category:	<3th	3th-4th	5th-9th	10th-24th	25th-74th	75th-84th	85th-95th	>95th

Number 5 is reference group. Whiskers represent 95% confidence intervals. Estimates are controlled for age at measurement, birth cohort and education. Measurement took place between 1963 and 1975. Follow-up ended on December 31, 2006.

We next explore the influence of BMI on the relative risk of dying from certain causes controlled only for date of birth and age at time of measurement. We use fewer categories of BMI than in Figure 1 because stratification by cause of death reduces the number of observations in each category. Columns 2, 5, 8 and 11 in Table 5 resemble Table 2 in Bjorge et al. (2008). Their paper serves as the starting point for the analyses done here. Nonetheless, relative-risk ratios shown here are not identical to the aforementioned paper. Although based on the same Norwegian data set, our paper employs a slightly different, edited version of it; there is an additional year of follow-up, and there are fewer observations, on account of missing observations of some of the additional control variables. Reference is the 25th -to- 74th percentile category. Hazard rates in bold type indicate statistical significance at the 5% level while numbers in italics indicate significance at the 10% level. We find that a BMI below the 25th percentile has no significant influence on the relative risk of dying from natural causes, for boys or girls (Table 5, Column 2). Exceptions are diabetes mellitus, among boys, and respiratory illnesses, among girls. Moreover, underweight girls are more likely to commit suicide than are girls of normal weight.[8] Belonging to the 75th -to- 85th percentile group doubles the mortality risk from endocrine, nutritional, and metabolic diseases for both boys and girls. The relative risk of dying from diseases of the circulatory system is 1.5 for boys and 1.4 for girls (Table 5, Column 8).

The relative risk of dying is even more elevated for the group above the 85th percentile (Column11) reaching as high as 4.3. The overall relative risk of dying for both boys and girls in this BMI group is 40% higher than for the reference group.

The Cox-PH regressions are repeated with completed education as a proxy variable for socio-economic status (Table 5, columns 3, 6, 9, 12). The inclusion of education changed the estimated coefficients only marginally or not at all. Most of the hazard ratios change by only 0.1, which is by 10 percentage points. For boys, the increased relative risk of dying from diabetes mellitus becomes insignificant as does the increased relative risk of dying from diseases of the respiratory system for girls in the lowest BMI percentile group (Column 3); in addition, the risk of death caused by endocrine, nutritional, and metabolic diseases declines in the highest BMI category by 0.3 among boys and 0.5 among girls (Column 12). The relative risk ratios of the

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[8] The category "Other" contains the following causes of death: infectious and parasitic diseases, tuberculosis, meningococcal infection, AIDS (HIV-disease), viral hepatitis, neoplasms, diseases of the blood, diseases of the nervous system, meningitis, diseases of the skin and subcutaneous tissue, diseases of musculoskeletal system/connective tissue, rheumatoid arthritis and osteoarthritis, diseases of genitourinary system, diseases of kidney and ureter, complications of pregnancy, childbirth and puerperium, certain conditions originating in the perinatal period, congenital malformations and chromosomal abnormalities, congenital malformation of the nervous system, congenital malformations of the circulatory system, symptoms, signs, abnormal findings, ill-defined causes, sudden infant death syndrome, unknown and unspecified causes, homicide, events of undetermined intent.

remaining important diseases also decrease slightly.[9] [10]

Thus, adding socio-economic-status, either in the form of education or income or both, as control variables into the regressions does not affect the influence of BMI on cause-specific mortality substantially. Additional regressions in which birth region was included as an explanatory variable did not alter the results, and are not reported here.

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[9] We repeat the above COX-PH regressions with BMI divided into eight, not four, categories in order to explore the robustness of the results to changes in category boundaries. Comparison of the results of these estimates with the above outcomes reveals that there is no significant change in the coefficients (not shown here). These models also confirm the "U"-shaped relationship between BMI values and the risk of death.

[10] Using household income instead of education as proxy for the socio-economic background of the subjects also confirms the above mentioned results. Adding income does not alter the association between BMI and risk of death meaningfully. Moreover, adding both household income and education does not alter the relation between BMI and death by and large. Only the influence of the highest BMI percentile group on death caused by endocrine, nutritional and metabolic diseases as well as on death from diseases related to the circulatory system is affected for both boys and girls. Furthermore, the probability of death from causes related to the respiratory system is diminished by controlling for income and education.

Table 5: Relative risk of death for 114,015 male and 109,352 female Norwegian adolescents, 14-19 years old at the time of measurement as a function of BMI percentiles. Adjusted for year of birth, age at time of measurement (Columns 2, 5, 8, 11) and additionally education (3, 6, 9, 12).

