The Economics of Body Height: Applications in Economic History and Labor Economics

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Preface

The economics of body height studies the complex interrelationship between physical stature and the economic environment in which it thrives. This interrelationship is bi-directional as, initially, the economy has a direct impact on physical growth whereas, later, body height through productivity has an impact on labor outcomes.

Physical stature is the result of a combination of genetic and environmental factors. About genetics, physical growth is a polygenic process as numerous genes have been found to be associated with growth (Silventoinen, 2003). Previous studies have assessed that heritability of body height is about 80 percent whereas the remaining 20 percent is determined by environmental factors.[1] Some studies also suggest that heritability of body height is not constant: the correlation seems to be comparatively lower in poor environments (Mueller, 1976; Lauderdale and Rathouz, 1999, Silventoinen *et al.* 2000). This fact is very important as body height is largely studied for historical periods in which individuals lived in very poor economic frameworks. Anyway, the genetic component of height cancels out when comparing averages across homogenous populations or, within a given population, when comparing average heights of different socio-economic groups.

Nutrition and disease are regarded as the main environmental factors affecting physical stature. Height mirrors the *net nutritional status* that is the

[1] See Silventoinen (2003) for an exhaustive literature review of relevant twin studies on body height heritability.

balance between caloric intake and expenditure of energy. Adult final height reflects then the accumulated past nutritional experience throughout the growing years, including the fetal period. Disentangling the effect of caloric intake and claims on nutrients is non-trivial. In fact, both the caloric intake and the expenditure of energy depend on the health status of the individual. Diseases can prevent food intake, cause nutrient losses, and increase energy expenditure. Furthermore, the analysis of physical stature must account not only for health and nutritional inputs but also for workload and labor organization (Steckel, 1995). Despite the objective difficulties to disentangle the net effect of nutrition and disease on body height, the latter yields precious information on how a social group or a population fared during childhood and adolescence in its socio-economic and epidemiological environment (Komlos and Snowdon, 2005).

Determinants of height include also real disposable family income and the relative price of nutrients. Cross-sectional systematic differences in height between different income groups have been established, without exception, everywhere and for all time periods (Komlos and Snowdon, 2005). In fact, higher social status, linked to income and education, is generally highly correlated with taller physical stature (Steckel, 1995). It is noteworthy also the relationship between income distribution and average height at a population level. Due to decreasing marginal returns to nutrient intake, an increase in income distribution will result in a decrease in average height: the loss in height experienced by the poorest share of the population will overweight the gain of the richest.

The growth process of the human body can also be very informative. From the change in height (named velocity) during childhood or adolescence it is possible to infer whether the individual was subjected to economic stress.[2] An illuminating example of the plasticity of body height comes from the investigation about the nutritional status of nineteenth-century American slaves. Richard Steckel showed that slaves' children were remarkably malnourished due to hard work of pregnant women, early interruption of breast-feeding, and a low protein diet. Once the children, by age 8 to 12, started working they overcame much of their early childhood height deficit. The vigorous adolescent growth spurt indicates that the diet of working slaves was nutritionally adequate for their

[2] For economic stress we mean one of the following factor or a combination of those: insufficient caloric intake, excessive workload during adolescence, weakening disease.

physical effort (Steckel, 1986; Steckel, 1998). We also know that in modern societies final height is attained between age 18 and 20 (Eveleth and Tanner, 1976). We shall see that for the period of the industrial revolution final height was attained around the age of 23. In fact the human body when subjected to economic stress tends to postpone growth. Therefore the comparison of average ages of final attainment of height for different socio-economic groups can reveal different nutritional patterns experienced during childhood and adolescence.

Anthropometric History is the study of body height as a complementary indicator of the standard of living. That physical stature was subject to the effect of environmental factors was already known to the famous French physician and sociologist Louis-René Villermé (1829). He realized that poverty was much more important than climate in influencing growth. In the 1960s, French historians adherent to the Annales Schools (*École des Annales*) such as Emmanuel Le Roy Ladurie investigated the possible determinants of body height and utilized military records to draw regional differences, time-trends, and socio-economic patterns in heights (Le Roy Ladurie *et al.* 1969). But it was only at end of the 1970s, in the field of Cliometrics,[3] that the study of body height as an indicator of living standard took definitely off. Usually, the highly controversial study of Fogel and Engermann (1974) about American slaves' nutritional status is acknowledged as the starting point of modern anthropometric history (Steckel, 1998). Since then, the study of anthropometric history contributed substantially to issues such as slavery, mortality, inequality, and living standard during industrialization (Steckel, 1998). Milestones in anthropometric history are the studies of Robert Fogel and Dora Costa who investigated the relationship between technological progress and improvements in human longevity, the so-called "technophysio evolution" (Fogel and Costa, 1997). According to their view advances in technology allowed for *(i)* a larger production of calories for human consumption and *(ii)* improvement in the treatment of infectious diseases (Fogel, 1994; Sunder, 2005). Both factors contributed to the physical evolution of human beings and established an inverse relationship between body height

[3] Cliometrics refers to the systematic use of economic theory and econometric techniques to the study of historical economic processes. The name Cliometrics derives its origin from the Greek muse of history Clio.

and mortality. Fogel in his Nobel prize lecture[4] stressed how height and weight at given ages, and Body Mass Index (BMI)[5] can be effective predictors of the risk of morbidity and mortality (Fogel, 1994). Yet, more recent research on the relationship between height and mortality provide contrasting results. Costa (2003) using a larger sample of a previous study (Costa, 1993) no longer finds a height-mortality association. Using another historical sample also Murray (1997) finds no association between height and all-cause mortality. Sunder (2005) using a cross-section of adult white Americans for the period 1971-1975 provides only weak evidence of a negative association between height and mortality.

As pointed out by Steckel (1998), the rise of anthropometric history "was boosted by a general disaffection with national accounting" and the need to supplement it with more comprehensive indicators of well-being. This disaffection is exemplified by the pursuit of alternative well-being indicators such as the *Physical Quality of Life Index* (PQLI) put forward in 1977 by the North-American Overseas Development Council and the best known Human Development Index (HDI) created by the United Nations.[6] Physical stature is a valid supplementary indicator of human well-being as it provides an historical record of nutritional status until adulthood and—as remarked by Steckel (1998, p. 807)—"even though far from comprehensive, everyone would agree that nutritional status is an important aspect of the standard of living". Further, given the high share of household income spent on nutrition and the frequent lack of classical economic indicators for the period before the middle of the nineteenth-century, one can understand why anthropometric history progressively gained consideration in the field of economic history and development economics in the last decades.[7]

The investigation of nutritional status proved particularly useful when applied to the study of the standard of living during the industrial revolution. Economic

[4] In 1993 the Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel was awarded to Robert W. Fogel and Douglass C. North "for having renewed research in economic history by applying economic theory and quantitative methods in order to explain economic and institutional change".
[5] The BMI is defined as weight in kilograms divided by the square of height in meters.
[6] The PQLI combines infant mortality rate, literacy rate, and life expectancy at age one. The HDI weighs life expectancy, literacy, and income.
[7] About the use of body height in development economics you are referred to the literature review of Strauss and Thomas (1998).

indicators such as consumption, real wages, income inequality, and life expectancy for many countries are scattered for the period before the middle of the nineteenth-century. Furthermore those indicators, when available, generally ignore entire segments of the population such as individuals outside the labor force and children. Clearly the literature has focused largely on the effects of the British industrial revolution and a long debate between optimists and pessimists flourished in the last two decades (Feinstein, 1998). Evidence on nutritional status in England, United States and several other European countries provides support to the pessimistic view about the impact of the industrial revolution on the standard of living (Komlos, 1998). A generalized decrease in average nutritional status characterized several economies starting from the second quarter of the nineteenth-century (Steckel, 1998). Since some classic economic indicators were found to trend upwards in some countries during the early industrialization period,[8] the findings about decreasing heights challenged previously established beliefs. The divergent pattern of heights and economic output has been termed by Komlos the "early industrial growth puzzle" (Komlos, 1998).

In the first two chapters of this dissertation we shall join the ongoing debate between optimists and pessimists and we shall provide new evidence about the anthropometric history of Saxony which was the pioneer region in the German modern economic growth (chapter 1). We shall see that the pattern of industrialization undertaken by Saxony resembles to a large extent the British experience characterized by high rate of population growth, large share of urban population accompanied by a rapid market integration. In chapter 2 we shall shed new light on the anthropometric history of industrializing Britain taking a clear position in the debate between optimists and pessimists. We provide new evidence about the negative effects of urbanization; the possible role played by the enclosures in deteriorating the standard of living of agricultural laborers is further explored.

Body height is the outcome of a given genotype[9] and environmental factors. These two elements—nature and nurture—are also correlates of individual

[8] Notably in England and in North-America.
[9] The genotype is the genetic constitution of an individual.

unobserved abilities which, in turn, have a direct impact on labor outcomes. Therefore height is also considered as an input variable which determines economic outcomes. In the field of labor economics scholars have tried to understand why tall stature is associated with higher economic success in terms of higher wages (Persico *et al.* 2004; Case and Paxson, 2006). Scholars have been also interested in assessing the mechanism underlying the transfer of human capital and economic status (Currie and Moretti, 2007). Knowledge about these mechanisms with the subsequent enhancement of economic policies directed to favor intergenerational social mobility is, needless to say, extremely worthwhile. In this fashion, body height was found to be positively associated with intelligence and cognitive abilities (Tanner, 1989). Yet, it is unclear which factor among nature and nurture (or which combination of the two) is prevalent at the basis of this correlation. Studies in favor of the nurture-effect stress the link between nutrition and cognitive development (Lynn, 1989; Kretchmer *et al.*, 1996). For instance, the cognitive development of initially growth-retarded children was shown to benefit significantly from better nutrition (Grantham-McGregor 2002). Conversely, body height and cognitive abilities could be both subject to the same chemical channels (Berger, 2001; Richards *et al.* 2002). Results on genetic linkages between height and cognitive abilities are mixed: a Norwegian twin study suggests that overlapping genetic factors explain circa one third of the correlation between height and cognitive abilities (Sunder *et al.* 2005). Silventoinen *et al.* (2000), and Magnusson and co-authors (2006) do not find evidence of genetic overlapping. Instead, there is a broad agreement about the fact that nutrition and health affect cognitive abilities throughout childhood (Walter, 1993; Pollitt and Mathews, 1998). Therefore children with low levels of cognitive development unlikely will be able to catch-up with their peers. Interactions between genetics and environment have also to be taken into account as the genotype determines the response to the environment (Silventoinen, 2003; Steckel, 1995). A given environmental factor can have different effects as people can be genetically more sensitive to external factors. In this respect, heights of men were found to increase more rapidly than those of women in twentieth-century England and Wales (Kuh *et al.*, 1991). There is also some evidence about higher resistance of women against starvation and other sources of stress.[10]

Social norms and applied psychology can contribute to explain why taller stature is associated with economic success. Evolutionarily, high physical stature represented an important advantage due to higher leverage and more physical strength. We can argue that this evolutionary advantage in physical strength translated today into a psychological advantage. Observations on social interactions seem to suggest the existence of an "equation" which links body height to social power (Judge and Cable, 2004). For instance, taller men have been shown to have greater ability to attract mates (Nettle, 2002) and having higher likelihood of getting married (Harper, 2000). Taller people tend to obtain higher respect and regard from the surrounding society (social-esteem) which in turn enhance people own self-esteem (Judge and Cable, 2004). Social- and self-esteem in the form of leadership and motivation have a direct effect on job-performances which then translate into economic success.

In the third chapter of this dissertation we shall provide new evidence about the correlation between body height and cognitive abilities for a selected group of European countries. This correlation will be exploited in order to assess whether the positive effect of height on earning potential is in place because body height is a biological marker for higher cognitive abilities, or rather, because employers tend to discriminate against shorter workers on account of the equation which links height and social power. We shall unveil the magnitude of the effect of height on earning potential and assess the extent of wage discrimination by height which affects male and female labor market. Finally, we shall provide substantive evidence about the role that body height plays in occupational sorting, uncovering different regional patterns across Europe which might inspire future research on this field of investigation.

[10] See Silventoinen (2003) on gene-environment interaction, p. 274-275.

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Chapter 1

On the Road to Industrialization: Nutritional Status in Saxony, 1690-1850

1.1 Introduction

The study of the effects of the industrial revolution on the living standards of the working class has involved much scholar attention. For obvious reasons much of the research has been devoted to the British industrial revolution and a long debate between optimists and pessimists characterized the literature in the last two decades. The formers found support in real wage estimates which suggested a significant amelioration of the standard of living for the period 1820-1850 (Lindert and Williamson, 1985). Successive revisions of the wage series and new studies on intra-household allocation moved the balance towards a more pessimistic view about the effects of the British modern economic growth (Crafts, 1985; Feinstein, 1998; Horrell and Humphries, 1992). In order to provide further evidence, classic economic indicators have been complemented by demographic and anthropometric measures. Indeed, the concept of the standard of living can be considered as multidimensional where nutrition constitutes an important component given the link between nourishment, health and productivity (Fogel, 1994). In the literature physical stature emerged as a reliable indicator of an individuals' nutritional status. In particular height is an indicator of an individual's nutritional status net of claims from the basal metabolism, epidemiological stress, and workload (Komlos, 1989; Steckel, 1995). The concept of nutritional status is also often associated with the biological standard of living. In this article we shall use the two concepts interchangeably. The genetic component is certainly the most important determinant of final height but this factor cancels out when comparing averages over time or between homogenous populations. Socio-economic conditions during early childhood and adolescence are expected to have a strong impact on the final attainment of height (Steckel, 1995; Silventoinen, 2003). Therefore the study of average height of a population in a cross-section and over time permits to obtain insights about the living standards across different social groups and their temporal dynamic. Given the large share of income spent on purchasing food, real wage constitutes an important determinant of the nutritional status. Nevertheless, issues such as demographic growth, urbanization, child labor and the effect of the relative price of food could counteract a possible rise of the real wage. This is one of the explanations at the base of the so-called *early industrialization puzzle*, a period characterized by a divergence between increasing economic output and decreasing nutritional status (Komlos, 1998). In this respect, declining trends in height have been established for many European countries for the period 1820-1850.[1] A common denominator for these countries is the rapid demographic growth and increase in urbanization that occurred in the first half of the nineteenth-century. The rise of population density with the consequent pressure on food resources determined an increasing trend in food prices which started to affect the European economies already during the last decades of the eighteenth-century. In the subsequent period the detrimental effect of urbanization and the

[1] For the United Kingdom see Floud, Wachter and Gregory (1990), Komlos (1993), and Cinnirella (2007); for the Habsburg-Austrian Empire Komlos (1985); for Northern Italy A'Hearn (2003); for Sweden Sandberg and Steckel (1987); for the Netherlands Drukker and Tassenaar (1997).

rapid increase of the price of food in terms of other goods—for instance clothing—outweighed even a possible increment of the income per capita.

The study of the living standards in Germany during the industrial revolution has to follow necessarily a regional approach. The economic history of Germany before the political unification in 1871 is a regional history as Germany was divided into numerous independent principalities which formed the Holy Roman Empire. The Empire was characterized by a very heterogeneous economic structure and different growth patterns were undertaken during the century 1750-1850 (Lee, 1988; Tipton, 1976). Saxony, together with the Rhineland, started her industrialization process relatively early. Many scholars consider Saxony the pioneer region in the German modern economic growth (Kiesewetter, 1988). In this article we shall investigate the effects of the early industrial growth on Saxons' nutritional status. The analysis of physical stature is particularly valuable here as economic data for the earlier decades of the nineteenth-century are scant. There are no reliable series on economic output for Saxony for the period before 1850 and evidence on wages and prices are limited to some selected sectors and few cities in Germany. The analysis of the nutritional status will then permit to shed some light on the evolution of the biological standard of living during the early industrial growth and to analyze differences among economic areas and social groups within Saxony. Our analysis is particularly valuable as we shall trace the nutritional status back to the proto-industrial period of the eighteenth-century. Saxony was, after France, the second earliest country in collecting systematic information about its soldiers. To our knowledge there are no other cliometric studies that can extend the analysis to such an extent. An important study in German anthropometric history focuses on cohorts born in the period 1725-1794 in southern Germany, namely Bavaria and Palatinate (Baten, 2001). Those regions differ markedly from Saxony as their economies were prevalently based on agriculture throughout the whole nineteenth-century. We shall see that there are significant differences between the trends in nutritional status followed by Saxony and southern-Germany, due to the different industrialization patterns undertaken.

In some respects the process of industrialization in Saxony resembles the English paradigm: *(i)* an exceptionally strong demographic growth with a relatively high degree of urbanization, *(ii)* a robust textile sector, and *(iii)* a relative rich endowment of raw materials (ore-mountains in the south). In the last three decades of the eighteenth-century Saxony could already enumerate several textile factories, a trend that was strengthened significantly during the Napoleonic period.[2] Yet, the early industrial growth in Saxony can be identified in the first half of the nineteenth-century. In 1815 the share of cotton spindles accounted for 80 percent of the whole Germany, in 1845 around 60 percent (Kiesewetter, 2004). Already in the middle of the nineteenth-century, the share of population employed in industry (45.6 percent) was larger than the share employed in agriculture (37.4 percent). It is important to note that, for the same period, in Germany the share of population employed in industry was only 24.5 percent.[3]

As mentioned, the exceptional rise of population in Saxony constitutes another important parallel with the British industrialization pattern. For the period 1775-1811 the population grew at an annual rate of about 0.52 percent, whereas in the successive period 1815-1830 the rate increased to 1.16 percent which implies a doubling population in about 60 years; in England the annual rate was 0.83 percent for the period 1751-1801. Also the rate of urbanization was unusually high in Saxony with respect to the rest of Germany. In the period 1800-1830, the share of British population living in urban areas was 38.7 percent (Steckel, 1999); in Saxony for the same period circa 32 percent (Kiesewetter 1988, p.220). Given the increase of urban inhabitants of circa 19.5 percent between 1815 and 1830, the rate of urbanization was above the average in the area of Dresden (21.7 percent) and Chemnitz (23.3 percent).[4]

In 1815, following the decisions taken at the Congress of Vienna, Saxony had to cede circa three-fifths of its land to Prussia, diminishing significantly its territorial extension (see figure 2 in the following section). As the territories ceded were the northern ones prevalently utilized in agriculture, this change had a strong impact on food production and consequently on the amount of food imports. Between 1814 and 1815 total population decreased by 39 percent while the production of rye decreased by 49 percent, wheat by 61 percent, barley by 58

[2] Forberger (1958) reports that 170 new big factories were founded in the whole 18th century; 101 of those had been founded between 1771 and 1800.