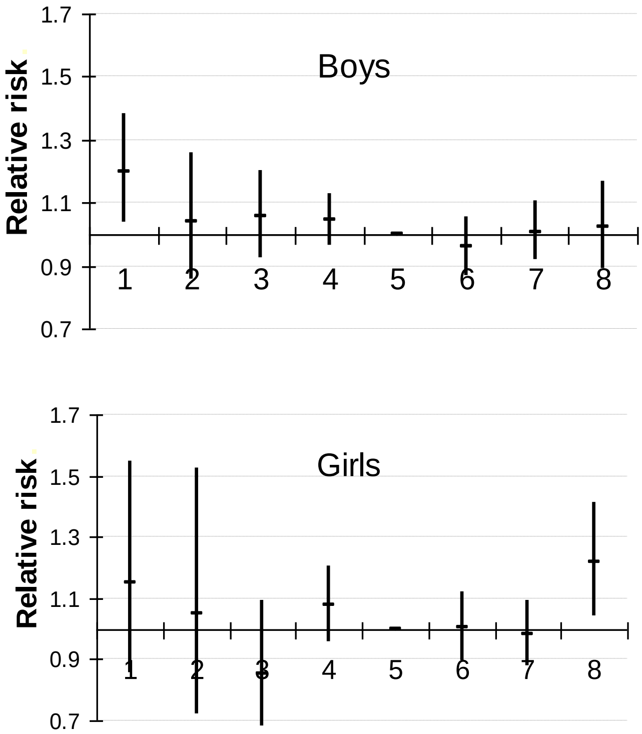
	BMI percentiles											
	<25th			**Basis**			**75th-85th**			**>85th**		
	No. of death	**RR**	**RR**	**No.of death**	**RR**	**RR**	**No.of death**	**RR**	**RR**	**No.of death**	**RR**	**RR**
Column No.	1	2	3	4	5	6	7	8	9	10	11	12
Boys:												
Malignant neoplasms	330	0.9	0.9	988	1.0	1.0	128	1.0	1.0	94	1.1	1.1
Endocrine, nutritional	38	*1.4*	1.4	74	1.0	1.0	20	**2.1**	**2.2**	18	**3.0**	**2.7**
Of which diabetes	32	**1.6**	*1.5*	56	1.0	1.0	15	**2.1**	**2.2**	13	**2.8**	**2.6**
Circulatory system	273	1.0	0.9	790	1.0	1.0	158	**1.5**	**1.6**	150	**2.3**	**2.1**
Respiratory system	28	1.3	1.2	64	1.0	1.0	10	1.2	1.2	12	**2.3**	**2.1**
Digestive system	63	1.1	1.1	160	1.0	1.0	20	1.2	1.0	21	*1.6*	1.4
Of which liver	46	1.3	1.2	105	1.0	1.0	15	1.1	1.1	14	1.6	1.4
Subtotal 1	732	1.0	1.0	2,076	1.0	1.0	336	**1.3**	**1.3**	295	**1.7**	**1.6**
Mental disorders	67	1.3	1.2	150	1.0	1.0	14	0.7	0.7	4	**0.3**	**0.3**
External causes	404	1.0	1.0	1100	1.0	1.0	116	*0.8*	0.8	101	1.1	0.9
Of which suicide	175	1.0	1.0	489	1.0	1.0	56	0.9	0.9	41	1.0	0.9
Subtotal 2	471	1.1	1.0	1,250	1.0	1.0	130	**0.8**	**0.8**	105	1.0	0.9
Other	192	1.0	1.0	514	1.0	1.0	67	1.0	1.0	60	1.4	1.2
Grand Total	1,395	1.0	1.0	3,840	1.0	1.0	533	**1.1**	1.1	460	**1.4**	**1.3**
Girls:												
Malignant neoplasms	271	0.9	*0.9*	1251	1.0	1.0	241	1.0	1.2	187	*1.2*	1.1
Endocrine, nutritional	6	0.8	0.8	29	1.0	1.0	12	**2.2**	**2.3**	16	**4.3**	**3.8**
Of which diabetes	0	-	-	19	1.0	1.0	11	**3.2**	**3.0**	14	**5.7**	**5.0**
Circulatory system	61	1.1	1.1	223	1.0	1.0	58	**1.4**	**1.4**	67	**2.4**	**2.1**
Respiratory system	20	**1.7**	*1.7*	49	1.0	1.0	14	1.5	1.5	11	1.6	1.5
Digestive system	14	0.9	0.9	62	1.0	1.0	13	1.1	1.2	13	1.6	1.4
Of which liver	12	1.3	1.2	39	1.0	1.0	8	1.1	1.1	5	1.0	0.8
Subtotal 1	372	1.0	0.9	1,614	1.0	1.0	338	1.1	*1.1*	294	**1.4**	**1.3**
Mental disorders	15	1.6	1.6	37	1.0	1.0	5	0.7	0.8	7	1.5	1.4
External causes	77	1.2	1.2	258	1.0	1.0	49	1.0	1.1	28	0.8	0.8
Of which suicide	53	**1.4**	**1.4**	157	1.0	1.0	29	1.0	1.0	12	*0.6*	*0.6*
Subtotal 2	92	**1.3**	*1.3*	295	1.0	1.0	54	1.0	1.0	35	0.9	0.9
Other	64	1.1	1.1	243	1.0	1.0	43	1.0	1.0	54	1.7	1.6
Grand Total	528	1.0	1.0	2,512	1.0	1.0	435	**1.1**	1.1	383	**1.4**	**1.3**

RR reflects the relative risk of death compared to the reference group of adolescents belonging to the 25th to 74.9th BMI- percentile group. A figure greater than one thereby represents an elevated risk of death, a figure smaller than one a relatively lower risk. Bold face hazard rates indicate significance at the 5% level while numbers in italics indicate significance at the 10% level.The titles of the disease-categories are sometimes abbreviated.

The effect of height on mortality

Results of a Cox-PH model controlled for age at the time of measurement, birth cohort and education show no clear effect of height on the overall relative risk of dying for both boys and girls (Figure 2).

Figure 2: Relative risk of dying of adolescents 14 to 19 years of age at time of measurement as a function of the height percentile categories.



Note: X-coordinate represents the eight height groups as specified below:

Number:	1	2	3	4	5	6	7	8
Percentile category:	<3th	3th-4th	5th-9th	10th-24th	25th-74th	75th-84th	85th-95th	>95th

Number 5 is reference group. Whiskers represent 95% confidence intervals. Estimates are controlled for age at measurement, birth cohort and education. Measurement took place between 1963 and 1975. Follow-up ended on December 31, 2006.

The relative risk of dying from different causes as a function of height percentile categories adjusted for age shows a more diverse pattern (Table 6). Boys belonging to the lowest height percentile category show an elevated relative risk of dying in most categories (Column 2). Their probabilities of dying from diseases of the circulatory system, respiratory system, and digestive system are higher, than for those of average height. Moreover, women in the lowest height percentile group also have a higher relative risk of dying from endocrine, nutritional, and metabolic diseases (RR: 2.3) as well as diseases of the circulatory system (RR: 1.6).