[3] See Tipton (1976). Unfortunately the shares for the whole Germany include also Saxony.

[4] See Kiesewetter (1988) chapter VII.

percent, oats by 45 percent, and potatoes by 37 percent (Kiesewetter 1988, p.278). Thus, only the production of potatoes could keep pace with the population change, whereas the largest loss was in terms of wheat which was also the most expensive cereal. Obviously this territorial change increased also the population density. In 1816 Saxony had circa 79.6 inhabitants per square kilometers, a measure second only to Alsace-Loraine which had a population density of 88.2. In 1871 Saxony would have reached the highest population density of the whole unified Germany (figure 1).

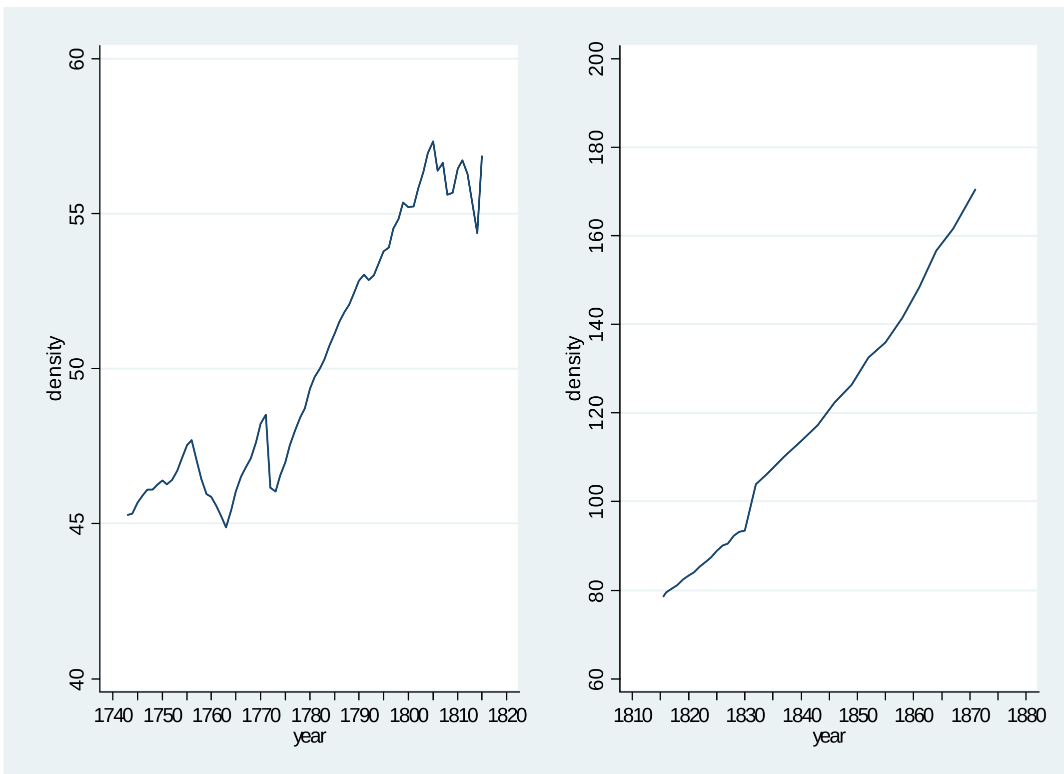

Figure 1. Population density in Saxony

Source: Schirmer (1996); Kiesewetter (1988).

1.2 Data and statistical issues

Saxony, despite its limited geographic extension, had a relatively large army. Among the eighteenth-century European kingdoms, the Saxon army was the third force after Austria and Prussia in terms of number of soldiers per working inhabitant (table 1). Important for our purposes, it was also the second in history after France in recording systematic information about its soldiers: the French army started in 1716 whereas the Saxon army in 1730. The recruitment of soldiers, until the Napoleonic period, was based partly on volunteers and partly on a mandatory system (Kroll 2006, p. 63). Individuals who belonged to specific economic sectors—such as farm owners, master craftsmen, artists, students, and selected manufacturing—were exempted from recruitment.[5] Therefore our sample is representative of the poorer social stratum composed mainly by daily laborers, simple craftsmen, domestic workers and unemployed people. We collected information on more than 70 thousand soldiers, covering a very large period which spans from those born in the 1690s until the cohorts born in the1840s. Our principal sources are the recruitment lists, originally kept in the State archive in Dresden, which contain detailed information about physical stature and various socio-economic variables. Around 64 percent of the soldiers are adults (age 23-49), 32 percent youths (age 18-22), and the rest below the age of 18 or over 50 years. The recruitment lists report also the full names (first, second and family name), military rank, age, height in Saxon inches (1 inch ≈ 2.3686 cm), and origin. About 44 percent of the recruits reported a previous occupation. The birth years were recovered through the date of enlistment and the reported age. Due to the fact that the recruitment lists provide stock information, we encountered circa 4,000 duplicates which means that the same soldiers were present in more than one list. We could identify duplicates crossing the registry names, birth year, and provenance. Once identified, we retained the individual observed lastly, eliminating the others. As for some soldiers height was measured in different points in time—generally two or three times—with this strategy we retain the observations with the most updated information. Anyway, for the large majority of the duplicates differences in height are equal to zero;

[5] See Kroll (2006) and Forberger (1958).

differences are noteworthy, in the range of 2-3 Saxon inches, when soldiers were measured before adulthood and later when their physical maturity was reached.

The literature on anthropometric history is plentiful of truncated height distributions and our new dataset is not an exception. European armies tended to accept only recruits whose height was above a certain minimum standard. The Saxon government considered important to have a particularly tall army both for representation and practical purposes.[6] We carefully examined height distributions grouped by recruitment year in order to identify the effective minimum height requirement (henceforth MHR) applied in different point in time.[7]

Table 1. Size of selected European armies in 1790

Country	Country size in miles square	Population (Mil.)	Serving soldiers	Soldier per inhabitant	Soldier per working inhabitant
Russia	305,000	24,0	224,500	1:91	1:33
Austria	12,281	19,0	297,000	1:64	1:24
France	10,200	25,0	182,000	1:140	1:52
Prussia	3,600	6,0	190,000	1:32	1:12
Kurpfalz-Bayern	1,064	2,0	12,200	1:164	1:62
Saxony	736	1,895	24,600	1:73	1:28

Source: Kroll (2006), p. 73.

We found that, besides being function of time periods, the MHRs changed also according to military rank. Furthermore, from a closer inspection of height distributions it clearly appears that, after the Napoleonic period, the recruiting process has changed quite dramatically. Indeed, there is a shift in the age composition of the army for those cohorts recruited after the Congress of Vienna. It is important to remember that the Saxon army during the period 1806-13 was assimilated under *La Grande Armèe*. All the European states after the Napoleonic period, including Saxony, moved towards a system of universal

[6] For example taller people were more able to reload the bayonets. See Kroll (2006).

[7] When there is universal conscription at a given age, height distributions by recruitment year or by cohort are not different. But when, as in Saxony before Napoleon, the recruitment is also based on volunteers of different ages, height distributions should be inspected by recruitment year in order to avoid misspecification of the MHR.

conscription for the army, with the notable exception of the British army.[8] The mean age for the period before 1815 is 27.3 years, whereas the same statistic for the post-Napoleonic period is 24.2 years. For the last birth-cohort considered in this article, 1840-49, the mean age is 20.8 years (n = 1,245). The minimum height requirements changed quite dramatically between the two periods: After 1815, in circa 85 percent of the cases a MHR of 68 Saxon inches was applied (≈ 161 cm), whereas for those recruited before Napoleon a MHR of 70 inches (≈ 166 cm) or 72 inches (≈ 170 cm) was mainly enforced. Besides the French Wars, height standards were lowered also during other war periods such as the Seven Years' War in 1756-63. In the two recruitment years which precede the war we observe distributions truncated at about 68 inches (circa 160 cm). The need of a larger army in prevision of the war provides a reasonable explanation for such low height standard.[9] The changes in the recruiting practices that took place under Napoleon and after 1815 have to be taken into due consideration in order to avoid estimating artificial height fluctuations. Furthermore, the exogenous shock of the territorial loss consequent to the Congress of Vienna renders eighteenth-century Saxony hardly comparable with the later period. Then, we decided to analyze the period pre- and post-Napoleon separately. Secular trends in nutritional status will be estimated through separate regression analysis.

The mean of a left-truncated distribution is clearly upwardly biased. Several statistical methods have been proposed to obviate to this problem (Komlos, 2004). In the related literature there is a widespread consensus about the superiority of the Truncated Maximum Likelihood Estimator (TMLE) with respect to other estimators (A'Hearn, 2004; Heintel, 1998; Komlos, 2004). The TMLE is based on the normality assumption and the probability density function of the dependent variable is standardized by the probability that the variable is observable, *i.e.* the soldiers' physical stature is greater than the truncation point. Contrary to other estimation methods, the TMLE estimator permits to run multiple regression models. It provides unbiased results and allows defining a

[8] The model of army followed by Saxony after 1815 was the French one with a relatively long service (around 8 years) with a strict selection and the possibility of substitutions. An individual initially chosen for the army could pay a second person in order to substitute for him. For a comparison between European army systems see Ilari (1989).

[9] For a detailed description of the history of the Saxon army in the eighteenth-century see Kroll (2006).

flexible truncation point which can vary according to military rank and recruitment period. A'Hearn (2004) showed that when the truncation point is allegedly close (or above) the true population mean, one obtains more precise estimates restricting the population standard deviation to a fixed value. In such a case we have the Restricted TMLE. Our eighteenth-century height distributions show a fairly high truncation point which can be reasonably assumed to be close to the true population mean. Therefore in estimating the trend in nutritional status for the eighteenth-century we do constrain the standard deviation of the adult population to the value of 6.86 cm as suggested by Komlos (2003) and A'Hearn (2004). Conversely, we do not constrain the population standard deviation for the nineteenth-century sub-sample given the significantly lower truncation points evidenced before.

The boundaries of Saxony changed through the period considered in this article. After the French Wars Saxony, following the decisions taken at the Congress of Vienna, was forced to cede its northern part to Prussia (figure 2). In the sake of simplification we categorized counties and macro-areas according to the actual administrative boundaries. We could codify around 82 percent of the reported origins which we assume being the soldiers' birthplace. In particular, since in the regression analysis we want to control for the area of origin, we divided the Saxon territory into three macro-areas according to the economic structure: *(i)* the textile district which includes the south-western part of the Vogtland with the towns of Chemnitz and Zwickau; *(ii)* the mining area of the southern ore mountains (*Erzgebirge*); *(iii)* the rural area which embraces the remaining northern and eastern part with two large urban centers such as Dresden and Leipzig. This categorization aims to capture the effects of an agricultural or industrial area on the individual's nutritional status in terms of economic prosperity but also of epidemiological environment. A separate dummy variable for urbanization is also used. It groups the four largest and rapidly growing towns: Dresden, Leipzig, Chemnitz, and Zwickau.

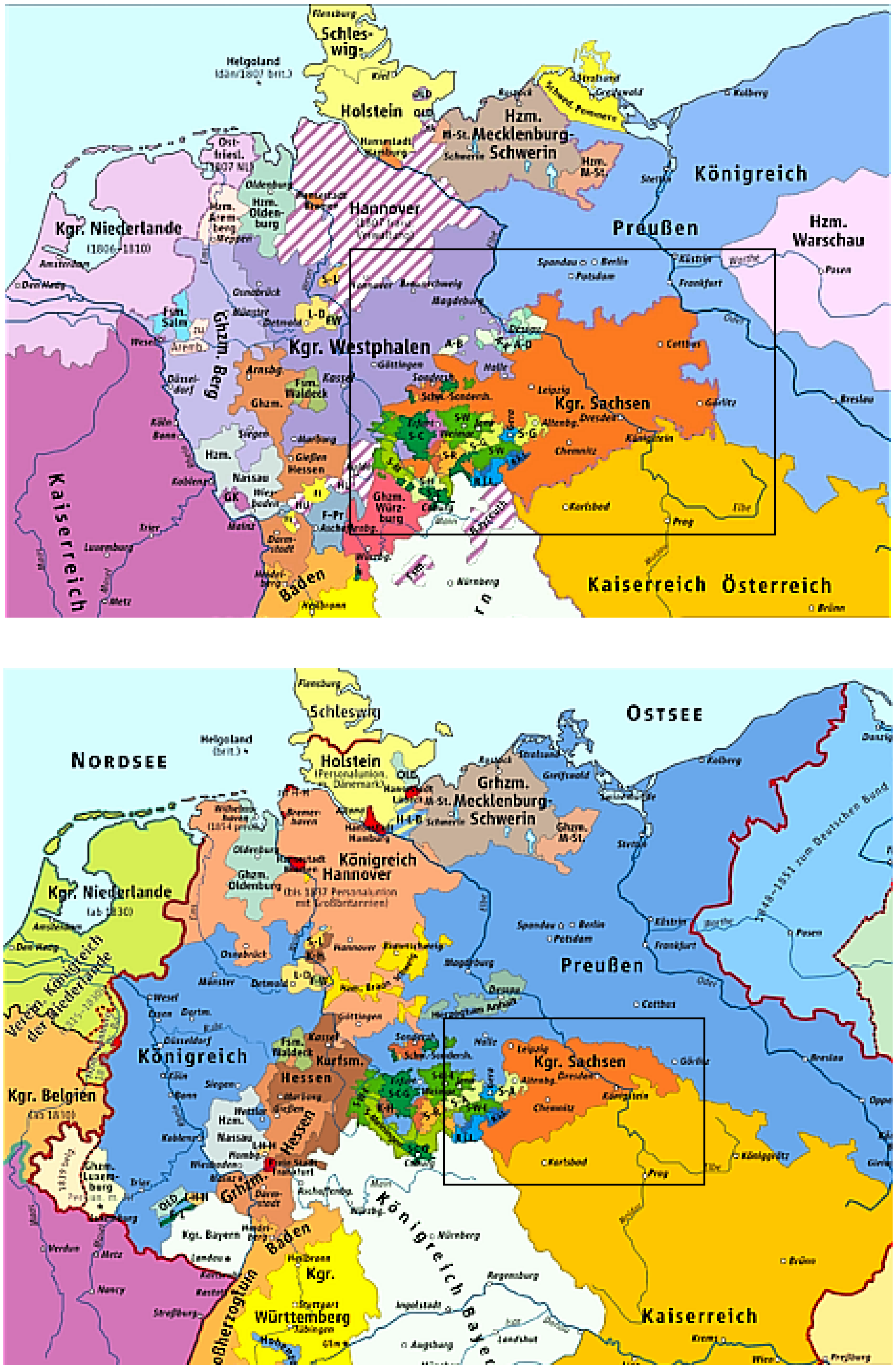

Figure 2. The Kingdom of Saxony in the Confederation of the Rhine 1808 before the territory loss (panel above) and in the German Confederation 1815-1866 (panel below)

Source: Klaus Günter Berger from Putzger (1965).

As shown in table 2, the three selected areas are fairly covered: about two-thirds of the soldiers came from the rural district, whereas the remaining of the sample is equally split between the textile and the mining district. This composition changes slightly across the two sub-periods with an increase in the two industrial districts with respect to the rural area in the later period. This change is consistent with the Saxon demographic evolution. In the early industrialization period higher marriage and fertility rates were registered in western and southern areas which were the areas with the fastest rate of industrialization (Tipton, 1976).

The occupation reported by the soldiers is expected to mirror the socio-economic background in which the individual was raised.[10] Clearly, it is an important determinant of the individual nutritional status. Therefore we created eight occupational categories (plus a ninth category for people who did not state a previous occupation) to employ in our regression model: *(i)* educated people such as engineers, physicians, and musicians; *(ii)* people employed in agricultural activities; *(iii)* occupations that entail a direct access to food (bakers, butchers, etc.); *(iv)* craftsmen; *(v)* people employed in factories or mining; *(vi)* textile workers; *(vii)* employed in the service sector and *(viii)* unskilled. Due to our *ad hoc* definition of occupations which is functional to the next regression analysis, a comparison of the sample occupational break-down with that provided by the Saxon census of the year 1849 is rather difficult. Nevertheless, the composition of our sample is surely biased towards the secondary sector and the share of those employed in agriculture is definitely under-sampled.[11] But the distribution within the industrial employment is fairly similar to that reported in the Saxon census, in particular the supremacy of the textile sector with respect to the other manufacturing.[12]

[10] We assume a low degree of intergenerational mobility.

[11] According to the figures of the census, in 1849 the occupational distribution was 37.4 percent in agriculture, 45.6 percent in industry, and 17.0 percent in the service sector (Tipton 1976, p.185).

[12] Within manufacturing, textile and clothing accounted for more than 75 percent (Tipton 1976, p.185).

Table 2. Descriptive statistics

	Whole Sample	Recruited before 1806	Recruited after 1806
Mean height (cm)	168.7	171.8	166.8
	(5.19)	(4.45)	(4.7)
Mean age	25.7	27.7	24.4
	(5.53)	(6.9)	(3.9)
Military unit (%)			
Infantry	88.1	85.9	89.4
Officers/Non-comm.	7.9	8.6	7.5
Musician	2.5	3.7	1.8
Carpenter (Zimmermann)	1.5	1.8	1.3
Total	100	100	100
Regional distribution (%)			
Rural district	65.7	76.7	58.7
Textile district	17.2	12.0	20.6
Mining district	17.1	11.3	20.7
Total	100	100	100
Urban	0.14	0.12	0.14
Occupation (%)			
Educated	1.1	1.4	0.9
Agriculture	0.9	1.0	0.7
Textile	14.1	7.9	17.9
Food	4.9	3.7	5.6
Crafts	21.5	21.5	21.6
Mining & factories	1.5	0.6	2.0
Service	1.6	1.6	1.6
Unskilled	3.1	0.6	4.6
No occupation	51.3	61.6	44.9
Total	100	100	100
Sample size	42,032	16,445	25,587

Note: Standard deviation in parenthesis.

Source: Saxon army.

1.3 Nutritional status, 1680-1784

This new dataset represents the second earliest military record used so far in anthropometric history.[13] We can estimate the secular trend in nutritional status starting with the cohorts born in the last decade of the seventeenth-century. Recruits younger than 18 years are not considered here as they were formally not allowed to join the army. Further, from the inspection of their height distribution it is not clear which criteria were followed to let them pass the physical examination.[14] With respect to the army units, the regression sample includes infantry, officers (and non-commissioned officers), musicians, and carpenters. In the sake of estimates accuracy we disregard also grenadiers and cavalry because of their upward biased physical stature (with respect to the other units) and odd distributions which do not allow a precise definition of their MHR.[15] In the previous section we mentioned the substantial differences between pre- and post-Napoleon Saxony, and in particular the changes occurred in the army-recruiting process. Thus, for the analysis of the eighteenth-century we decided to constrain the regression sample to those soldiers recruited before 1806. We estimate the mean height using the restricted TML estimator constraining the population standard deviation to the value of 6.86 cm as the truncation points are allegedly close to the true population mean. Indeed, considering the sub-sample recruited before 1806 we found that in 25 percent of the cases it was applied a minimum height requirement of 72 Saxon inches (≈ 170 cm!) and of 70 inches (≈ 166 cm) in other 65 percent of cases. These remarkably high standards justify the adoption of a truncated regression with a constrained standard deviation.

The trend in nutritional status is estimated regressing physical height on a set of dummy variables indicating the birth decade, age, military rank, origin, and occupation. We also use a dummy variable to control for urbanization, grouping the four principal Saxon towns.[16] The usual assumption of independence among observations could be violated as the outcome of individuals with the same origin—therefore sharing the same economic framework and epidemiological

[13] Komlos (2003) analyzed French soldiers born between 1660 and 1760.
[14] The share of soldiers younger than 18 years is anyway negligible.
[15] Their inclusion does not alter qualitatively our results.
[16] The towns are Dresden, Leipzig, Chemnitz and Zwickau.

environment—could be correlated. To obviate to this problem the regression standard errors are adjusted for clustering, *i.e.* we allow for correlation among individuals within the same county (landkreis) maintaining the assumption of independence between counties.

In table 3 we report the estimates for the period 1690-1784. The coefficients linked to the birth-cohorts indicate the variation in height with respect to the reference birth-cohort, 1760-69. The estimated trend is displayed in figure 3. The trend of nutritional status shows cycles which, to some extent, were already found in studies focusing on other European countries.[17] Average nutritional status increased from the last decade of the seventeenth-century for almost 20 years, a period of particularly good harvests. The cohorts born around 1710 reached the remarkable measure of 168 cm. Thereafter we find a local minimum which affected the cohorts born during the 1720s; such negative swing is coherent with recent findings about the anthropometric history of England and Ireland which experienced a similar downturn for the same period.[18] The subsistence crisis of the period 1725-29 in England and Ireland, supported by record-high crude death rate and declining real wage, seems to have occurred also in Saxony. After a fast recovery, a remarkable worsening in average nutritional status is also estimated for the cohorts born in coincidence with the Austrian Succession War, 1741-1748.[19] In that period the Saxon people reached the lowest measure of the whole eighteenth-century. One could argue that the low point for the period 1740-45 could be due to the recruitment that took place during the Seven Years' War (1756-1763). We can discard this argument as we found no significant correlation between the cohorts born in 1740-45 and the recruitment of the Seven Years' War. Also the insertion of a control variable for the recruitment during the Seven Years' War does not alter the previous findings.

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[17] For studies on height cycles see Woitek (2003).
[18] See Komlos and Cinnirella (2005).
[19] In the period analyzed in this article, three wars had a large impact on Saxony: *(i)* the Austrian Succession War (1741-1748); *(ii)* the Seven Years War (1756-1763), and *(iii)* the Napoleonic Wars (1793-1815).

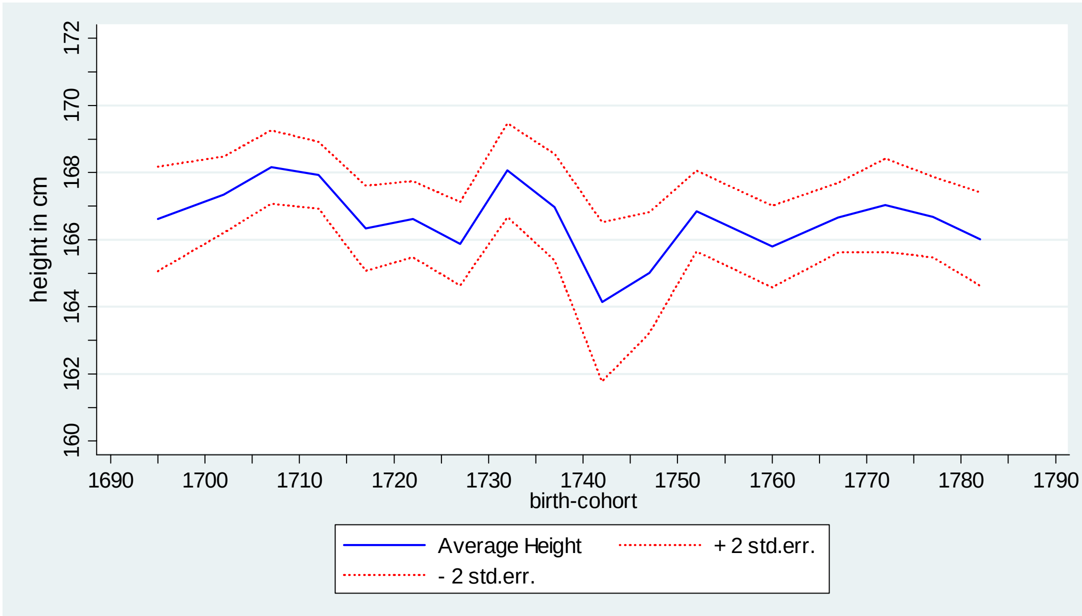

Figure 3. Height trend, 1695-1785

Note: Standardized for adults (23-49), infantry, craftsmen, born in the textile district. Standard errors are adjusted for clustering and account for the estimated covariance with the constant.

Source: Table 3.

Unexpectedly, the Seven Years' War did not have such a disruptive effect as the Austrian Succession War. The nutritional status of those born around 1760 is not significantly lower than the contiguous cohorts. Indeed, the Seven Years' War had a strong economic and demographic impact in Saxony. In fact, the war determined the bankruptcy of the Saxon government, and more important, some calculations impute a loss of around 100 thousands human lives which accounted for 6 percent of the total population (Schirmer, 1996). Because of the war, Saxony had in 1763 the same population level as of the 1740s. How can we reconcile this evidence with a nutritional status that shows no substantial decline for that period? We hypothesize that the Seven Years' War, with the subsequent loss of population, acted as a sort of Malthusian check. A lower population density meant a lower pressure on food resources and therefore an easier access to food. Statistics on wheat and rye prices partially support this hypothesis as the level of these prices in the central years of the war (1757-1760) was similar to the period before it (Elsas, 1940). In favor of our hypothesis, marriage rates did not sink as one would expect, but instead peaked in the years 1760 and 1761. The average marriage rate in the period 1756-1763 was 9.87; in famine years, 1771-72, average marriage rate declined to 6.51.[20] Furthermore, wages might have also increased: Evidence on the Malthusian effect of wars and epidemics is provided by Clark (2007). He shows that in the presence of sudden population losses—due for example to the Black Death and recurrent famines in the period 1350-1430—nominal wages increased in response to shortage of labor supply.[21] We argue that the same Malthusian dynamic may have acted in Saxony during the Seven Years' War.

As mentioned above, 1771 and 1772 were years of famine in Saxony due to extraordinary harsh winters which brought about a remarkable increase in food prices and mortality rates (see figure 1).[22] In our estimates we do not find a clear negative effect of those years as the nutritional status started to decline around the half of the 1770s. This decline is common to many other European countries which, for the same period, experienced decreasing living standards due to strong demographic growth and a general increase of food prices. We shall see in the next section that this declining pattern continued until the middle of the nineteenth-century.

The cross-sectional results show that officers (and non-commissioned) were significantly taller than infantrymen (almost 4 cm) confirming a different social extraction. The other army units were substantially shorter but given the limited number of observations for these categories these findings should be interpreted *cum grano salis*. The coefficient of the dummy variable for urbanization has the right sign but it is not statistically different from zero. Yet, this coefficient hides some important evidence. When used separately, the towns of Dresden and Zwickau show a significant negative effect on height of about 1.2 cm. Dresden was the largest town in Saxony,[23] whereas Zwickau is a city located at the foot of the *Erzgebirge* (Ore Mountains) which experienced a rapid demographic growth in the early phase of the industrial revolution. Therefore the usual suspects for

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[20] Marriage rates are here defined as the ratio of total number of marriages on population per 1000.

[21] Given the scarcity of labor with respect to land and capital, also real wages should rise. See Clark (2007) pp.115-116.

[22] Rising food prices are reported in Schirmer (1996) and Gerhard (2001). See also Baten (2001) and Klasen (1998).

[23] Dresden had 21,000 inhabitants in 1699, 46,000 in 1727. During the Seven Years War Dresden had around 63,000 inhabitants; after the war 44,000. In 1852 it had 100,000 inhabitants. Leipzig had 14,000 in 1648, 32,000 in 1753, and 26,000 after the Seven Years War.

the negative impact of urbanization on nutritional status seem to apply also here, namely scarce sanitation, high food prices and lower food quality.

In a society characterized by a limited intergenerational mobility the occupation reported by the recruits is expected to mirror the socio-economic background in which the recruits grew during infancy and childhood. Moreover, the cross sectional height differences among the occupations are generally intended to mirror the income distribution in the society. The estimates for the eighteenth-century do not show systematic height differentials among the occupations. There is only a consistent height advantage of 1.4 cm for those who had a direct access to food, namely millers, butchers, and bakers. The other categories are not statistically different from the reference group of craftsmen. The estimates show also that, on average, there were not systematic differences among the three geographic areas used for the regression analysis. The absence of occupational disparities in nutritional status and the fact that no systematic differences among the geographical areas were found suggest a low level of inequality in eighteenth-century Saxony.

Table 3. Truncated regression, 1690-1784

Dependent variable: height	Coefficient	Standard error
Constant	166.8***	0.51
Age		
Age18	-5.89***	1.44
Age19	-2.15***	0.60
Age20	-1.08**	0.52
Age21	-0.46	0.47
Age22	-0.26	0.41
Adults	reference group	
Military unit		
Infantry	reference group	
Officer	3.83***	0.37
Musician	-7.29***	0.77
Carpenter	-6.39***	0.90
Region		
Textile district	reference group	
Rural district	-0.06	0.40
Mining district	-0.74*	0.39

Dependent variable: height	Coefficient	Standard error
Urban	-0.50	0.36
Occupation		
Misc.crafts	reference group	
Educated	0.23	0.83
Agriculture	1.45	0.96
Access to food	1.42***	0.41
Mining and Factories	1.35	1.17
Textile	0.17	0.45
Service	0.93	0.66
Unskilled	-1.30	1.02
No occupation	0.51	0.32
Cohorts		
1690-99	-0.11	0.75
1700-04	0.58	0.60
1705-09	1.41***	0.46
1710-14	1.19**	0.49
1715-19	-0.42	0.67
1720-24	-0.19	0.51
1725-29	-0.89	0.67
1730-34	1.25	0.79
1735-39	0.18	0.74
1740-44	-2.61**	1.06
1745-49	-1.65*	0.86
1750-55	0.25	0.50
1756-63 (Seven Years' War)	-1.00	0.64
1764-69	reference group	
1770-74	0.30	0.69
1775-79	-0.07	0.52
1780-84	-0.83	0.61
Observations	13,866	

Note: Robust standard errors adjusted for clustering.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Further evidence on eighteenth-century Germany is rather scarce. Baten (2001) investigated nutritional status for Bavaria and Palatinate analyzing military records of cohorts born between 1725 and 1794. The southern states of Germany are not directly comparable to Saxony as the formers followed a completely different industrialization path. Indeed, the Bavarian economy was prevalently based on the primary sector throughout the whole nineteenth-century, whereas Saxony already at the end of the eighteenth-century could experience the birth of the factory system. Nevertheless it could be instructive to compare the average nutritional status of these two German regions. The height trend estimated by Baten is increasing between the cohorts 1725-29 and 1750-54, whereas it is decreasing for the period 1750-1770. For the remaining period, 1770-1790, the average nutritional status in Bavaria increases slightly, as it recovers from the famine years, even though it did not reach the high levels of the 1750s. Therefore the trends in height in Saxony and Bavaria follow the same pattern only to a limited extent. For the last third of the century under investigation the two trends diverge. This finding is not surprising whether we consider the very different economic structure of the two regions. As stressed by Baten, the average nutritional status in Bavaria was probably more affected by the climate and its effect on food production than by demographic pressure, urbanization, workload or the disease environment. Our estimates for Saxony are more consistent with trends estimated for countries on the road to industrialization such as England or the region of Bohemia in the Habsburg-Austrian Empire. In those countries the decline in nutritional status during the last third of the century is a common feature (Floud *et al.*, 1990; Komlos, 1993a; Komlos 1989). Thus, the differences in the nutritional status between Saxony and Bavaria emphasized here suggest that the economic history of eighteenth-century Saxony is more similar to England, characterized by a strong demographic increase and urbanization which, in turn, contributed to increase food prices already in the last decades of the century. For Britain, evidence of increasing food prices and decreasing real wages during the last decades of the eighteenth-century has been recently confirmed (Clark, 2001; Clark, 2007). In the case of Saxony evidence on real wages for this period is scarce. Some scattered evidence shows that in Germany real wages were on decline and remained low until 1850 (Gerhard, 1984). Klasen (1998) reports that per capita meat consumption in Germany declined by 36 percent in the period 1770-1800 and he ascribes this phenomenon to declining real wages.

1.4 Nutritional status and early industrial development

In this section we focus on the nutritional status of the soldiers born between 1785 and 1845, recruited after 1806. As mentioned, a considerable shift in the age composition of the Saxon army occurred after the Congress of Vienna. Enrolment practices changed and the army recruited relatively more youths. Similarly to most of the European armies, also Saxony after Napoleon moved toward a system of universal conscription. The share of soldiers between age 18 and 22 years recruited after 1806 is 44 percent; the same age-group makes only 25 percent of the pre-1806 recruitment sample. Accordingly, also the height distributions changed with respect to the previous century. The predominant (86 percent of the cases) MHR enforced in the nineteenth-century was 68 Saxon inches (≈ 161 cm). This measure is significantly lower than the standard mostly applied in the previous century which was around 70 inches (≈ 166 cm). Given the lower truncation point, in the estimation we do not constrain the population standard deviation to a fixed value but we leave it as a parameter to estimate in the maximization procedure.[24] The model specification is almost identical to the one adopted in the previous section. We have an additional control variable for the recruitment under *La Grande Armée* (1806-13) which, otherwise, could introduce some bias in our results. Alike for the eighteenth-century, standard errors are adjusted for clustering where the counties constitute the clusters (table 4).

The estimated trend in nutritional status is displayed in figure 4 and is standardized for a 21 year infantryman, born in 1785-89 in the textile district, and previously employed as a craftsman. The trend is decreasing throughout the whole period. Physical stature, which remained constant during the first decade of the nineteenth-century, declined substantially from 1815 reaching a remarkable low measure in 1845. Average height decreased between the cohorts 1806-14 and 1840-49 by more than 6 cm. The estimated trend shows that the average nutritional status remained constant during the Napoleonic period, whereas in the previous and subsequent period average heights were on decline.

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[24] See the data section for an explanation of the different approaches in dealing with truncated distributions.

What is the economic fact that halted the declining trend in nutritional status in the period 1800-1815? We believe that the Continental System pursued by Napoleon and extended to all the countries under his influence played a determinant role. Already in the last decades of the eighteenth-century Saxony could enumerate several textile factories (Forberger, 1958). This number increased significantly during Napoleon: In that period the number of mule spindles increased from 13,000 to 256,000 units (Crouzet 1964, p.576). In 1815 Saxony possessed 80 percent of the cotton spindles of the whole Germany (Kiesewetter, 2004). The Continental System, which took effectively place in 1806-14, gave a considerable boost to investments in the Saxon cotton industry. The Blockade, restricting all trade with Britain or her colonies, suddenly eliminated the highly competitive British textile produces from the Saxon market thus favoring the relatively inefficient Saxon cotton manufactures. The Blockade stimulated the demand for more expensive domestic products favoring on one side the textile sector, and on the other side triggering a decrease in the relative price of food. Indeed, prices of European industrial goods rose substantially in Germany with respect to rye[25] and that might have contributed to keep the population nutritional status constant. The positive effect of the Blockade is also mirrored by changes in demographic variables: Between 1806 and 1811 population increased by 6.4 percent, marriage rate by 38.8 percent, birth rate by 20.3 percent, and infant mortality rate declined by 19.1 percent (Kiesewetter 1988, p.208). These figures are comparable in magnitude with those for the period 1820-25, when the population recovered from the hunger-years of 1816/17.

After the collapse of the Blockade the Saxon cotton industry suffered tremendously from the reintroduction of the British products. As a consequence the Saxon textile industry went through an industrial re-conversion from cotton toward wool manufacturing (Tipton, 1976). As a result, the number of cotton spindle mules in Saxony between 1815 and 1825 increased by only 5.6 percent, whereas in the rest of Germany it increased by 18.4 percent (Kiesewetter, 2004).