Being taller than the reference group generally has no significant influence on the relative risk of dying. The only exceptions are women in the 75th -to- 84th percentile group, who have a relative risk of dying from diseases of the circulatory system 40 percentage points lower than the reference group (Column 8). Regarding non-natural death, boys belonging to the tallest height category have a lower-than-average risk of dying from external causes, such as injury and poisoning (RR: 0.7) (Column 11).

Table 6: Relative risk of death for 114,015 male and 109,352 female Norwegian adolescents, 14-19 years old at the time of measurement as a function of height percentiles. Adjusted for year of birth and age at time of measurement (Columns 2, 5, 8, 11) and additionally education (3, 6, 9, 12).

	Height percentiles											
	<25th			**Basis**			**75th-85th**			**>85th**		
	No. of death	**RR**	**RR**	**No.of death**	**RR**	**RR**	**No. of death**	**RR**	**RR**	**No. of death**	**RR**	**RR**
Column No.	1	2	3	4	5	6	7	8	9	10	11	12
Boys:												
Malignant neoplasms	342	1.1	1.0	785	1.0	1.0	158	1.0	1.0	255	1.1	*1.2*
Endocrine, nutritional	30	0.9	0.8	83	1.0	1.0	15	0.9	1.0	22	0.9	1.0
Of which diabetes	24	1.0	0.9	62	1.0	1.0	12	1.0	1.0	18	1.0	1.1
Circulatory system	349	**1.2**	1.1	711	1.0	1.0	124	0.9	0.9	187	0.9	1.0
Respiratory system	36	**1.6**	1.4	55	1.0	1.0	8	0.	0.8	15	0.9	1.0
Digestive system	77	**1.4**	1.3	127	1.0	1.0	21	0.8	0.9	39	1.0	1.2
Of which liver	52	**1.4**	1.3	86	1.0	1.0	16	0.9	1.0	26	1.0	1.1
Subtotal 1	834	**1.1**	1.0	1,761	1.0	1.0	326	0.9	1.0	518	1.0	1.1
Mental disorders	76	**1.6**	**1.4**	117	1.0	1.0	18	0.8	0.8	24	*0.7*	0.8
External causes	469	**1.2**	1.1	884	1.0	1.0	154	0.9	0.9	214	**0.7**	0.9
Of which suicide	201	*1.2*	1.1	387	1.0	1.0	69	0.9	0.9	104	0.9	1.0
Subtotal 2	545	**1.2**	*1.1*	1,001	1.0	1.0	172	*0.9*	0.9	238	**0.8**	0.9
Other	237	**1.4**	**1.2**	404	1.0	1.0	82	1.0	1.1	110	0.9	1.0
Grand Total	1,616	**1.2**	**1.1**	3,166	1.0	1.0	580	**0.9**	1.0	866	**0.9**	1.0
Girls:												
Malignant neoplasms	265	0.9	0.9	1,026	1.0	1.0	261	1.1	0.9	398	1.1	**1.1**
Endocrine, nutritional	19	**2.3**	**2.1**	30	1.0	1.0	5	0.7	**2.1**	9	0.8	0.9
Of which diabetes	13	**2.3**	**2.1**	20	1.0	1.0	4	0.8	**2.1**	7	1.0	1.1
Circulatory system	93	**1.6**	**1.5**	221	1.0	1.0	31	**0.6**	**0.6**	64	0.8	0.9
Respiratory system	22	1.5	1.4	52	1.0	1.0	7	0.6	1.4	13	0.7	0.8
Digestive system	20	1.3	1.2	54	1.0	1.0	16	1.3	1.2	12	0.6	0.7
Of which liver	11	1.1	1.0	35	1.0	1.0	9	1.1	1.0	9	0.7	0.8
Subtotal 1	419	*1.1*	1.1	1,383	1.0	1.0	320	1.0	1.1	496	1.0	1.1
Mental disorders	14	1.5	1.4	36	1.0	1.0	7	0.8	1.4	7	0.5	0.6
External causes	63	1.0	1.2	224	1.0	1.0	47	0.9	1.2	78	1.0	1.0
Of which suicide	33	0.8	0.8	142	1.0	1.0	24	0.7	0.8	52	1.0	1.1
Subtotal 2	77	1.1	1.0	260	1.0	1.0	54	0.9	1.0	85	0.9	1.0
Other	71	1.2	1.1	225	1.0	1.0	40	*0.8*	0.8	68	0.8	0.9
Grand Total	567	**1.1**	1.1	1,868	1.0	1.0	414	0.9	1.0	649	1.0	1.0

RR reflects the relative risk of death compared to the reference group of adolescents belonging to the 25th to 74.9th height- percentile group. A figure greater than one thereby represents an elevated risk of death, a figure smaller than one a relatively lower risk. Bold face hazard rates indicate significance at the 5% level while numbers in italics indicate significance at the 10% level. The titles of the disease-categories are sometimes abbreviated. Table 10 in the appendix describes the exact categories.

If education is added as a control variable (Columns 3, 6, 9, 12), the elevated risk of death among shortest boys remains only in the mental and behavioral disorders category as well as in the grand total and is still higher by 10% (Column 3). As for girls, when education is added as a control variable there is a slight decrease in the significant risk ratios in the lowest height category.[11]

4.4.2 Adults

The effect of BMI on mortality

Descriptive statistics indicate that the distribution of the sample by BMI groups is similar for men and women with the latter tending to have the more extreme values (Table 7).[12] Results of Cox-PH model controlled for age at the time of measurement, birth cohort and education show a "U"-shaped effect of BMI on relative risk of dying (Figure 3). The boundaries of the BMI categories are now absolute values, not percentiles as for the youth data. Reference BMI category on the X-coordinate is the third group, subjects with a BMI between 23 and 24.9. The "U"-shaped form of both the men's and the women's curves indicate an elevated relative risk for both underweight and overweight persons of between 1.4 and 1.6.

Table 7: Distribution of the adult sample by BMI groups.