[25] O'Rourke (2005).

Figure 4. Height trend, 1785-1845

Note: Standardized for adults (23-49), infantry, craftsmen, born in the textile district. Standard errors account for the estimated covariance with the constant.

Source: Table 4.

Therefore, the strong decline in average heights after 1815 could be a partial response to the structural change that touched one of the core sectors of the Saxon economy.

The interaction between population density and food supply played also a substantial role in shaping the nutritional status in Saxony. In the period 1775-1811 the population grew at an annual rate of about 0.5 percent, whereas in 1815-1830 at an impressive rate of circa 1.2 percent which implies a doubling population in about 60 years. As a consequence of the decisions taken at the Congress of Vienna, Saxony in 1815 had to concede to Prussia a significant part of its predominantly agricultural and low-density populated area which made almost three-fifths of the whole country. Such a loss had a relevant impact on the country food-provision and on the population density. In 1816, according to the new boundaries, the population density in the Kingdom of Saxony was 79.6 inhabitants per square kilometers. The dependence on food imports rose significantly after 1815 and worsened with the poor harvests of 1825/26. Between 1814 and 1815, due to the loss of land, total population decreased by 39 percent while the production of rye decreased by 49 percent, wheat by 61 percent, barley by 58 percent, oats by 45 percent, and potatoes by 37 percent (Kiesewetter 1988, p.278). Unfortunately we are not able to trace the trend in food imports for the period 1815-1850, but it is undisputable that Saxony relied heavily on imports of rye and wheat, and mainly from the neighboring Bohemia, Hamburg (through the river Elbe), and Prussia. Saxony in the period 1837-1844 imported on average circa 654,000 bushel of cereals[26] which correspond to about 7 percent of the cereal production in Saxony in 1846.[27] It is also important to note that potato was the main agriculture produce during that period in Saxony. Kiesewetter shows that in the period 1846-1871 potato cultivation constituted more than half of the total agricultural production (Kiesewetter 1988, p.284).[28]

Therefore the increasing pressure on food resources and the increasing dependence on food imports likely triggered high food prices contributing to the deterioration of the average nutritional status. The rise in population could occur only at the cost of a lower average nutritional status. The relative price of food increased substantially in the nineteenth-century. Using German price series of Jacobs and Richter (1935) we constructed an index which goes from 1790 until 1860 (figure 5). The index is the ratio of a weighted average of agricultural prices over a weighted average of industrial prices. The quadratic interpolation on the figure shows clearly the increasing trend in the relative price of food that occurred in Germany in the first half of the nineteenth-century. During the Blockade, in particular in 1810, the relative price of food reached its lowest value consistently with our hypothesis about the positive effect of the Blockade on the average nutritional status. After Napoleon, prices of industrial products declined steadily whereas agricultural prices, considering also the crisis of 1816-17, moved upward driven by a strong demand and urbanization.

The cross-sectional results for the period 1785-1849 show some important differences with respect to the previous period (table 4). Whereas the coefficient for officers (and non-commissioned) confirms again a different social extraction, the results linked to the geographic area and the occupations present interesting insights.

[26] Rye, wheat, barley, and oats.
[27] See Kiesewetter (1988), table 15 on p.284 and table 23 on p.321.
[28] On the importance of potatoes in Saxony see also Baten (2001).

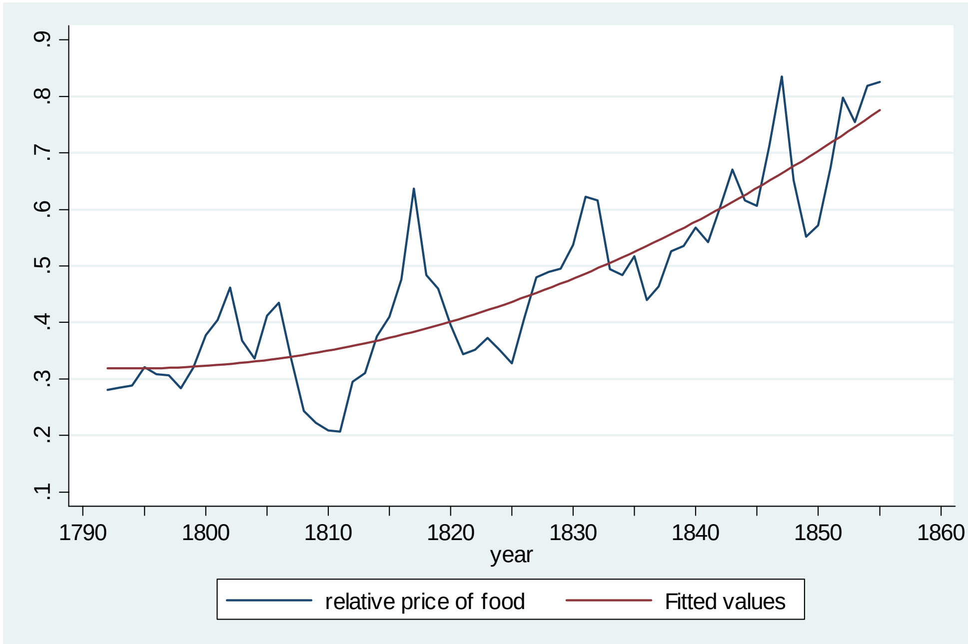

Figure 5. Trend of the relative price of food in Germany

Source: Jacobs and Richter (1935).

Both the north-eastern rural area and the southern part of Saxony present a height penalty with respect to the textile district (around the town of Chemnitz) of more than one centimeter. The urban dummy has a coefficient not statistically different from zero but, as in the previous case, it hides important findings. When disaggregated,[29] the regression shows a consistent urban penalty for Dresden (0.4 cm) and for Chemnitz (1 cm) which was at the hearth of the Saxon industrialization. Individuals born in the latter town were likely exposed to a particular epidemiological stress due also to a rapid demographic increase. Indeed, the area around Chemnitz had the highest population growth rate in the period 1815-1830.[30] Internal migration could also explain partially the urban disadvantage: economically destitute people from the countryside may have moved towards urban agglomerates in search of better job opportunities lowering the average urban biological standard of living. This conjecture is plausible as we know that soldiers from towns were recruited mainly from the periphery of the urban centers (Kroll, 2006).

[29] Estimation results not reported here.

[30] Ewert (2006) on the contrary finds a height advantage for urban residents. His evidence can hardly be reconciled with the strong urbanization of early industrial Saxony.

Table 4. Truncated regression, 1785-1849

Dependent variable: height	Coefficient	Standard error
Constant	167.3***	0.70
Age		
Age18	-0.03	0.67
Age19	0.69	0.47
Age20	0.68**	0.31
Age21	reference group	
Age22	0.23	0.26
Adults	-0.18	0.22
Military unit		
Infantry	reference group	
Officer	4.22***	0.24
Musician	1.02*	0.58
Carpenter	1.56***	0.53
Recruited 1806-1813	0.69	0.57
Region		
Textile district	reference group	
Rural district	-1.20***	0.32
Mining district	-1.20**	0.48
Urban	-0.18	0.32
Occupation		
Misc.crafts	reference group	
Educated	3.60***	0.65
Agriculture	4.63***	0.81
Access to food	-0.41	0.28
Mining and Factories	0.68**	0.31
Textile	0.78***	0.20
Service	0.82*	0.43
Unskilled	-0.97***	0.33
No occupation	-0.10	0.15
Cohorts		
1780-84	reference group	
1785-89	-1.64***	0.39
1790-94	-1.90***	0.48
1795-99	-0.78*	0.41
1800-05	-1.50***	0.53
1806-14	-1.48***	0.55
1815-19	-3.65***	0.61
1820-24	-4.68***	0.61
1825-29	-5.77***	0.66
1830-34	-5.63***	0.58
1835-39	-8.11***	0.83
1840-49	-7.84***	0.69

Dependent variable: height	Coefficient	Standard error
Observations	23,290	

Note: Robust standard errors adjusted for clustering. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Contrary to the estimates for the eighteenth-century, the height differentials among occupations signal here an increase in income inequality during the period of early industrialization. The absolute difference between the tallest category (agricultural workers) and the shortest (unskilled) is equal to 5.6 centimeters.[31] With respect to the estimates for the previous century, the coefficient for those with privileged access to food lost statistical significance. This result is consistent with the model put forward by Komlos (1989) and with the more recent empirical evidence about the negative effect of market integration on the nutritional status (see Baten and Fertig, 2000; Craig and Weiss, 1988). As food demand from rapidly-increasing urban centers increased and transportation costs diminished, people with privileged access to food had a greater incentive to market food products instead of self-consuming, and spend more on other goods such as tobacco, sugar, and clothing (Komlos, 1989). As market integration proceeded in Saxony, the nutritional status of those with an initial surplus in nutrients leveled-off. Similar result was found by A'Hearn (2003) for those who specialized in dairy production in pre-unification Italy. A'Hearn argues that those people used all the milk to produce cheese which could be transported and then marketed in the cities.

People previously employed in the textile, in mining or in factories, and in the service sector (mainly barber and salesmen) enjoyed a nutritional advantage relative to craftsmen. On the left tail of our imaginary income distribution we find the unskilled with a height disadvantage of about 1 cm. An increasing income distribution is not at odd with a declining trend in height: assuming the income elasticity of demand for food being less than one and given the strict concavity between height and food intake, *ceteris paribus*, a shift toward a more skewed income distribution results in a decrease in average height.

[31] Similar differentials in magnitude have been estimated for 20th century India in a recent study by Guntupalli and Baten (2006). Komlos (2005) estimated a very large differential between rich (Sandhurst) and poor (Marine Society) British youths in the 18th and 19th century: at age of 16 the height gap reached 22 cm.

1.5 Nutritional status by district

The model specification adopted in the previous section assumes that the effects of the three economic districts are constant over time. The large number of observations in our sample permits to relax this assumption estimating height trends for each district separately. We focus on the period of the early industrial revolution which is of major interest. The cohorts analyzed here cover the period 1785-1845 and refer to the soldiers recruited under and after Napoleon (recruitment ≥ 1806). The regression output is presented in table 5 and the three patterns in nutritional status are displayed in figure 6. Most of the findings illustrated in the previous section are confirmed by the district-level regressions, in particular the overall decreasing pattern and the superiority of the nutritional status for those born in the textile district. Yet, there are some interesting patterns worth mentioning here. The Napoleonic period and in particular the period of the Continental Blockade present interesting results: there is a clear divergence in the pattern of the nutritional status between the industrial districts (textile and mining) and the rural one. Whereas the nutritional status of those born in the rural area in the period 1795-1810 decreased, for those born in the industrial district the trend takes an opposite direction. Admittedly, the amelioration of the nutritional status for the industrial districts seems to have started shortly before the blockade, around the beginning of the 1790s. Nevertheless we can legitimately argue that the Blockade sustained and maybe also reinforced a positive trend in nutritional status for those born in the rapidly developing industrial districts. This is also confirmed by the positive and significant coefficients estimated for the textile occupations in both industrial districts.[32] We also checked whether the interaction of the textile variable with the cohorts born in the blockade period, 1806-13, could support our hypothesis. Indeed, in the height regression for the mining district the combined effect of textile occupation and being born during the blockade determined an increase in physical stature of circa 3.5 cm. The Continental Blockade, by imposing trade restrictions to and from Britain, boosted the development of the textile sector in

[32] The fact that the coefficient for the textile occupation is much larger in the mining district probably derives from our allocation of counties between the textile and mining area. The two districts obviously cannot be easily defined as some counties could in principle belong to both areas. In any event, this does not flaw our results.

Saxony ameliorating the living standards of those attached to that sector. Those individuals born in the textile district during the blockade, whose families were presumably working in the textile sector, enjoyed a remarkable nutritional advantage comparable to that estimated for army officers who generally had a higher social status. Instead, the strong decrease in nutritional status after 1815 was common to all the three areas. The industrial stagnation that followed in the early 1820s (Kiesewetter, 2004) and the increased dependence on food imports contributed to the deterioration of the average nutritional status.

The last important feature that we can observe in figure 6 is the sharp decline in heights that occurred in the rural area for the cohorts 1835-39. We do not have a clear explanation for that also because a jump of four centimeters occurred in only a five-year period seems quite implausible. There are no systematic differences between the cohort 1835-39 and the preceding one, neither in the age nor in the occupational composition. Yet, two major economic changes took place in that period: *(i)* the agrarian reform and *(ii)* the introduction of the German customs union (*Zollverein*). The agrarian reform was passed in 1832 and most of the commons were divided. It is difficult to establish *a priori* the potential effects of the reform on the population living standards. On one side, agricultural productivity probably increased favoring food-supply (Kiesewetter, 2004); on the other side, many laborers were deprived from land which could have provided food for self-sufficiency. More people then became dependent on wages and sensitive to changes in food prices.[33] The *Zollverein* was introduced in 1834 and internal customs barriers were removed within the majority of the states of the German Confederation. The impact of the *Zollverein* on the German economic development was probably fairly limited (Dumke, 1977). As stressed by Lee (1988), the motives behind the formation of the customs union were primarily fiscal. If anything, the *Zollverein* contributed to reinforce the already existing regional patterns established before 1834.

[33] See Cinnirella (2007) and Humphries (1990) for studies about the impact of the English enclosures on the standard of living.

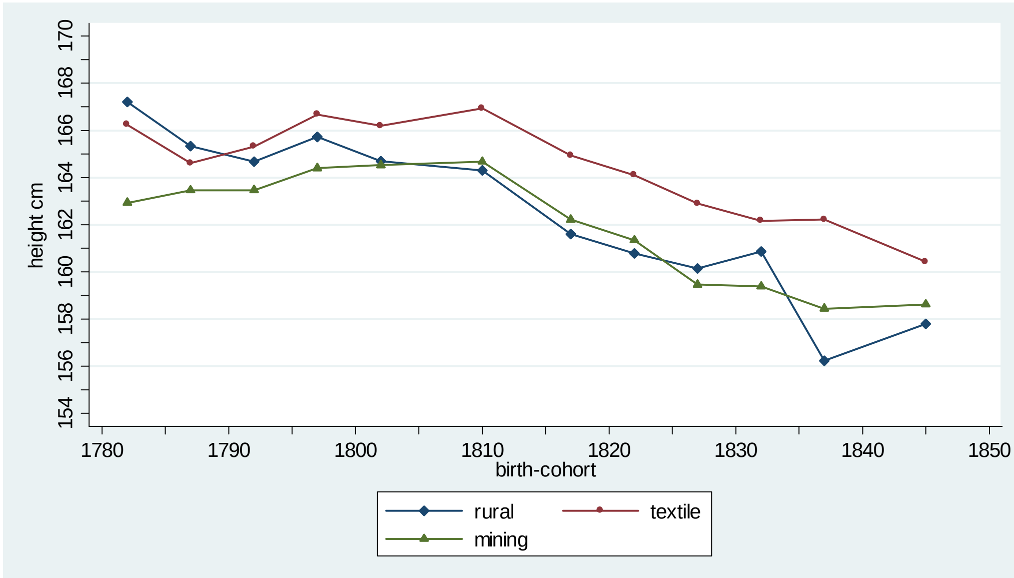

Figure 6. Regional trends in height, 1780-1845

Note: trends standardized for infantry, age 22 years, craftsmen.

Table 5. Truncated regressions by economic district

Variables	Rural district	Textile district	Mining district
Constant	167.21***	166.25***	162.93***
	[0.48]	[1.40]	[1.21]
Birth cohorts			
	output omitted	output omitted	output omitted
Army unit			
Infantry	reference group	reference group	reference group
Officers	4.25***	4.25***	3.91***
	[0.25]	[0.40]	[0.44]
Other units	output omitted	output omitted	output omitted
Age			
Age18	0.23	0.65	-1.06
	[0.80]	[1.36]	[1.81]
Age19	1.46***	-0.04	-2.00
	[0.54]	[0.93]	[1.38]
Age20	0.97**	0.46	0.42
	[0.38]	[0.58]	[0.66]
Age21	reference group	reference group	reference group
Age22	0.18	-0.00	0.62
	[0.31]	[0.45]	[0.53]
Adults (23-49)	-0.44*	-0.27	0.52
	[0.24]	[0.37]	[0.44]
Urban	0.19	-0.63***	-

	[0.23]	[0.24]	
Occupation			
Misc. crafts	reference group	reference group	reference group
Educated	3.95***	-0.54	4.09***
	[0.72]	[1.88]	[1.57]
Agriculture	4.29***	3.27*	7.50***
	[0.76]	[1.70]	[1.80]
Access to food	-0.17	-0.25	-0.80
	[0.37]	[0.62]	[0.52]
Mining & factories	0.53	1.04	0.75
	[0.93]	[1.15]	[0.59]
Textile	0.62**	0.28	2.19***
	[0.26]	[0.31]	[0.42]
Service	0.09	0.99	3.13***
	[0.65]	[1.03]	[1.17]
Unskilled	-1.02**	-1.59	0.52
	[0.51]	[1.02]	[0.92]
No occupation	-0.14	-0.01	-0.21
	[0.21]	[0.32]	[0.33]
Cohorts			
1780-84	reference group		
1785-89	-1.87***	-1.64	0.53
	[0.43]	[1.43]	[1.19]
1790-94	-2.53***	-0.93	0.53
	[0.41]	[1.36]	[1.11]
1795-99	-1.48***	0.43	1.47
	[0.41]	[1.36]	[1.11]
1800-05	-2.52***	-0.06	1.59
	[0.43]	[1.38]	[1.18]
1806-14	-2.90***	0.68	1.74
	[0.40]	[1.33]	[1.09]
1815-19	-5.61***	-1.31	-0.72
	[0.53]	[1.36]	[1.13]
1820-24	-6.42***	-2.15	-1.59
	[0.53]	[1.39]	[1.15]
1825-29	-7.07***	-3.34**	-3.47***
	[0.58]	[1.44]	[1.34]
1830-34	-6.34***	-4.08***	-3.55***
	[0.64]	[1.52]	[1.35]
1835-39	-10.98***	-4.03***	-4.49***
	[0.71]	[1.52]	[1.34]
1840-49	-9.41***	-5.82***	-4.31***
	[0.62]	[1.52]	[1.31]
Observations	13,505	4,931	4,855

Note: Robust standard errors adjusted for clustering.