	BMI						
	<18.5	18.5-22.9	Basis	25.0-27.49	27.5-29.9	30.0-32.49	>32.5
Men	0.76	29.84	26.94	25.92	11.37	3.77	1.40
Women	2.05	32.31	19.81	19.31	12.47	7.42	6.64

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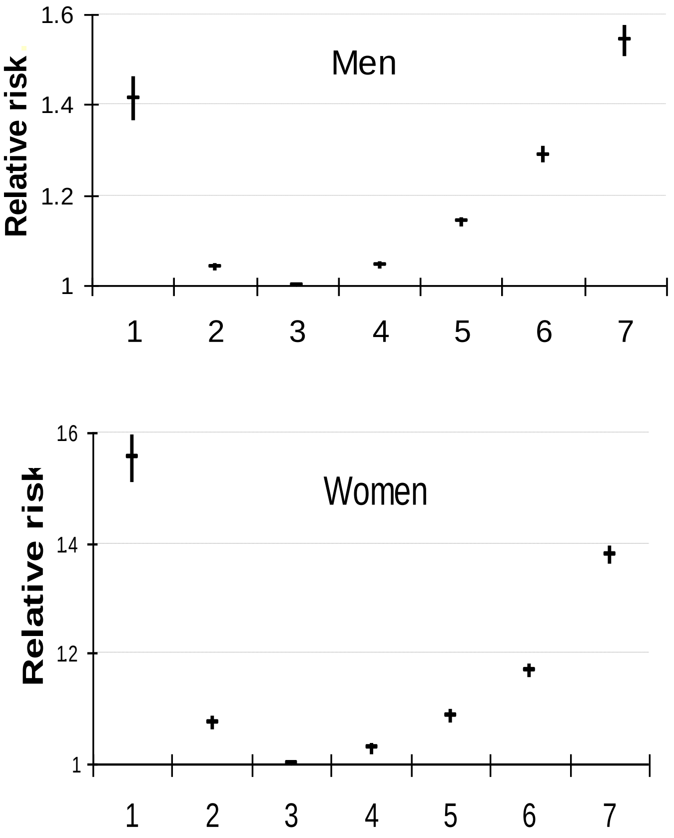
[11] The results when calculated as a function of eight instead of four percentile categories remain unchanged and are therefore not shown here.

[12] The BMI categories used in this paper adopt the principal cut-off points of the WHO International Classification of underweight, overweight, and obese adults (http://www.who.int). Partly we also use the additional cut-off points as suggested by WHO.

Figure 3: Relative risk of dying for adults at least 20 years of age at the time of measurement as a function of BMI.



Note: X-coordinate represents the seven BMI groups as specified in Table 8. Number 3 is reference group. Whiskers represent 95% confidence intervals. Estimates are controlled for age at measurement, birth cohort and education.

The cause-specific results indicate that relative to men of normal weight, underweight men have an elevated risk of dying from every cause included in the analysis except diabetes mellitus (Table 8, Column 1). In the lowest BMI category (BMI < 18.5) the relative risk of death from diseases of the respiratory system is especially high as is the relative risk of dying from mental and behavioral disorders. These results persist if one repeats the regressions with deliberately left-truncated data to account for the potential influence of a pre-existing chronic disease.

In the second BMI category (BMI: 18.5–22.9, Column 3) the relative risk of dying from problems related to the respiratory system is 30% higher compared to the reference category. In the fourth BMI category (BMI: 25.0-27.49, Column 5), too, the increased risk of death from endocrine, nutritional, and metabolic diseases is 30%, and mostly due to diabetes mellitus (RR: 1.4). The risk of death from chronic liver disease is somewhat elevated as well (RR: 1.3). In the next-to-last category (BMI: 30.0-32.49, Column 9) the relative risk of death from diabetes mellitus and chronic liver disease is clearly elevated, and the relative risk of death from any other cause, natural or not, is slightly so. The relative risk of dying from any of the diseases included in the sample increases as BMI increases to the right of the normal range. That is, men with a BMI higher than 32.5 (Column 11) have an excess relative risk of 5.1 for dying from endocrine, nutritional, and metabolic diseases. The relative risk of dying from chronic liver disease is also very high, at 5.0. When education is added to the regressions (Columns 2, 4, 6, 8, 10, 12) the changes are minor. Several risk ratios decrease, but only by quite a small amount of 0.1 to 0.3 points.

Table 8: Relative risk of death for 734,040 male and 829,634 female Norwegian adults 20 years or older at the time of measurement as a function of BMI. Adjusted for year of birth and age at time of measurement (Columns 1, 3, 5, 7, 9, 11) and additionally education (Columns 2, 4, 6, 8, 10, 12). Table 13 in the appendix shows the according numbers of death.