* p < 0.10, ** p < 0.05, *** p < 0.01.

1.6 Discussion and conclusion

We present new estimates of the nutritional status for the proto-industrial and the early industrialization period in Saxony which was the pioneer region for the German modern economic growth. In the eighteenth-century, nutritional status shows cycles mostly due to recurrent subsistence crisis and war periods. Average height peaked for the cohorts born around 1710 and the beginning of the 1730s—the latter was a favorable period in terms of crops—whereas it reached a minimum in correspondence with the Austrian Succession War (1743-48). The period of the Seven Years' War (1756-63) was characterized by stagnating heights, though less than expected. We hypothesize that the disruptive effect of the war acted as a sort of Malthusian check. Evidence on non-increasing food prices and high level of marriage rates tend to back this hypothesis.[34] Then, the nutritional status started to decline substantially from the middle of the 1770s.

The Continental Blockade of Napoleon by eliminating the British competition on textile products boosted investments in the Saxon cotton industry which increased notably its production capacity. We provide new evidence that the Blockade had a temporary positive effect on the average nutritional status in Saxony. In fact, physical stature increased slightly in the industrial district (textile and mining), whereas it declined in the remaining areas in the first decade of the nineteenth-century. The regression results show a strong positive effect on height for workers who reported occupation in the textile sector and were born during the Blockade. Evidence about increasing population, marriage rates, fertility rate, and decreasing infant mortality rate between 1806 and 1811 strongly corroborate our finding about the impact of the Blockade.

Early industrial development in Saxony can be dated around the period 1815-50. During that phase the average nutritional status declined substantially. In the middle of the nineteenth-century average heights reached an extremely low measure (slightly below 160 cm) which places Saxony at the bottom of the European scale in terms of nutritional status.[35] British workers, who also

[34] See also Clark (2007) about Britain before 1800.
[35] See Steckel and Floud (1997), p.424.

experienced a decline in height in the period 1820-1850, were comparatively taller with a measure of 165-166 cm.[36] Only the industrial-backward Japan shows height levels that are below those estimated for Saxony for the period around 1850 (Honda, 1997). The causes for such a negative record are multiple and resemble to a large extent those individuated for Britain. In particular, we believe that the timing of industrialization and the extent of urbanization played a major role in shaping the Saxon nutritional status between 1815 and 1850.[37] In fact, much before the rise and acceptance of the germ theory of disease—which can be dated around the 1880s—Saxony was already experiencing a fairly rapid industrial growth accompanied by high levels of urbanization and very high levels of population density. More than one-third of the Saxon population lived in an urban centre during the early industrialization period. We found that in Dresden and in the rapidly growing town of Chemnitz there was a significant penalty in terms of nutritional status. Precarious hygienic conditions, lower food quality and higher prices are the usual suspects for such height disadvantage. On the contrary, countries which experienced the early phase of industrialization with relatively low levels or urbanization—notably France and Sweden—had height trends which diverge from what has been found for Saxony. In 1850, the share of urban population in France was 26 percent (Weir, 1997) and only 10 percent in Sweden (Sandberg and Steckel, 1988), while in Saxony in the same period it was already above 30 percent.[38] Additionally, Saxony had also a very high population density, due also to the exogenous change of the country borders commanded by the Congress of Vienna, which might have favored the spread of communicable diseases.[39]

The diet is another element which has to be considered when evaluating the causes of nutritional status. We suggest that the redefinition of the Saxon borders with the transfer of agricultural territories to Prussia partly contributed to the deterioration of the average nutritional status. In fact, Saxony encountered increasing difficulties in meeting a rising demand for food and became more

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[36] See Floud *et al.* (1990).
[37] Steckel and Floud (1997).
[38] Swedish people, due also to their high level of literacy, were more sensitive to government propaganda in favor of breast-feeding and general public health (Sandberg and Steckel, 1997).
[39] In this sense it is also important to note the role played the river Elbe which connected Dresden with the market of Hamburg.

dependent on food imports which came mainly from the neighboring Bohemia, Prussia, and Hamburg. The agrarian reform in 1832 and the participation in the customs union (*Zollverein*) few years later re-directed the import channels but the problem of dependence on food import persisted (Kiesewetter, 1988). In this respect, we provide some evidence about the increase in the relative price of food that took place in Germany in the first half of the nineteenth-century.

The importance of the quality of nutrients was shown by Weir (1997) for the case of France. He showed that another reason at the basis of the increase in French heights during the nineteenth-century was the parallel increase in meat consumption. Klasen (1998) provides evidence of a decline in livestock production in Germany: Meat consumption declined by ca. 35 percent between 1770 and 1800 reaching its lowest point at the end of the Napoleonic Wars.[40] Only after 1850 livestock production started to rise again. Evidence of a poor diet in Saxony is witnessed by the large production of potatoes which followed the country-borders-redefinition. Potato crops made up to 22 percent of the food production in 1810; in the middle of the nineteenth-century the share was above 50 percent (Kiesewetter, 1988).

Another factor that was shown to be an important determinant of height is the availability of milk. Regression analysis shows that in areas with higher availability of milk average heights were significantly superior (Baten, 2001; Baten and Murray, 2000; Baten and Fertig, 2005). As mentioned, the Saxon industrialization process was characterized by a high level of urbanization and, already in 1850, by an extremely high share of people employed in industry (45 percent). This meant that, as industrialization advanced, always fewer people had access to a high-protein nutrient such as milk. In fact, it was only towards the end of the nineteenth-century that milk could be traded and consumed in higher quantities by the urban workers. Therefore, the lack of milk in the diet of an increasing share of population in conjunction with the decrease in meat consumption played a role in the decline in heights during the Saxon early-industrialization phase.

The occupational differentials in height estimated here are similar in magnitude to those found by Twarog (1997) for Württemberg 1850-1939: In that

[40] The decline in livestock production in favor of grain production in Germany was probably due to the phenomenon of the enclosures (Klasen, 1998).

case the difference between upper and working class was circa 5.8 cm.[41] Similarly, A'Hearn finds for pre-unification Italy that educated people had circa 4 cm advantage with respect to blacksmiths or people employed in the textile sector. Floud *et al.* (1990), on the contrary, found very small occupational differentials for British soldiers born between 1815 and 1850. The absolute difference in height between the tallest category (white collars) and the lowest (domestic servants) did not reach 1 cm. In addition, they found that occupational differentials converged toward zero in the period 1750-1850, a finding which contrasts with our results for Saxony. In fact, our new estimates suggest a rise in inequality across the two centuries. The difference in height between officers and infantrymen increased from 3.8 cm in the eighteenth-century to 4.2 cm in the nineteenth-century; even more striking, while in the eighteenth-century only those with direct access to food had a significant nutritional advantage, in the first half of the nineteenth-century the difference in height between educated and unskilled people amounted to circa 4.5 cm denoting a significant increase in inequality. Dumke (1988) found rising income inequality for the period after the German unification in 1871. Our estimates suggest that the increase in inequality might have started in the first half of the nineteenth-century.

[41] Twarog (1997) can also control for father's occupation. The occupational differentials quoted here are for soldiers with the same occupation of the fathers.

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Chapter 2

Optimists or Pessimists? A Reconsideration of Nutritional Status in Britain, 1740-1865

2.1 Introduction

It is impossible to quantify the amount of ink that has been spent on the British industrial revolution and on the effects it had on the standard of living. The period under consideration is circa the century between 1750 and 1850. As correctly predicted by O'Brien and Engerman in 1981, and recalled more recently by Voth, much of the scholarly research has been devoted to improve real wage series, measuring inequality, and to investigate alternative welfare indicators.[1] Important studies reconstructing food-price series or that focused on consumption and intra-household allocation have the merit of having enriched our knowledge about the living conditions of the British working class. Even though the most recent contributions to the literature are more in support of the pessimistic view, there is not a broad consensus on the issue.[2] Optimists, who

[1] Voth (2004).
[2] See Mokyr (1988) and Feinstein (1998).

claim the benevolence of the industrial revolution, bring as evidence the increase in real wages especially for the period 1820-1850. The initial estimates of Lindert and Williamson (1983), which implied an increase in real wages by over 80 percent, provided a strong support to the optimists' view. Successive revisions of the wage series reduced the extent of the increase. More conservative estimates of Feinstein (1998) suggest that from the 1780s to the end of the Napoleonic Wars there was almost no increase in real earnings. Only thereafter there was a slight progress, though by the mid-1850s, the index was still less than 30 percent ahead of the level in the early 1780s.[3] The debate about the trend in real wages is due to the fact that the trend in living costs is controversial, whereas there is a widespread agreement about the trend in nominal wages. Therefore, efforts are directed to the creation of more reliable estimates of prices of food items, housing and clothing costs. A recent work of Clark goes in this direction providing new estimates of the cost of living for farm workers and a new series of farm labor real wages. According to Clark, Feinstein's pessimism "is probably too great".[4] In any event, added to the evidence that real wages declined between the 1760s and the 1780s,[5] the long-term trend in real wages during the industrial revolution shows, if anything, only a limited increase in purchasing power.

Numerous scholars have contributed to the debate on the standard of living using other welfare indicators. The study of physical stature as a complementary indicator of welfare originated already at the end of the 1970s.[6] Since then, numerous studies focused on the physical stature of children and adults in order to assess the welfare of populations from a different perspective than the classic economic indicators. The lack of data about income and the unreliability of such information for many historical periods made the anthropometric approach even more valuable.

Height is a measure of the individual's nutritional intake net of claims from the basal metabolism, epidemiological stress, and workload. In particular, height is a measure of the cumulative net nutritional status from birth until the age at which terminal height is reached. In modern and economically developed

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[3] See also Crafts (1985) for a correction of the estimates of Lindert and Williamson.
[4] Clark (2001), p.498. See also Clark (2007).
[5] Boyer (1990); Clark (2001).
[6] Trussell and Steckel (1978); Steckel (1979). We believe that physical stature is a complementary rather than an alternative indicator of welfare.

societies terminal height is reached between the age of 18 and 20 years. In past societies, where the individuals were subjected to a greater epidemiological stress and workload, terminal height was reached at a later stage in life.[7] The relationship between height and income is positive and non-linear and, in general, hard to disentangle.[8] In fact, we shall see that individuals coming from rural areas, therefore from presumable lower income areas, had a superior height with respect to people from higher income areas such as urban centers. This pattern is almost always verified in the eighteenth- and nineteenth-century. The disease environment, the price and the quality of food items played an important role in past societies invalidating to a large extent the relationship between height and income. In many studies focusing on the period of the early industrial revolution an inverse relationship between heights and income has emerged. This "puzzling" evidence has been termed as the early industrial growth puzzle.[9] Declining trends in average nutritional status in economies with rising income per-capita have been estimated for several European countries.[10]

Regarding the British industrial revolution, Roderick Floud, Kenneth Wachter, and Annabel Gregory (1990) undertook the admirable and pioneering project of collecting information on 108,000 army recruits, born between 1750 and 1880. The primary sources used in their study are the British Army and the Royal Marines, the Marine Society of London, and the Royal Military Academy at Sandhurst. Height distributions drawn from military samples often suffer from a truncation problem: Short recruits were disqualified in order to provide the army with sturdy soldiers. Therefore raw mean heights are upwardly biased.[11] The British army did not constitute an exception in this sense. After attempting to correct for this problem, Floud and co-authors produced some results which support the optimistic view about the impact of the industrial revolution on the standard of living. They suggested that the long-term trend in average nutritional status of adults was generally upward from the middle of the eighteenth-century

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[7] See Tanner (1990).
[8] For a review about the relationship between height and income see Steckel (1995).
[9] In the American economic history this is known as the antebellum puzzle. See Komlos (1996); Komlos (1987); Komlos (1998).
[10] For France, see Komlos (2003); for the Habsburg monarchy, Komlos (1989); for Northern Italy, A'Hearn (2003); for Sweden, Sandberg and Steckel (1987); for Saxony, Cinnirella (2007); for the Netherlands, Drukker and Tassenaar (1997); for Belgium, Alter *et al.* (2004).
[11] See the section on data for more detail.

until the 1820s, thereafter decreasing to the 1860s. For the period 1760-1820, crucial to the debate on the standard of living because of the paucity of data on real wages, their estimated trend in height has a lower peak for those born in the 1790s but thereafter it shows a strong improvement until the 1820s. Using a different statistical technique Komlos found partially opposite results: for the period 1760-1800 the average nutritional status declined, improved slightly until 1820, and thereafter worsened again.[12] The two positions then diverged only about the last four decades of the eighteenth-century. Successive estimates of alternative data sources supported the negative trend in height backing the pessimistic view about the effect of the early industrialization period on the British working class conditions.[13]

In this article we use part of the dataset employed by Floud *et al.* and we re-estimate the trend in nutritional status introducing some new elements. First, in order to minimize problems of heterogeneity we restrict our focus only to recruits of the British army, neglecting the data on the Royal Marines. In this way we avoid any contamination from sources that likely drew from a different underlying population and implemented different recruitment processes. This approach is expected to produce clearer results.[14] Second, in order to correct for the problem of truncation we consistently use the econometric approach most widely used in the anthropometric literature, namely the truncated normal maximum likelihood estimator which was not consistently used by Floud *et al.* for the controversial eighteenth-century. It will allow us to perform a multiple regression analysis by accounting for regional and occupational variation which should make the estimates more accurate. Third, we provide a further contribution to the standard of living debate analyzing how the age at terminal height changed during the eighteenth and nineteenth-century. Using the information on both the county of birth and that of recruitment we are able to identify a sub-sample of urban migrants whose origin was rural. Comparing the group of migrants with those who continued to reside in the same rural area we can estimate the effect of urbanization at different stage of life.

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[12] Komlos (1993a).
[13] Nicholas and Steckel (1991); Johnson and Nicholas (1995).
[14] The size of our sample is then around 45,000 observations. See section on data for details.

Our new estimates support the pessimistic view: Height trend declined substantially in the last four decades of the eighteenth-century. After a slight improvement around the end of the French wars, the British average nutritional status declined from the 1820s until the 1860s. Evidence about the shift of the age at terminal height corroborates our pessimism. Our findings are consistent with the recent estimates of food prices for the second half of the eighteenth-century and with the subsistence crisis reported for the last decade of the century.[15] We also provide an alternative explanation for the decline in heights in the eighteenth-century, namely the parliamentary enclosures of open fields and commons and the decline of the cottage industry. For farm laborers, which constitute a large share of our sample, the loss of common rights or allotments meant a significant reduction in food consumption as those lands were mainly devoted to self-sufficiency. In addition, farm laborers became more exposed to price fluctuations in an economic conjuncture of increasing food-prices.

2.2 Data and methodology

The dataset employed in this paper includes circa 45,000 soldiers born between 1740 and 1865 recruited by the British army.[16] With the notable exception of the British army, all the European states adopted and maintained during the Restoration period universal conscription for the army. Instead, the British army applied the universal conscription only at the outset of the First World War.[17] Until then, the army was manned mainly with voluntary forces and, when needed, with an additional militia which was selected by ballot (henceforth Ballot Militia). The institution of the Ballot Militia goes back to 1757 when it was created in order to make up for the shortage of volunteers in the army. Able-bodied men in the range of 18-50 years were eligible for service in the militia forces. Therefore it was a sort of forced recruitment which took place at a county level. Yet, men who were drawn to join the army were given the possibility to send a substitute. This possibility created a market for substitutes

[15] Clark (2001); Boyer (1990).

[16] Floud, R., Long-term Changes in Nutrition, Welfare and Productivity in Britain; Physical and Socio-economic Characteristics of Recruits to the Army and Royal Marines, 1760-1879 [computer file]. Colchester, Essex: UK Data Archive [distributor], July 1986. SN: 2131.

[17] Ilari (1989).

and the amount paid could be quite substantial.[18] The institution of the Ballot Militia was first suspended in 1816 and then abolished during the 1820s.[19] Only in 1852, before the Crimean War, was the Ballot Militia newly reinstituted, though not used extensively. Therefore, while the sample recruited until the defeat of Napoleon is made up of volunteers and of the Militia—which is allegedly a random draw from the male population—after 1820 the army sample included only young volunteers resulting in a lower mean and standard deviation of soldier's age. We find empirical evidence of this change in the recruitment practice. From a graphical inspection of height distributions mean and standard deviation of soldier's age, we find a "structural break" which start with the recruitment year 1820 (figure 1 and 2). After that year, mean and standard deviation of soldiers' age are systematically smaller than in the previous period. We believe that the presence of the Ballot Militia in the sample recruited before 1820, which introduced a share of random population into the army, contributes to determine higher values for the mean and standard deviation of age. Even though we are not able to identify within the first group the two types of soldiers (volunteers and militia), the difference between the two periods in the underlying population suggests that we should analyze pre- and post-1820 recruitment samples separately.[20]

The dataset at our disposal contains detailed information about physical stature, age, year of birth, previous occupation, and the county of origin and recruitment.[21] In order to check for systematic differences in nutritional status between geographic areas, we generated 13 wage-regions following the classification of Hunt.[22] Regarding the soldiers' previous occupation, we followed the industrial classification provided by Armstrong to generate dummy variables for the occupations.[23]

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[18] Floud, Wachter and Gregory (1990), p.34.
[19] Ilari (1989).
[20] Anyway, analyzing the sample altogether does not alter qualitatively our results.
[21] For a more detailed description of the British army and for a discussion whether it is representative of the British working class, you are referred to Floud *et al.* (1990), chapter 2 and 3.
[22] Hunt (1973).
[23] Armstrong (1972).

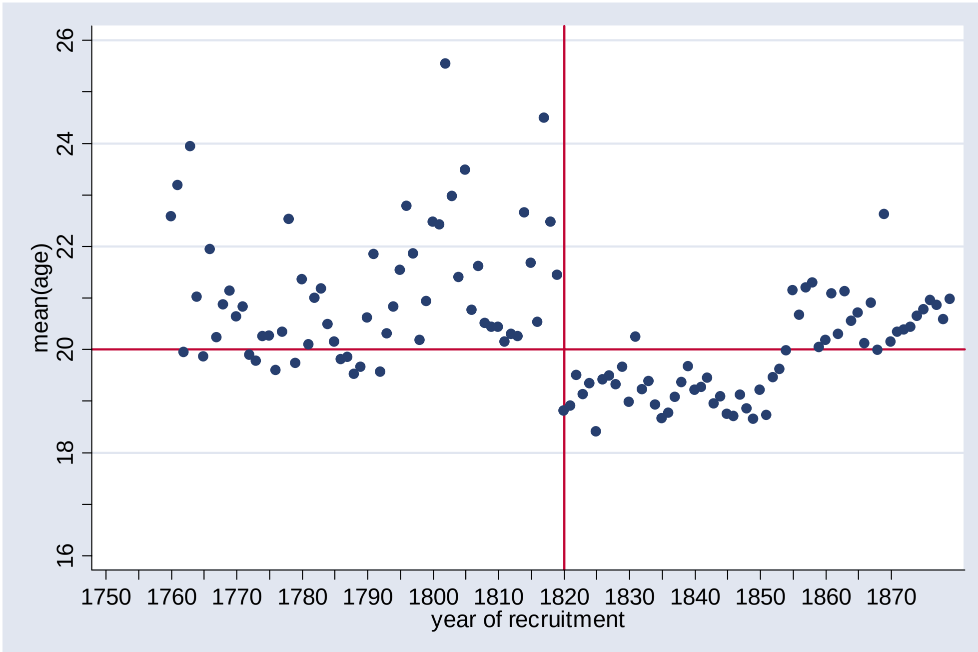


Figure 1. Mean of soldier's age by recruitment year

Source: British army.

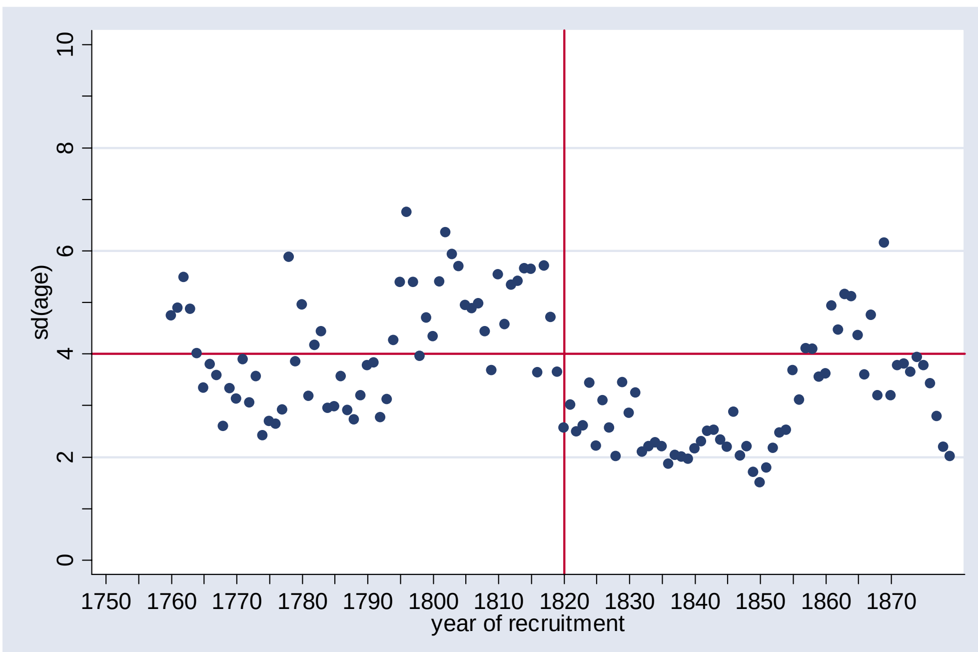


Figure 2. Standard deviation of soldiers' age by recruitment year

Source: British army.

Table 1. Descriptive statistics by sub-period

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

Note: Standard deviation in parenthesis. Sample constrained to recruits aged 16-49, born in England, Wales or Scotland.

Source: Floud, R., Long-term Changes in Nutrition, Welfare and Productivity in Britain; Physical and Socio-economic Characteristics of Recruits to the Army and Royal Marines, 1760-1879 [computer file]. Colchester, Essex: UK Data Archive [distributor], July 1986. SN: 2131.

In addition, exploiting the information about the place of birth and of recruitment we define "internal migrant" a soldier whose birth-county differs from the county of recruitment.[24] We intend to use a specific sub-sample of urban migrants coming from rural counties in order to estimate the detrimental effects of urbanization on average nutritional status and in particular the negative effect on the age at which terminal height is reached.

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

The literature in anthropometric history derived many of its results from the analysis of army samples. As usual when dealing with military data-sources truncated height distributions represent an important statistical issue. Another issue is that the minimum height requirement changed over time.[25] The need to increase the army during war periods provided an incentive to lower the physical standards and to allow shorter people into the army. In figure 3 and 4 we provide some examples of different height distributions with different minimum height requirements for the British army. The differences between the left and the right panel of figure 3 are striking: In 1805, at the onset of the French Wars, the minimum height requirement enforced was noticeably lower than in 1787.[26]

[24] A similar identification strategy was adopted by Nicholas and Shergold (1987) for a sample of British convicts used to study inter-county labor mobility.
[25] We found that the minimum height requirements applied by armies that switched to a universal conscription tended to be more constant. See the Saxon army in Cinnirella (2007).
[26] More details on the minimum height requirements applied by the British army in Floud *et al.* (1990).

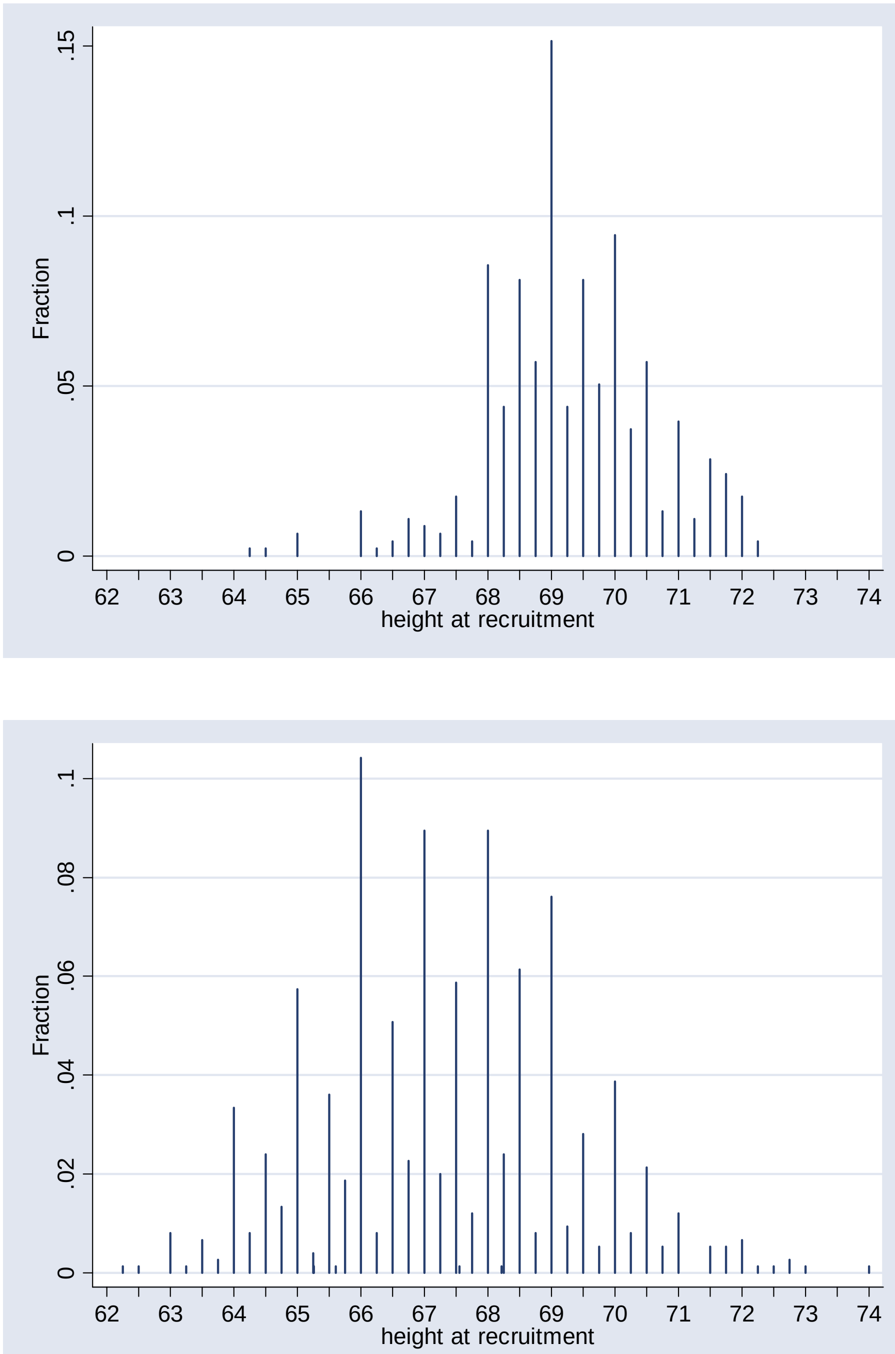
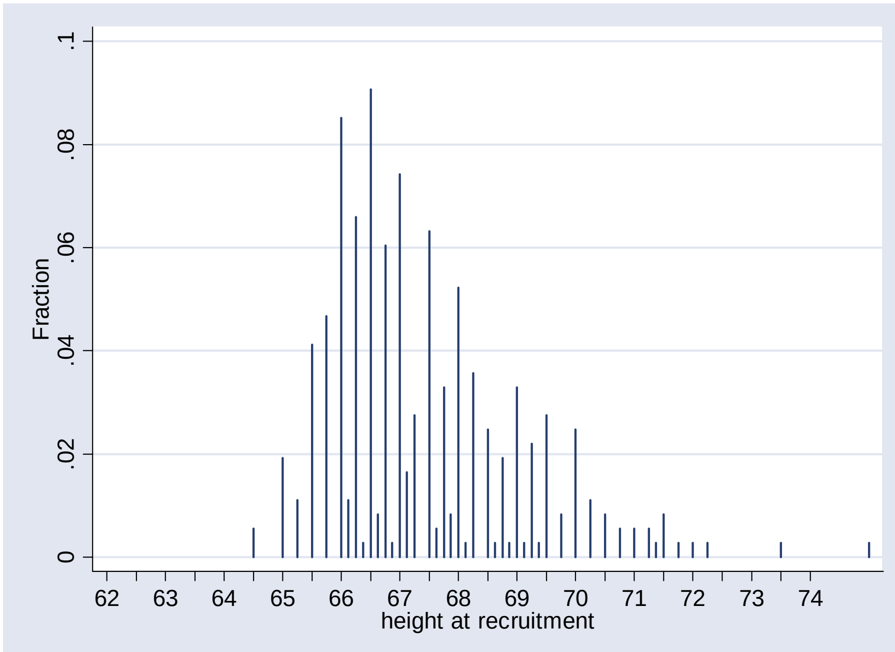


Figure 3. Height distributions of soldiers recruited in 1787 (top panel) and 1805 (bottom panel)

Note: recruits between 18-49 years; 457 observations in the top panel and 749 in the bottom panel.



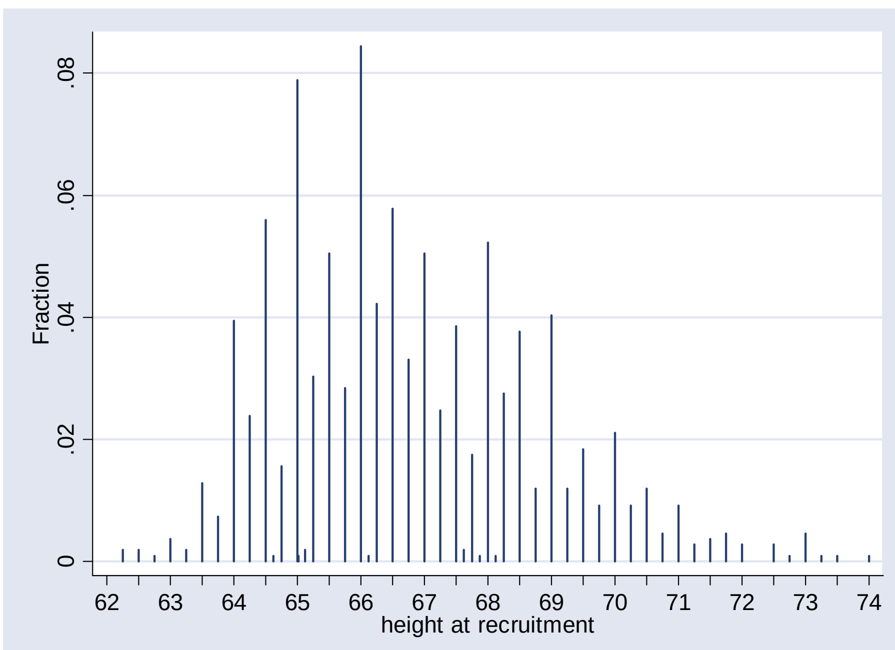


Figure 4. Height distributions of soldiers recruited in 1825 (top panel) and 1856 (bottom panel)

Note: recruits between 18-49 years; 364 observations in the top panel and 1090 observations in the bottom panel.

Several methods have been proposed in the literature in order to correct for the bias determined by the minimum height requirement. In their estimates Floud *et al.* employed two different methods: the *quantile bend estimator* (QBE)[27] and the *reduced sample maximum likelihood estimator*.[28] Some studies have shown the superiority of the truncated maximum likelihood estimator (MLE) as it is more efficient compared to the QBE, and the former method allows *(i)* the specification of a flexible truncation point, *(ii)* to perform a multiple regression estimation, *(iii)* the estimation of the population standard deviation, and *(iv)* it is also robust to problems of data-rounding.[29] The number of studies in anthropometric history which employ the truncated maximum likelihood estimator is very large.[30] In this article we shall use consistently the truncated MLE. In particular, after inspecting the height distributions by year of recruitment[31] we are able to assign different truncation points according to the period of enrolment in the army. As the recruiting process in Britain was, at least in the eighteenth-century, fairly decentralized, when inspecting the height distributions we also grouped the recruits by macro-area distinguishing between English and Scottish counties.[32]

2.3 The trend in nutritional status

In the previous section we motivated the decision to analyze the military sample in two sub-periods because of the institution of the Ballot Militia. We then estimate the trend in nutritional status regressing height on cohort dummy variables and a further set of exogenous variables such as age, region of

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[27] Wachter and Trussell (1982).

[28] For a debate about the methodology employed by Floud *et al.* see: Komlos (1993a; 1993b); Floud, Wachter and Gregory (1993a; 1993b).

[29] A'Hearn (2004); Komlos (2004).

[30] Most recently, A'Hearn, (2003); Komlos (2003); Mokyr and O'Grada (1996); Baten (2001). Furthermore, the estimator is implemented in many popular statistical computer programs such as Stata.

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

[32] For those recruited before 1820, a MHR of 62 inches was applied to circa 11 percent of the sample; 64 inches to 30 percent; 68 inches to 13 percent. For the sub-sample recruited after 1820, a MHR of 64 inches was applied to 26 percent of the recruits; 65 inches to 20 percent, and 66 inches to 14 percent.

provenance and occupation. In addition, a dummy variable for urban/rural differences is used to capture the possible negative effects of urbanization on nutritional status. The variable is set equal to one if the recruit was born in a town which had more than 100,000 inhabitants in 1851.[33] Further control variables are used in order to account for (possible) atypical recruiting practices that occurred during the Napoleonic and the Crimean war.

In a recent study, A'Hearn, Baten and Crayen (2006) suggest that age-heaping can be used as a proxy for literacy as the two seem to be highly correlated both between and within countries. They find that age heaping is a quite powerful measure of human capital as it yields estimates that are robust across different data sources, time, and space. We share their view that age awareness is a potential indicator of the individual skills in numeracy. Therefore recruits who were able to report their age with a monthly precision (not rounded to the nearest year) are considered to possess greater skills in numeracy, which proxies for a general higher level of education. In our dataset around 6,700 recruits (10 percent of the total) reported age with a monthly precision. It is important to note that, across the occupations, only 2 percent of recruits within the category of "no-occupation" had such a skill in numeracy. That signals the goodness of age-heaping as a proxy for literacy.