	BMI											
	< 18.5		**18.5-22.9**		**25.0-27.49**		**27.5-29.9**		**30.0-32.49**		**≥32.5**	
	RR	**RR**	**RR**	**RR**	**RR**	**RR**	**RR**	**RR**	**RR**	**RR**	**RR**	**RR**
Column No.	1	2	3	4	5	6	7	8	9	10	11	12
Men:												
Malignant neoplasms	**1.6**	**1.5**	**1.1**	**1.1**	**1.0**	**1.0**	**1.1**	**1.1**	**1.3**	**1.3**	**1.4**	**1.4**
Endocrine, nutritional	**1.9**	**1.9**	1.0	1.0	**1.3**	**1.3**	**2.1**	**2.0**	**3.3**	**3.2**	**5.1**	**4.9**
Of which diabetes	*1.6*	*1.6*	1.0	1.0	**1.4**	**1.4**	**2.3**	**2.2**	**3.8**	**3.6**	**5.8**	**5.5**
Circulatory system	**1.4**	**1.3**	1.0	1.0	**1.1**	**1.1**	**1.2**	**1.2**	**1.4**	**1.4**	**1.7**	**1.6**
Respiratory system	**2.5**	**2.4**	**1.3**	**1.3**	*1.0*	**1.0**	**1.1**	*1.0*	**1.3**	**1.2**	**1.6**	**1.5**
Digestive system	**1.9**	**1.9**	**1.1**	**1.1**	**1.1**	**1.1**	**1.4**	**1.3**	**1.8**	**1.8**	**2.3**	**2.2**
Of which liver	**2.0**	**2.0**	**0.9**	**0.9**	**1.3**	**1.3**	**1.8**	**1.8**	**3.4**	**3.3**	**5.0**	**4.8**
Subtotal 1	**1.4**	**1.4**	**1.0**	**1.0**	**1.1**	**1.0**	**1.2**	**1.1**	**1.3**	**1.3**	**1.6**	**1.6**
Mental disorders	**2.7**	**2.6**	**1.2**	**1.2**	1.0	1.0	**1.1**	1.1	**1.3**	**1.2**	**1.4**	**1.3**
External causes	**1.6**	**1.6**	**1.1**	**1.1**	1.0	1.0	**1.1**	**1.1**	**1.4**	**1.3**	**1.7**	**1.6**
Of whichSuicide	**1.6**	**1.6**	**1.2**	**1.2**	1.0	1.0	**1.1**	1.1	**1.5**	**1.4**	**1.7**	**1.6**
Subtotal 2	**1.7**	**1.7**	**1.1**	**1.1**	1.0	**1.0**	**1.1**	**1.1**	**1.3**	**1.3**	**1.7**	**1.6**
Other	**1.8**	**1.7**	**1.1**	**1.1**	1.1	1.0	1.2	1.2	1.4	1.4	**1.8**	**1.7**
Grand Total	**1.4**	**1.4**	**1.0**	**1.0**	**1.0**	**1.0**	**1.2**	**1.1**	**1.3**	**1.3**	**1.6**	**1.5**
Women:												
Malignant neoplasms	**1.5**	**1.5**	**1.1**	**1.1**	**1.0**	1.0	**1.1**	**1.1**	**1.2**	**1.2**	**1.2**	**1.4**
Endocrine, nutritional	**1.4**	**1.4**	**0.8**	**0.9**	**1.3**	**1.2**	**1.8**	**1.8**	**2.6**	**2.5**	**5.0**	**4.7**
Of which diabetes	0.7	0.7	**0.7**	**0.7**	**1.4**	**1.4**	**2.2**	**2.1**	**3.2**	**3.0**	**6.5**	**6.1**
Circulatory system	**1.5**	**1.5**	**1.0**	**1.0**	**1.1**	**1.0**	**1.2**	**1.1**	**1.3**	**1.2**	**1.5**	**1.5**
Respiratory system	**2.7**	**2.7**	**1.3**	**1.3**	1.0	1.0	**1.0**	1.0	**1.1**	**1.1**	**1.4**	**1.3**
Digestive system	**2.2**	**2.2**	**1.2**	**1.2**	**1.1**	**1.1**	**1.2**	**1.2**	**1.4**	**1.4**	**2.0**	**1.9**
Of which liver	**1.8**	**1.8**	1.1	*1.2*	1.1	1.1	1.3	1.2	*1.3*	1.2	**2.2**	**2.1**
Subtotal 1	**1.6**	**1.5**	**1.1**	**1.1**	**1.0**	**1.0**	**1.1**	**1.1**	**1.2**	**1.2**	**1.4**	**1.4**
Mental disorders	**1.8**	**1.8**	**1.1**	**1.1**	1.0	1.0	1.0	1.0	1.0	1.0	**1.2**	**1.2**
External causes	**2.0**	**2.0**	**1.2**	**1.2**	1.0	1.0	1.0	1.0	1.1	1.1	**1.4**	**1.3**
Of which Suicide	**2.0**	**2.0**	**1.4**	**1.4**	1.0	1.0	1.1	1.1	1.0	1.0	1.1	1.1
Subtotal 2	**2.0**	**2.0**	**1.2**	**1.2**	1.0	1.0	*1.0*	1.0	1.1	**1.1**	**1.3**	**1.3**
Other	**1.8**	**1.9**	**1.1**	**1.1**	*1.0*	1.0	**1.1**	**1.1**	**1.2**	**1.2**	**1.6**	**1.5**
Grand Total	**1.6**	**1.5**	**1.0**	**1.1**	**1.0**	1.0	**1.1**	**1.1**	**1.2**	**1.2**	**1.4**	**1.4**

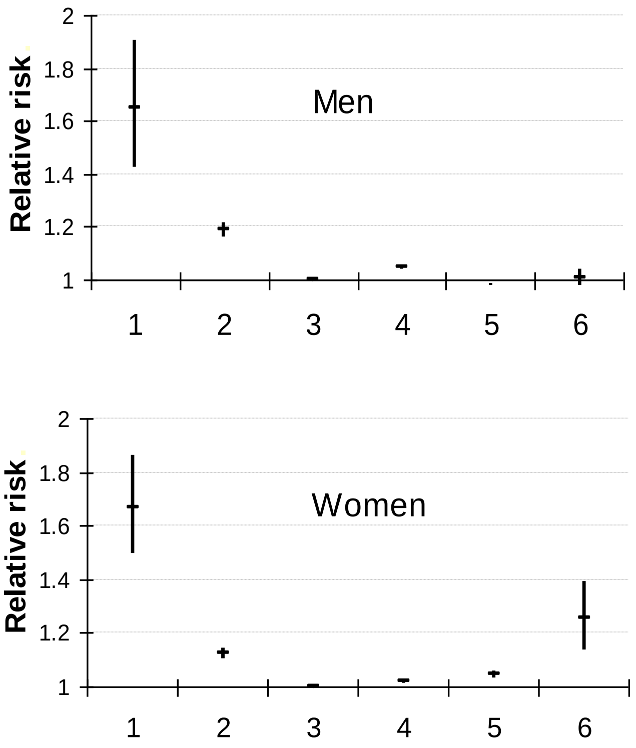
RR reflects the relative risk of death compared to the reference group of adults belonging to the 23 to 24.9 BMI group. A figure greater than one thereby represents an elevated risk of death, a figure smaller than one a relatively lower risk. Bold face hazard rates indicate significance at the 5% level while numbers in italics indicate significance at the 10% level. The titles of the disease-categories are sometimes abbreviated. Table 10 in the appendix describes the exact categories.