In table 2 we report the estimates of the truncated regressions by sub-periods. The estimated coefficients of the birth cohorts are used to construct the height trends displayed in figure 5, 6, and 7. The assumption of independence among the observations might be violated due to spatial correlation and that could falsify hypothesis testing. In particular, outcomes from adjacent observations, such as for individuals born in the same county, are likely to be correlated. To obviate to this problem our estimates are corrected for clustering in the sense that observations within each cluster (county of origin) are allowed to be correlated while the assumption of independence across clusters is maintained. As shown in figure 5 and 6, the secular trend in nutritional status was overall decreasing across the 130 years under consideration. In the eighteenth-century, after reaching a peak in 1745-55, the average nutritional status diminished steadily until the outset of the French wars. There was more

[33] The towns are London, Manchester, Liverpool, Edinburgh, Glasgow, Leeds, Sheffield, Birmingham, Bristol, Newcastle, and Bradford. See Szreter and Mooney (1998).

variation in height in the nineteenth-century but the general tendency was for heights to diminish. In figure 7 we combine the trend of the two periods in order to show the pattern in nutritional status over the whole period 1740-1865. The trend aims to represent the average British heights as it is averaged by the estimated coefficients for occupation and origin. The coefficients contributions to the height level are weighted by the sample frequencies. As can be seen from Figure 7, the trend estimated here presents significant differences compared to the previous trend established by Floud *et al.* (1990). We show that *(i)* the peak in height was reached around 1750 instead of the 1760s, anticipating then the decline in nutritional status by more than a decade; *(ii)* the strong upward trend from the 1790s until 1820s outlined by Floud *et al.* is here limited to the cohorts 1805-09 and 1810-14. Their claim that "the era of the early industrial revolution led to an improving standard of living"[34] finds here no support. The general trend we present is clearly declining during the whole period. Our findings are consistent with several alternative estimates of heights trends, including those for women.[35]

The effect of age and the concept of height-velocity are issues that will be treated in detail in the next section. Here it is worth mentioning the "effect" of the Napoleonic recruitment: soldiers recruited between 1805 and 1814 were on average about 1.4 cm shorter. The need to man the army during the war contributed to diminish substantially the physical requirements. The same phenomenon took place during the recruitment for the Crimean war, though on a smaller scale (0.34 cm). A problem of multicollinearity could potentially arise between the dummy variable for the Napoleonic recruitment and recruits born between 1780 and 1790. The correlation coefficients between the cohorts 1780-84, 1785-89, 1790-94 and the dummy for Napoleonic recruitment are 0.1, 0.36, and 0.41, respectively. Since the correlation coefficients are below 0.5, we decided to keep the dummy for Napoleonic recruitment in the regression model.[36] Quite unexpectedly we find a detrimental effect of urban agglomerates only for those born in the nineteenth-century who suffered a nutritional

[34] Floud et al. (1990), p.151.

[35] Komlos (1993a); Komlos (2004); Komlos (1998); Nicholas and Steckel (1991); Johnson and Nicholas (1995); Mokyr and O'Grada (1996); Nicholas and Oxley (1993).

[36] By eliminating the control for Napoleonic recruitment the decrease in height (figure 5) for the last quarter of the century would be even more accentuated.

disadvantage of circa 1.2 cm, whereas the effect is not statistically different from zero for the previous period. Hygienic conditions of rapidly increasing towns, food prices and quality, and claims on nutrients due to excessive workload are usual explanations for the urban penalty. In the next section we shall present further evidence on the negative effects of urbanization.

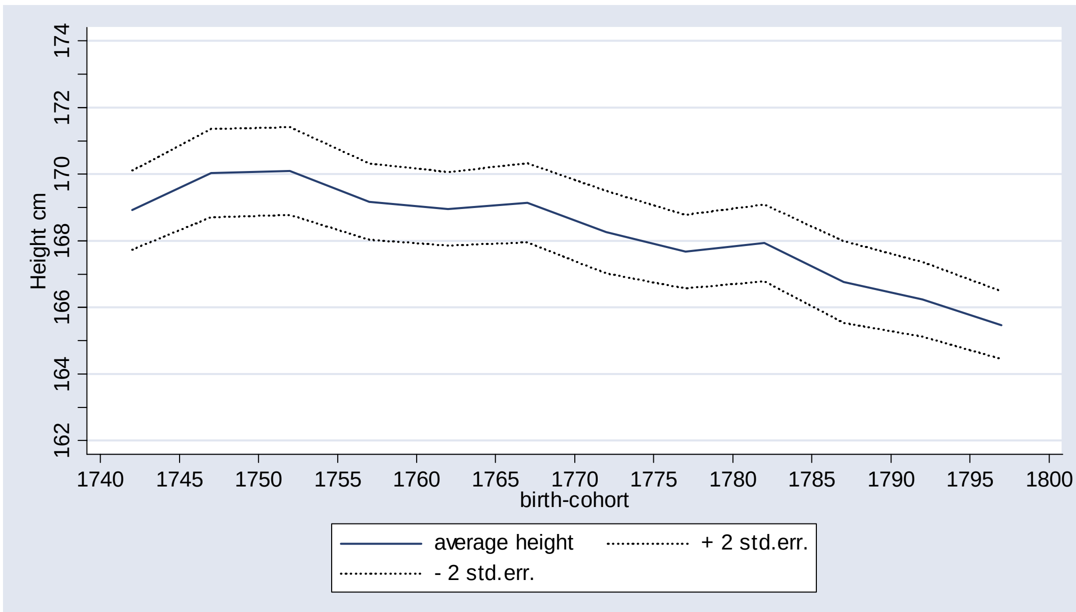

Figure 5. Secular trend in height, 1740-1800

*Note: S*tandard errors are adjusted for clustering and account for the covariance with the constant. The trend is for soldiers aged 18 born in "London and Home Counties" who worked as craftsmen.

Source: Table 2

Figure 6. Secular trend in height, 1800-1865

*Note: S*tandard errors are adjusted for clustering and account for the covariance with the constant. The trend is standardized for soldiers aged 18 born in "London and Home Counties" who worked as craftsmen.

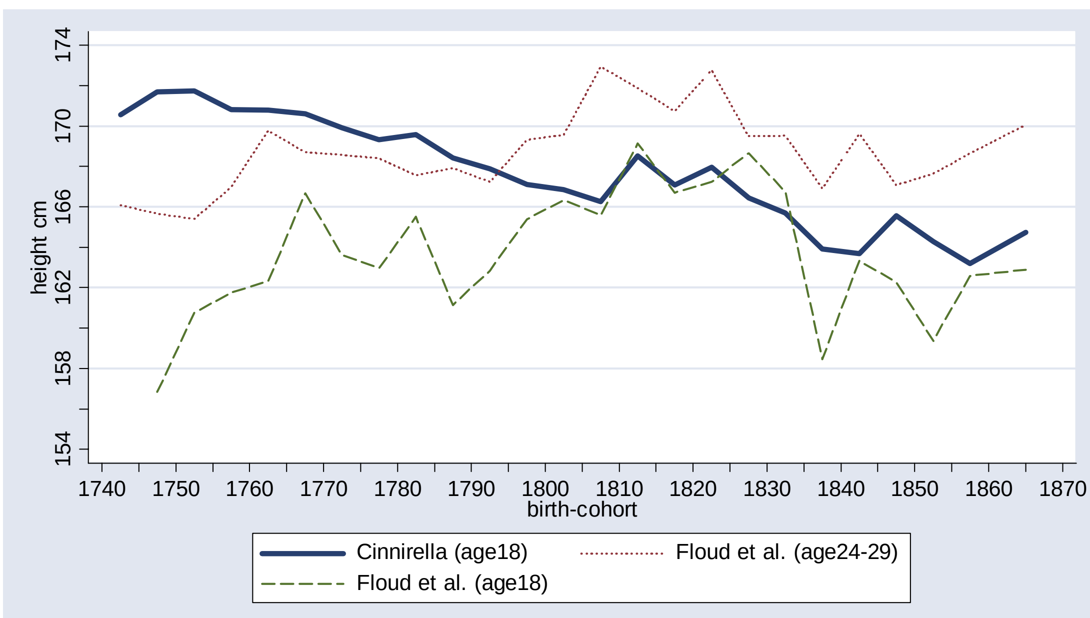

Figure 7. Average height trend in Britain, 1740-1865

Note: Our trend is averaged by occupations and origins. The weights of the coefficients are defined on the basis of sample frequencies.

Source: table 2; Floud *et al.* (1990), p.140-149.

Regarding the estimated occupational differentials, recruits who were classified as domestic servants were systematically shorter relative to the reference category of craftsmen mainly made up of weavers, tailors and shoemakers. The nutritional disadvantage of domestic servants persisted until the nineteenth-century. Recruits previously employed in services (mainly clerks) and in the category "other" show also a conspicuous height advantage which increased over time. A clerk was probably an individual able to read and write with duties such as accounting. Therefore it is not surprising that they enjoyed a significant nutritional advantage and that such advantage increased over time, in relative terms. The same happened to the individuals who fall in the category "other" which we believe included former students. The fact that they were classified as "without any previous occupation" and, most importantly, the fact that the mean age within this group is 16.6 years (the 75th percentile is 19 years), strongly suggests that we should consider the category "other" as students. Then, this result shows that there was a clear return to education in terms of nutritional status and it increased over time relative to craftsmen. Students were taller because, on one side, their parents tended to be richer and therefore they had a better access to nutrients; on the other side, claims on nutrients from work activities were reduced with an immediate benefit on their nutritional status. Similarly, we find a strong and positive association between the proxy for literacy and nutritional status: Those recruits who reported their age with a month precision had circa an advantage of 2.5 cm which remained constant over time. Across the two centuries we estimate a nutritional improvement for laborers, though small in magnitude (ca. 0.3 cm). This result is consistent with the increase in the wage rate that affected farm laborers in the nineteenth-century as a result of the mass migration toward urban centers.[37]

We use our new estimates to show the regional pattern of net nutritional status during the industrial revolution. After controlling for urbanization, across the two centuries the region of "London and Home Counties" had the lowest net nutritional status. In addition, for the whole period under consideration we find a clear north-south gradient in height which becomes starker in the nineteenth-century. The three regions which had the tallest population across the

[37] See section 2.3.2 for a discussion about migration.

whole period are the northern regions of Cumberland, Northumberland and South Scotland. Also the remaining regions of Scotland, as also shown by Floud *et al.*, enjoyed a comparatively superior nutritional status. These findings are displayed in figure 8 and 9. The color gradations (shorter measures of heights are associated with darker colors) of the figures illustrate the main findings of this section: *(i)* physical stature declined substantially over time and across all regions; *(ii)* the less industrialized northern regions kept a superior nutritional status with respect to southern and central regions. In figure 10 we display average height for macro-areas: we divided Britain into three areas and performed separate truncated regression.[38] The trends confirm the generalized deterioration of the nutritional status throughout the period and show how the difference in height between northern and southern regions increased in the first half of the nineteenth-century. The primacy of the northern regions of Scotland (solid line in figure 10) which also show a less steep decline in average nutritional status is very likely due to a superior diet rich in oatmeal and milk (Devine, 2004; Floud *et al.*, 1990). For the central regions[39] (dashed line in figure 10) the increase in average nutritional status at the beginning of the nineteenth-century seems to have persisted slightly longer, from 1805-09 to 1820-24.

[38] Estimation results are not presented here.

[39] Wales, Midlands, Lancashire, Cheshire, W. Riding, Lincs., Rutland, E. and N. Riding, Cumberland, Westmoreland, Northumberland, and Durham.

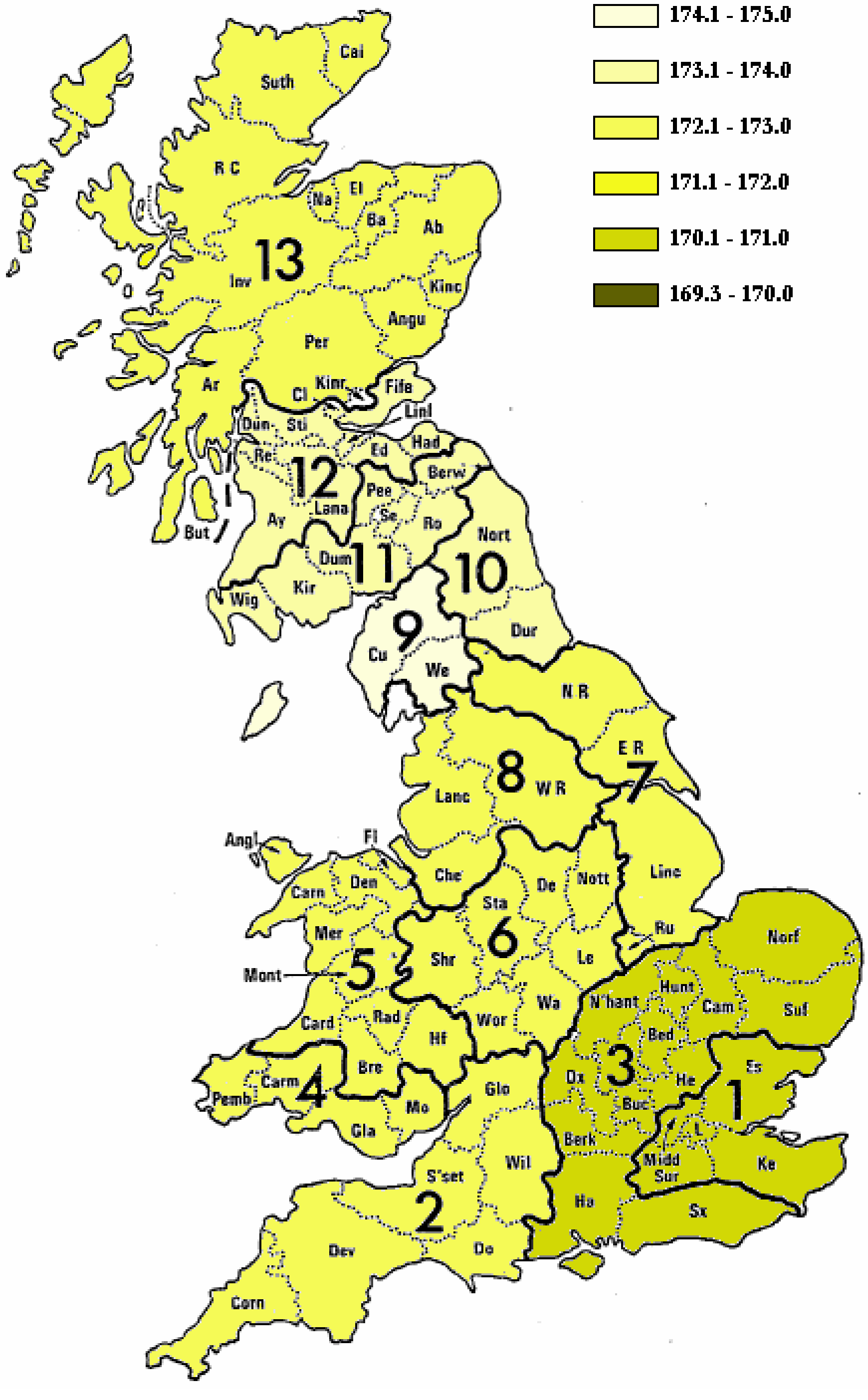

Figure 8. Mean heights by wage-region, birth cohort 1760-64

Note: Standardized for adults, craftsmen.

Source: Own estimates. Map re-elaborated from Hunt (1973).

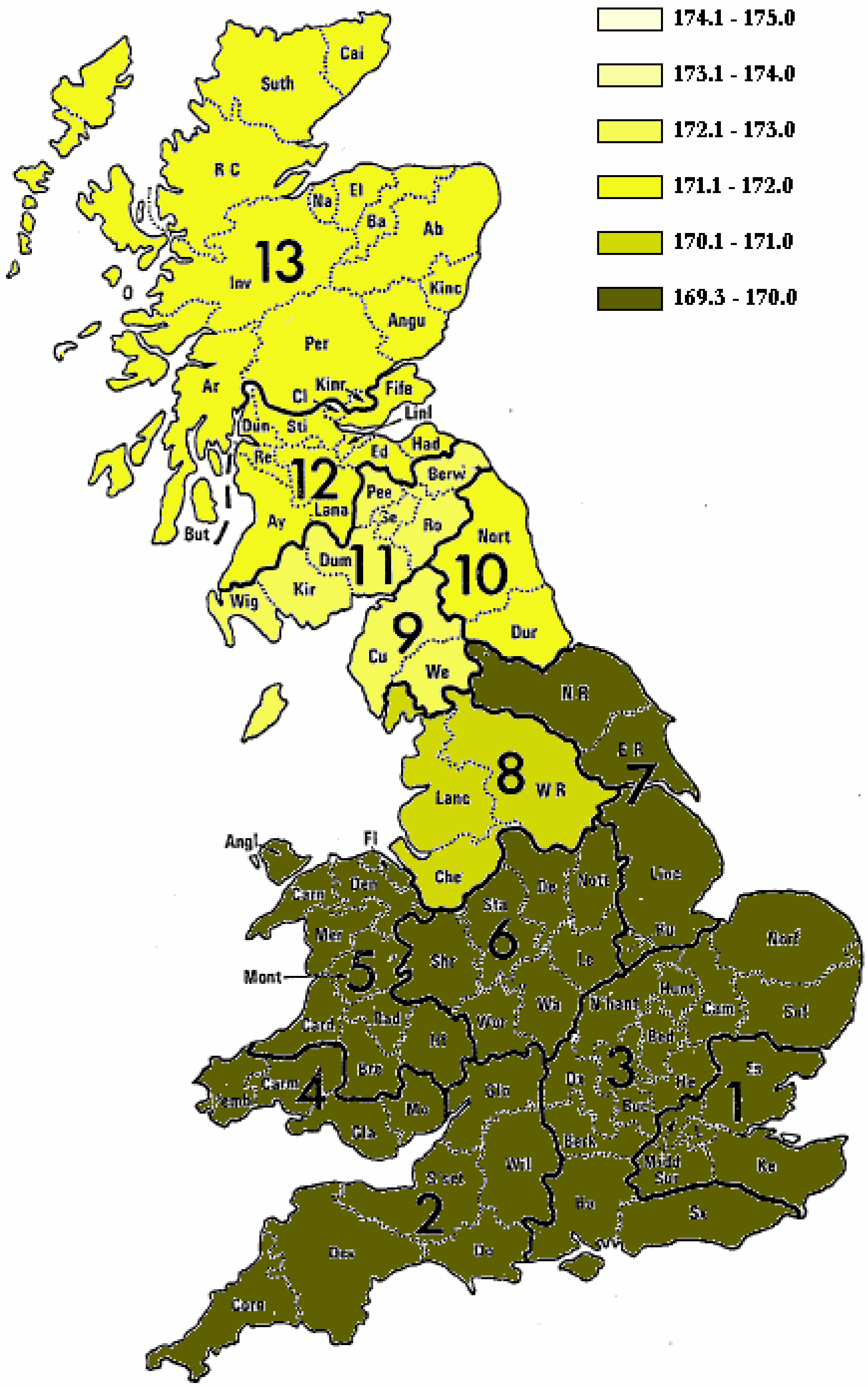

Figure 9. Mean heights by wage-region, birth cohort 1800-04

Note: standardized for age 22, craftsmen.