The results for women are quite similar to that of men (Table 8, lower part). If education is not included, being underweight is correlated with a significantly increased relative risk of dying from every cause except diabetes mellitus. The greatest risk that comes with being overweight is diabetes-related, but the risk of death from all other causes is significant as well. Education's effect is, again, minimal; it is only in the highest BMI group that the relative risk of dying from diabetes mellitus declines, by 0.4 (Column 12).

The effect of height on mortality

The Norwegians have become one of the tallest populations in the world (Sunder 2003). In 2008 the average Norwegian conscript at age 18 was 179.7 cm tall (Statistics Norway 2008). Results of a Cox-PH model controlled for age at the time of measurement, birth cohort and education show a clear effect of height on the overall relative risk of dying for both men and women (Figure 4).

Figure 4: Relative risk of dying for adults at least 20 years of age at the time of measurement as a function of height.



Note: X-coordinate represents the six height groups as specified in Table 9. Number 3 is reference group. Whiskers represent 95% confidence intervals. Estimates are controlled for age at measurement, birth cohort and education.

The inverse relationship between height and mortality is similar to those reported in previous studies (Engeland et al. 2003, Jousilahti et al. 2000). The relative risk of dying from diseases of the circulatory system for example decreases from 1.2 (150.0 -159.9 cm) to 0.9 (180.0 -189.9 cm) for men and from 1.2 (140.0 -149.9 cm) to 1.0 (170.0 -179.9 cm) for women (Table 9, Columns 5 and 11). The relative risk of dying from endocrine, nutritional and metabolic diseases decreases with height from 1.4 to 1.0 for men and from 1.5 to 1.0 for women. For a discussion of the explanations of the inverse relationship between height and cause-specific death see Batty et al. (2009). However, the death from malignant neoplasm increases significantly for the small percentage of very tall men (>190 cm) and women (>180 cm). Adding education as an explanatory variable decreases a few relative-risk ratios by a negligible amount - both among men and women (Columns 3, 6, 9, 12, 15).

Table 9: Relative risk of death for 734,040 male and 829,634 female Norwegian adults 20 years or older at the time of measurement as a function of height. Adjusted for year of birth and age at time of measurement (Columns 1, 3, 5, 7, 9, 11) and additionally education (2, 4, 6, 8, 10, 12).

Height	**< 150.0**			**150.0 -159.9**			**160.0 –169.9**			**180.0 -189.9**			**>190.0**		
Column No.	No.of death 1	RR 2	RR 3	No. of death 4	RR 5	RR 6	No.of death 7	RR 8	RR 9	No.of death 10	RR 11	RR 12	No.of death 13	RR 14	RR 15
Men:															
Neoplasms	26	*1.4*	*1.4*	1,069	**1.2**	**1.1**	23,461	**1.0**	**1.0**	21,509	1.0	**1.0**	1,085	**1.1**	**1.1**
Endocrine,	2	*3.7*	*3.5*	92	**1.4**	**1.3**	1361	**1.3**	**1.2**	1,031	1.0	1.0	39	*0.7*	0.8
Of which diabetes	1	2.2	2.1	68	**1.4**	1.2	1153	**1.3**	**1.2**	834	1.0	1.0	35	0.9	0.9
Circulatory	93	**1.6**	**1.5**	3,645	**1.2**	**1.2**	60,917	**1.1**	**1.1**	31,920	**0.9**	**0.9**	1,306	**0.9**	1.0
Respiratory	23	**2.1**	**2.0**	895	**1.4**	**1.3**	11,610	**1.1**	**1.1**	5,241	**0.9**	**1.0**	200	*0.9*	1.0
Digestive	7	**2.4**	**2.2**	178	**1.3**	**1.2**	2,790	**1.1**	**1.1**	1,787	**0.9**	1.0	86	1.0	1.1
Of which liver	0	-	-	18	1.0	0.9	396	**1.3**	**1.2**	421	**0.9**	0.9	20	*0.7*	0,7
Subtotal	151	**1.6**	**1.5**	5,879	**1.2**	**1.2**	100,139	**1.1**	**1.0**	61,488	**1.0**	**1.0**	2,716	**1.0**	1.0
Mental	4	**6.9**	**6.6**	76	**1.4**	*1.3*	1,295	**1.3**	**1.2**	909	**0.9**	0.9	41	0.8	0.9
External	5	*2.2*	*2.3*	206	**1.4**	**1.3**	3,742	**1.1**	**1.1**	3,192	**0.9**	**0.9**	181	0.9	1.0
Of which suicide	1	2.4	2.1	28	1.1	0.9	699	1.1	1.1	1,026	0.9	1.0	66	*0.9*	1.0
Subtotal	9	**2.9**	**3.0**	282	**1.4**	**1.3**	5,037	**1.2**	**1.1**	4,101	**0.9**	**0.9**	222	*0.9*	1.0
Other	23	**3.0**	**2.8**	741	**1.4**	**1.3**	10,772	**1.1**	**1.1**	6,642	**1.0**	**1.0**	305	1.0	1.1
Total	183	**1.7**	**1.6**	6,902	**1.2**	**1.2**	115,948	**1.1**	**1.1**	72,231	**1.0**	**1.0**	3,243	**1.0**	**1.0**
Women:															
	< 140.0			**140.0 -149.9**			**150.0 –159.9**			**170.0 -179.9**			**>180.0**		
Neoplasms	35	**1.8**	**1.7**	1,958	1.0	1.0	33,484	**1.0**	**1.0**	8,511	**1.1**	**1.1**	154	**1.4**	**1.5**
Endocrine,	4	1.3	1.2	280	**1.5**	**1.4**	3,271	**1.1**	**1.1**	456	1.0	*1.1*	4	0.7	0.8
Of which diabetes	3	**3.4**	*3.0*	243	**1.5**	**1.4**	2,591	**1.1**	*1.1*	351	1.0	1.1	3	0.7	0.8
Circulatory	166	**1.8**	**1.6**	8,312	**1.2**	**1.1**	94,282	**1.1**	**1.0**	9,217	*1.0*	*1.0*	118	1.1	1.2
Respiratory	39	**3.8**	**3.6**	1,899	**1.3**	**1.2**	18,140	**1.1**	**1.0**	1,898	**1.0**	**1.1**	22	1.1	1.2
Digestive	16	**2.0**	**1.9**	483	**1.1**	*1.1*	5,645	**1.0**	1.0	646	*0.9*	1.0	11	1.1	1.2
Of which liver	1	*6.5*	6.2	26	0.9	0.8	432	1.0	0.9	102	**0.8**	**0.8**	3	1.4	1.5
Subtotal	260	**1.7**	**1.7**	12,932	**1.2**	**1.1**	154,822	**1.0**	**1.0**	20,728	**1.0**	**1.0**	309	**1.2**	**1.3**
Mental	3	1.7	1.7	298	**1.2**	**1.2**	3,769	1.0	1.0	389	1.0	0.9	3	1.1	0.6
External	11	**2.5**	**2.4**	499	**1.1**	**1.1**	5,595	1.0	*1.0*	781	1.0	1.0	12	1.1	0.6
Of which suicide	0	-	-	25	1.3	1.2	434	1.0	1.0	202	1.0	1.0	2	0.6	0.6
Subtotal	14	**1.9**	**1.9**	797	**1.2**	**1.1**	9,364	1.0	1.0	1,170	1.0	1.0	15	**0.9**	1.0
Other	41	**2.3**	**2.2**	1,576	**1.2**	**1.2**	18,270	**1.0**	*1.0*	2,458	1.0	**1.1**	42	*1.3*	**1.4**
Total	315	**1.7**	**1.7**	15,305	**1.2**	**1.1**	182,456	**1.0**	**1.0**	24,356	**1.0**	**1.0**	366	**1.2**	**1.3**

RR reflects the relative risk of death compared to the reference group of 170.0 to 179.9 cm tall men and 160.0 to 169.9 cm tall women, respectively. A figure greater than one thereby represents an elevated risk of death, a figure smaller than one a relatively lower risk. Bold face hazard rates indicate significance at the 5% level while numbers in italics indicate significance at the 10% level. The titles of the disease-categories are sometimes abbreviated. Number of death belonging to the categories are shown in Table 11 in the appendix.

4.5 Discussion

In light of the current global obesity epidemic, it is important to know how body weight influences overall and cause-specific mortality (Komlos and Baur 2004). We therefore explore the association of BMI on cause-specific death rates and particularly the role of education and household income as a confounding variable which has not yet been included in the analysis of the Norwegian data.

Norwegian data from 1963-1975 were used in connection with information from the national death files to analyze this relationship. Regressions comprised two subsamples, youth (14-19 years of age) and adults (20 years of age and older) at the time of measurement. Standard control variables were birth cohort and age at time of measurement. Further variables, such as education and household income were added in a second round of regressions to discover, the extent to which they influence the association between BMI and mortality.

Both the strengths and limitations of this study stem directly from the characteristics of the Norwegian data set. On the positive side is the high number of observations. Even after stratification, the number of observations and events of death remains high particularly among adults. Furthermore the observation period is extraordinarily long: subjects are followed for a period of up to 43 years, whereas in comparable studies 15 to 20 years is the norm. A third advantage is the fact that height and weight were measured by professionals, significantly reducing error and eliminating the biases of self-reported measures.

On the other hand, information about smoking status of the subjects is not available. As there is a correlation between smoking and body weight (Rásky et al. 1996) as well as between smoking and certain causes of death such as some types of cancer or obstructive pulmonary disease (Doll et al. 1994), this lacuna creates an omitted variable bias regarding the effect of BMI on the risk of death. This bias mainly pertains to underweight persons. Also missing from the data set is information on the subjects' disease history. Chronic disease is likely to cause weight loss therefore further distorting the relationship between (under)weight and relative risk of death.

The size of this effect is controversial. Wannamethee and Shaper (1989), Lindsted et al. (1991) and Manson et al. (1995) found that the BMI - death association is positive throughout the BMI range including underweight persons. They argue that the seemingly increased risk of death on account of underweight found in earlier studies is a consequence of insufficient control for smoking and for preexisting chronic diseases and not of low weight itself (Manson et al. 1995). Other studies, however, do find that, even after adequately controlling for chronic diseases and smoking status low BMI values are still associated with increased mortality, therefore supporting the "U"-shape thesis (Vandenbroucke et al. 1984, Engeland et al. 2003).

The common strategy to reduce the influence of this missing information is to delete the first years of follow-up, to eliminate the bias during that period. Nonetheless, this truncation cannot control for the long-term effect of a disease. When, following Bjorge et al. (2008), we deleted the first 5 years of follow-up, the relative-risk ratios by and large remained the same, and therefore are not reported.[13] The results confirmed the often-reported "U"-shaped relation between BMI and mortality risk However, our main finding is that the association between BMI and overall as well as cause-specific death rates was virtually unaffected by the inclusion of socio-economic status variables. The only exception is diabetes mellitus, where the effect of BMI is substantially lower for both adults and adolescents with the inclusion of the education variable (Tables 5 and 8).

Furthermore, the relation between height and mortality risk was analyzed similarly. Among youth there was a considerable elevated risk of mortality for those in the lower 25th percentile of the height distributions, particularly among boys. For example, for death due to respiratory diseases the penalty was as high as 60% (Table 6). We also found a general tendency for mortality rates to decline with increasing heights among adults for all natural causes of death except malignant neoplasm

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[13] The two described limitations should be of little consequence in the analysis of the adolescent age group, as any smoking or disease history that they might have had would have been of relatively short duration. As Willet et al. (1991) observe smoking's adverse effects accumulate over the decades, and thus affect adults mainly over the age of 35.

(Table 9). Thus, our results confirm those of Waaler (1984) and of Engeland et al. (2003) regarding all-cause mortality, even when education or income is included as an additional variable. We conclude that omitting socio-economic status from the analysis did not bias the Norwegian results substantially.

The reason for that finding may well be that in the cause-effect triangle of BMI and socio-economic status on mortality, the effect of socio-economic status on BMI is rather small in Norway compared to the magnitude of the other relationships.[14] The same is true for the cause-effect triangle of height, socio-economic status and mortality.

However, before generalizing these results, one needs to keep in mind that Norway is an exception in terms of its socio-economic structure and health care system. It is one of the most egalitarian societies in the world – in all facets. It has a more equal distribution of income than most developed countries. The Gini coefficient of Norway was 0.23 in the mid-1980s compared to 0.34 in the United States or 0.43 in the United Kingdom. Norway also has a very comprehensive health care system and better health education and promotion than most other countries. Therefore the population might not only be better informed about the adverse effects of too high/ low BMI-values but might also have the better support structure to fight under/ overweight. As a consequence these results may not be representative for the world at large. Insofar as it is legitimate to pose the question to what extent is the mortality -- BMI link predicated on socio-economic vs. biological processes. The result of the above exploration implies that at least in the case of Norway, the link appears to be primarily biological.

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[14] Additional regressions show that having an university degree lowers the BMI of a man by -0.4 compared to the reference of a male adult with completed middle school. With women the according value is -1.3.

Appendix

Table 10: European short-list for causes of death as used in the paper:

Malignant neoplasms	**07** Malignant neoplasm **08** Malignant neoplasm of lip, oral cavity and pharynx **09** Malignant neoplasm of esophagus **10** Malignant neoplasm of stomach **11** Malignant neoplasm of colon **12** Malignant neoplasm of rectum and anus **13** Malignant neoplasm of liver and intrahepatic bile ducts **14** Malignant neoplasm of pancreas **15** Malignant neoplasm of larynx and trachea/bronchus/lung **16** Malignant melanoma of skin **17** Malignant neoplasm of breast **18** Malignant neoplasm of cervix uteri **19** Malignant neoplasm of other parts of uterus **20** Malignant neoplasm of ovary **21** Malignant neoplasm of prostate **22** Malignant neoplasm of kidney, except renal pelvis **23** Malignant neoplasm of bladder **24** Malignant neoplasm of lymphoid/hematopoietic tissue
Endocrine, nutritional, and metabolic	**26** Endocrine, nutritional and metabolic diseases **27** diabetes mellitus
Of which Diabetes mellitus	**27** diabetes mellitus
Circulatory system	**33** Diseases of the circulatory system **34** Ischemic heart diseases **35** Other heart diseases **36** Cerebrovascular diseases
Respiratory system	**37** Diseases of the respiratory system **38** Influenza **39** Pneumonia **40** chronic lower respiratory diseases **41** Asthma
Digestive system	**42** Diseases of the digestive system **43** Ulcer of stomach, duodenum and jejunum **44** chronic liver disease
Of which Chronic liver	**44** chronic liver disease
Mental and behavioral disorders	**28** Mental and behavioral disorders **29** Alcohol abuse (including alcoholic psychosis) **30** Drug dependence, toxic mania
External causes of injury and poisoning	**58** Violent deaths, total **59** Accidents **60** Transport accidents **61** Accidental falls **62** Accidental poisoning **63** Suicide and intentional self-harm

Table 11: Number of death belonging to the categories in Table 8.

	BMI						
Men:	**< 18.5**	**18.5-22.9**	**Basis**	**25.0-27.49**	**27.5-29.9**	**30.0-32.49**	**≥32.5**
Neoplasms	759	30,250	28.782	29,652	13,436	4,430	1,536
Endocrine	30	1,100	1.156	1,546	1,005	498	322
Of which diabetes	18	827	897	1,307	889	450	297
Circulatory	1,241	48,881	53,778	64,406	33,954	12,563	4,937
Respiratory	613	12,539	9,714	9,717	4,582	1,564	533
Digestive	111	2,707	2,666	2,966	1,551	594	256
Of which liver	16	430	484	538	303	144	65
Subtotal	2,754	95,477	96,096	108,287	54,528	19,649	7,584
Mental	48	1,550	1,382	1,330	608	172	63
External	165	5354	4,364	4,075	1,792	589	237
Of which suicide	34	1,402	1,140	998	414	141	47
Subtotal	213	6,904	5,746	5,405	2,400	761	300
Other	383	10,799	10,159	11,204	5,635	1,899	769
Total	3,350	113,180	112,896	124,896	62,563	22,309	8,653
Women:							
Neoplasms	1,503	25,181	18,635	20,165	13,917	8,630	8,100
Endocrine	62	941	1,012	1,406	1,445	1,168	1,679
Of which diabetes	24	576	705	1,113	1,187	1,009	1,546
Circulatory	2,014	34,748	35,291	47,469	37,961	25,435	24,367
Respiratory	886	9,364	7,393	8,937	6,267	3,870	3,165
Digestive	213	2,682	2,192	2,803	2,163	1,449	1,553
Of which liver	35	419	246	248	177	88	107
Subtotal	4,678	72,916	64,523	80,780	61,753	40,552	38,864
Mental	114	1,963	1,793	2,089	1,402	765	575
External	307	3,465	2,569	2,964	2,009	1,197	989
Of which suicide	56	746	316	261	160	76	57
Subtotal	421	5,428	4,362	5,053	3,411	1,962	1,564
Other	692	9,430	8,229	9,785	7,021	4,334	3,861
Total	5,791	87,774	77,114	95,618	72,185	46,848	44,289

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