Source: Own estimates. Map re-elaborated from Hunt (1973).

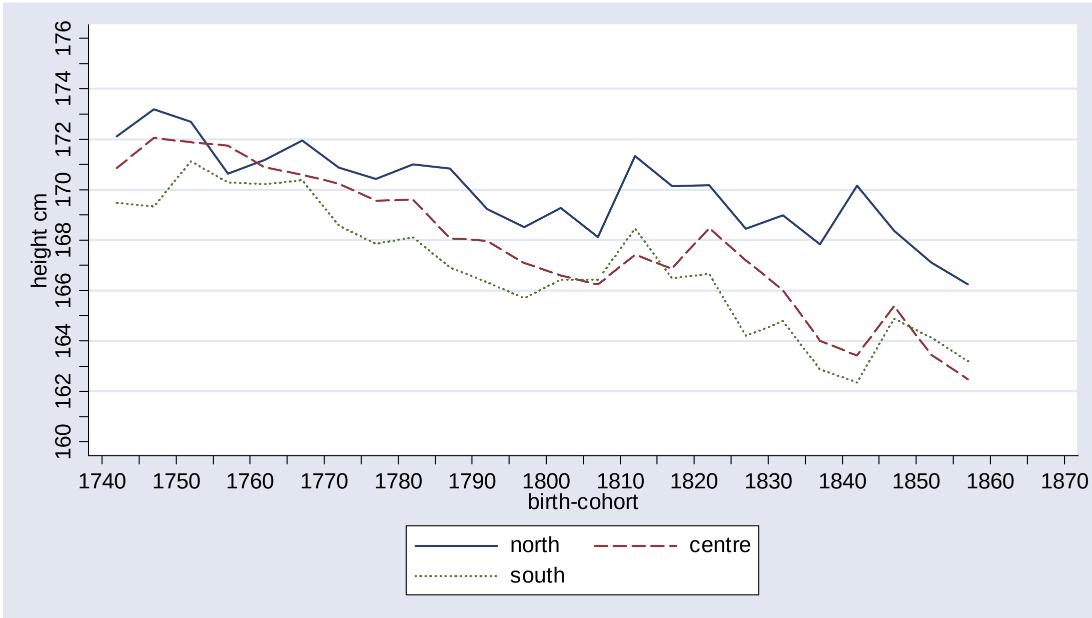

Figure 10. Height trend by macro area

Note: Referring to the wage regions of figure 8 and 9, the macro-area "north" includes regions 11, 12, and 13; "centre" includes from region 4 to region 10; "south" includes regions 1, 2, and 3. The trends are averaged by occupations. The weights for the coefficients are defined on the basis of sample frequencies.

Source: own estimates.

Table 2. Truncated regression by sub-period

Variables	Recruited before 1820	Standard errors	Recruited after 1820	Standard errors
Age				
16	-4.66***	0.319	-7.98***	0.791
17	-2.18***	0.228	-4.98***	0.498
18	reference group		reference group	
19	1.33***	0.217	1.49***	0.136
20	2.25***	0.198	2.01***	0.183
21	2.66***	0.210	2.98***	0.187
22	2.78***	0.207	3.21***	0.205
Adults (23-49)	1.97***	0.238	2.88***	0.261
Birth-cohort				
1740-44	-0.04	0.336		
1745-49	1.07*	0.475		
1750-54	1.13***	0.413		
1755-59	0.21	0.270		
1760-64	reference group			
1765-69	0.18	0.303		
1770-74	-0.70**	0.327		
1775-79	-1.28***	0.292		

Variables	Recruited before 1820	Standard errors	Recruited after 1820	Standard errors
1780-84	-1.02***	0.264		
1785-89	-2.20***	0.322		
1790-94	-2.72***	0.408		
1795-99	-3.50***	0.357		
1800-04			Reference group	
1805-09			-0.58	0.334
1810-14			1.69***	0.396
1815-19			0.23	0.350
1820-24			1.10***	0.302
1825-29			-0.39	0.519
1830-34			-1.16**	0.391
1835-39			-2.93***	0.398
1840-44			-3.15***	0.414
1845-59			-1.27***	0.364
1850-54			-2.57***	0.305
1855-59			-3.64***	0.359
1860-69			-2.09	1.07
Origin				
London and Home Counties	Reference group		Reference group	
Southwest	1.20*	0.674	0.18	0.483
Rural Southeast	0.67	0.498	0.25	0.402
South Wales	1.22**	0.583	-0.27	0.354
Rural Wales	1.30*	0.667	0.07	0.498
Midlands	1.48***	0.515	-0.32	0.377
Lincolnshire	1.18**	0.464	0.36	0.295
Lancashire	1.62***	0.609	1.02***	0.352
Cumberland	3.31***	0.599	2.70***	0.328
Northumberland	2.98***	0.478	2.62***	0.702
South Scotland	2.47***	0.547	2.88***	0.459
Central Scotland	2.31***	0.523	1.85***	0.451
North Scotland	2.06***	0.506	2.51***	0.539
Napoleonic recr.	-1.38***	0.306		
Crimean-war recr.			-0.34*	0.204
Urban	-0.08	0.329	-1.25***	0.376
Literacy (proxy)	2.66*	1.408	2.56***	0.242
Occupation				
Craftsman	Reference group		Reference group	
Agriculture	1.64***	0.301	0.29	0.408
Building	0.60***	0.214	0.03	0.219
Dealing	0.58	0.433	0.63	0.472
Domestic	-0.84**	0.376	-0.67***	0.232
Laborers	0.02	0.146	0.37***	0.131
Mining	0.75**	0.335	-0.28	0.363
Service	1.83***	0.619	2.23***	0.274

Variables	Recruited before 1820	Standard errors	Recruited after 1820	Standard errors
Transport	-0.88	0.805	-0.45	0.393
Other	1.25***	0.401	1.84***	0.657
No occupation	-2.49***	0.639	0.86	0.595
Constant	168.96***	0.523	166.14***	0.492
Observations	15,740		23,031	

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

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

2.3.1 Height velocity and the English industrial revolution

In the anthropometric history literature the analysis of the adolescent growth-spurt and the age at which terminal height is reached are generally complementary to the study of the secular trend. Insufficient caloric intake, insults from the epidemiological environment, and an excessive workload during childhood or adolescence will affect not only the measure of final height but also the path of the height-by-age profile. In modern and economically developed societies terminal height is reached between the age of 18 and 20 years.[40] Previous studies have shown that in past societies the growth spurt and final height were reached with some delay compared to modern societies (Floud *et al.*, 1990; Komlos, 1989; Nicholas and Steckel, 1991; Johnson and Nicholas, 1995). For the period of the industrial revolution final height was reached between age 22 and 23 years. In this section we investigate the evolution across time of the height-by-age profile and the difference in the growth path between rural and urban sub-populations.

In figure 11 we show the English (England and Wales) height-by-age profile for three cohorts: 1760-64, 1805-09, and 1850-54. The three curves are derived from separate truncated regressions performed on the relevant subgroup. As usual, we account for time-trend, origin and, occupations.

[40] Eveleth and Tanner (1976).

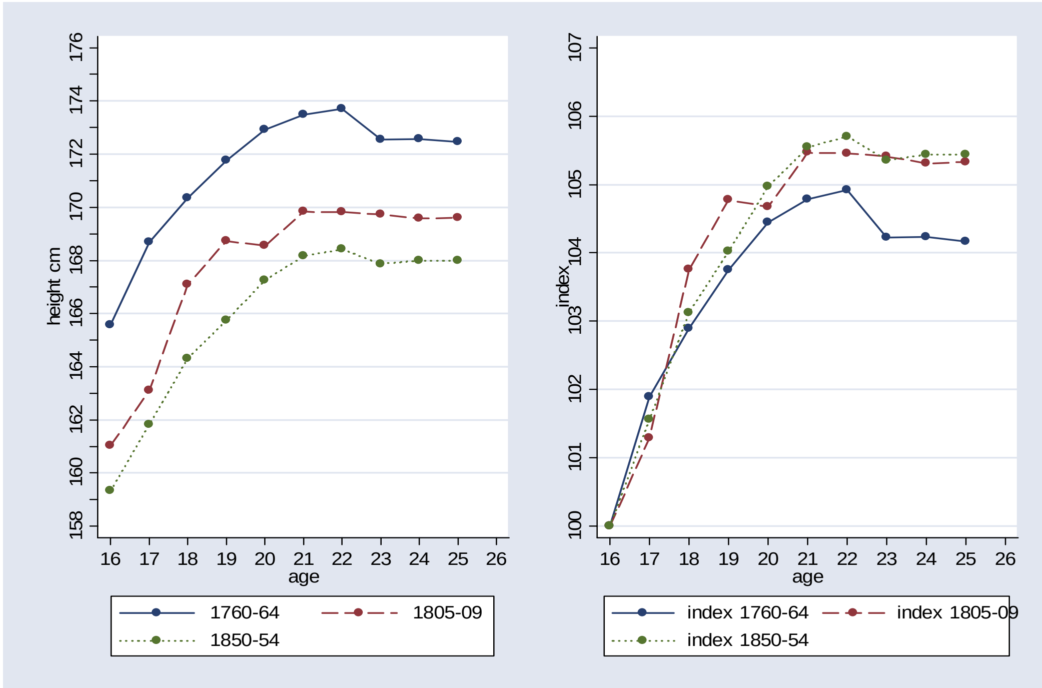

Figure 11. Height-by-age profile by time-period

Note: Heights are standardized for craftsmen from "London and Home Counties". The index is set equal to 100 for height at age 16.

Source: See text.

We use here a non-parametric approach, namely we insert dummy variables in the regression analysis in order to estimate the age coefficients. The differences in the levels in the left-panel of figure 11 confirm the declining secular trend presented in the previous section: recruits born in 1820-69 were notably shorter at all ages relative to the preceding cohorts. The three curves, apparently parallel, have different growth rates. On the right panel of figure 11 we report the profiles shifted down so that heights are equal at age 16. The cohorts who were taller at age 16 grew less successively. This is the case because the cohorts with the higher average stature at age 16 experienced the adolescent growth spurt earlier than the later cohorts. With reduced nutritional status the growth spurt is delayed, and as a consequence, the later cohorts grew more after age 16.

Later birth-cohorts probably delayed also the age at which they attained their final height. In order to ascertain the exact age at which final height was attained we need to include age as a continuous variable in the regression analysis. The relationship between height and age is known to be nonlinear and concave with decreasing marginal returns. The inclusion of age in its linear and quadratic form would lead to a model misspecification as we would allow also for a negative effect of age for large values of the variable. To obviate to this problem we censored the original age variable: the new variable takes on a constant value 23 if the original variable is equal or greater than 23 years.

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

Thus, the new variable constrains the effect of age to be zero for values greater than 23 years. We keep the quadratic form of the new censored variable in order to allow for decreasing marginal returns before the censorship. Due to the fact that the maximum of the quadratic function lies somewhere before the age of 23, we are able to compute the maximum of the function.

Using the transformed variable for age we find slight differences in age at terminal height across the three sub-periods (table 3): The later cohorts show a deferment of about one third of a year. This difference between early and later cohorts, though small in magnitude, is statistically significant as can be seen from the confidence interval. This finding adds further evidence that early industrialization and the successive period of stronger industrialization were detrimental to the English biological standard of living.

Table 3. Height at terminal height for three selected cohort groups

Cohort	Age at terminal height	95% confidence interval
1740-1779	21.25	21.03, 21.47
1780-1819	21.37	21.18, 21.56
1820-1869	21.63	21.31, 21.96

Source: Separate truncated regression with age as a continuous variable censored at age 23.

2.3.2 Urbanization and the nutritional status

The analysis of the height-by-age profile proves useful when studying the effects of urbanization on the biological standard of living. Next we intend to explore the effect of urbanization on nutritional status during the industrial revolution. From the results of the regression analysis in the previous section we showed that urbanization had a significant negative impact (of circa 1.5 cm) on mean heights in the nineteenth-century. Here we show how urbanization affected the height-by-age profile adopting a comparative approach: We select a group of individuals who initially shared a similar rural environment; then we compare the height-by-age profile of those who remained in the rural environment with those who, at some point in time, decided to leave the countryside for an urban environment. We employ the same procedure of Boyer and Hatton (1997) who investigated the determinants of male migration from southern and eastern rural counties to six urban destinations.[41] They found that migration rates were affected by the real wage, the expected income gap, the distance between origin and destination, and the size of the migrant stock.[42] In a previous paper Nicholas and Shergold (1987) analyzed a sample of British convicts shipped to Australia and found that skilled and educated individuals had higher probabilities of being inter-county migrants. Their finding seems to be robust to short- and long-run distance migration.

Exploiting the information on both the counties of birth and of recruitment we can construct a sample of migrants whose rural-urban migration pattern resembles that of Boyer and Hatton. We have around 3,500 soldiers who were born and recruited in the southern agricultural counties, whereas circa 2,500 were born in the same rural counties but recruited in an urban one. We assume that the urban migrants, before recruitment in the army, were exposed for some time to the precarious hygienic conditions typical of a rapidly growing urban centre, to some economic stress in terms of more expensive food items (and likely of lower quality), and to an increment of workload. Those effects should be mirrored by

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[41] The 19 origin rural counties are Beds., Herts., Berks., Bucks., Oxon., Sussex, Hants., Hunts, Cambs., Suffolk, Norfolk, Wilts., Dorset, Devon, Somerset, Cornwall, Northants., Rutland, and Lincs. The six destinations are London and the Home Counties (excluding the rural counties of Surrey, Kent, and Essex), Lancashire and Cheshire, Yorkshire, the West-Midlands, the East-Midlands, and South-Wales. See also Boyer and Hatton (1997).

[42] Boyer and Hatton (1997), p.712.

their height-by-age profile, possibly with a significant deferment of age at terminal height. The comparison with those who resided in the southern rural counties should uncover the urbanization effect.

We compare the mean heights of urban-migrants and rural-residents: urban migrants were significantly shorter of circa 0.2 inch (ca. 0.4 cm). The estimation of a standard probit model provides additional information about the characteristics of urban migrants (table 4). A possible interesting result regards the coefficients associated to the dummy variables for the recruitment during the Napoleonic and Crimean wars which are not statistically significant. This result might indicate that migration towards industrial districts or towns was initially motivated by the search of new job opportunities rather than military employment. In order to check for the occupational characteristics of the migrants we adopted Armstrong's industrial classification which groups the occupations according to the degree of skills embodied.[43] Probit estimates show that professionals and skilled individuals were more likely to be urban migrants; unskilled people had 14 percent less probability of being urban migrants compared to skilled; professionals were 37 percent more likely than skilled people. Admittedly, there might be a problem of reverse causality: The lack of information about the timing of migration does not permit to assess whether higher skilled people decided to migrate, or migration itself occurred before the acquisition of skills in town. The coefficient associated with the proxy for literacy[44]—which in the previous section was strongly and positively correlated with height—is not different from zero in the probit regression. In synthesis: *(i)* urban migrants appear to be on average shorter then their counterparts who stayed at home; *(ii)* they had a higher skilled job; *(iii)* their level of education (proxied by age-rounding) was not superior compared to the rural residents.

We next compute the age at which final height was attained for the urban migrants.[45]

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[43] We have 4 categories: professionals, skilled, unskilled, and no occupation.
[44] Age-rounding was used as a proxy for education (or literacy) in the height trend estimates.
[45] In principle, the analysis of the age at terminal height for the urban migrants should account for sample-selection as the decision to migrate in the first place might be correlated with height. Unfortunately, the lack of identifying restrictions does not allow us to estimate the Heckman two-step procedure. If tall people were more likely to migrate, then we underestimate the urban effect. In the case where short people were more likely to migrate, our results overestimate the effect of urbanization.

Table 4. Probit estimates of urban migrants

Dependent var.: migrant	Coefficients	Standard errors
Professionals	1.01***	0.192
Skilled	reference	
Unskilled	-0.363***	0.066
No occupation	0.24	0.156
Napoleonic recr.	-0.02	0.101
Crimean war recr.	0.05	0.123
Literacy	-0.05	0.055
Birth-cohort	yes	
Age controls	yes	
Observations	6,096	
Pseudo R-squared	0.12	

Note: Robust standard errors adjusted for clustering on counties.

* p < 0.10, ** p < 0.05, *** p < 0.01.

Separate truncated regressions are performed and cohort plus origin fixed effects are used to account for possible geographical effects on the nutritional status of both migrants and non-migrants.[46] The quadratic function for the urban migrants has a maximum at age 22.43 (*n* = 2,336); for those who stayed in the rural southern and eastern counties the maximum height was attained at age 21.39 (*n* = 3,475). The difference in age of slightly more than one year is statistically significant at a 5 percent level. The height-by-age profiles of the two sub-groups are shown in figure 12: on the left panel we present the profile with the actual heights, whereas on the right panel we show heights standardized at age 16. The predicted terminal height for the two sub-groups is very similar, in the range of 170-171 cm. With the exception of height at age 16, the profile of the rural group is always superior to the urban migrants. The index on the right panel shows a pattern which is opposite to what we have shown in figure 11: the urban migrants grew comparatively "less" than their rural counterparts. Those who were taller also grew more after age 16. In particular, from age 16 to age 18 the rural youths grew by 3 percent whereas the urban boys by a mere 1 percent.

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

To ensure that these results are not biased because of a different age composition, in figure 13 we report the age distributions of the two regression samples to show that they are almost identical.

Therefore, the estimated growth rates seem to suggest that adolescents who migrated toward industrial or urban centers were more exposed to the negative consequences of urban migration, namely to the harsher disease environment and the higher relative price of food. Even though we cannot identify at which age and which urban effect modified the growth process of the migrant, we provide substantial evidence about the existence of such an urban effect. The deferment of age at terminal height is only one of the signals of the detrimental effects that urbanization brought about on the individuals' biological standard of living. The large difference in the growth rate shows that the transition from a rural to an urban environment at a relatively early stage of life might have put at serious risk the individual's biological standard of living.

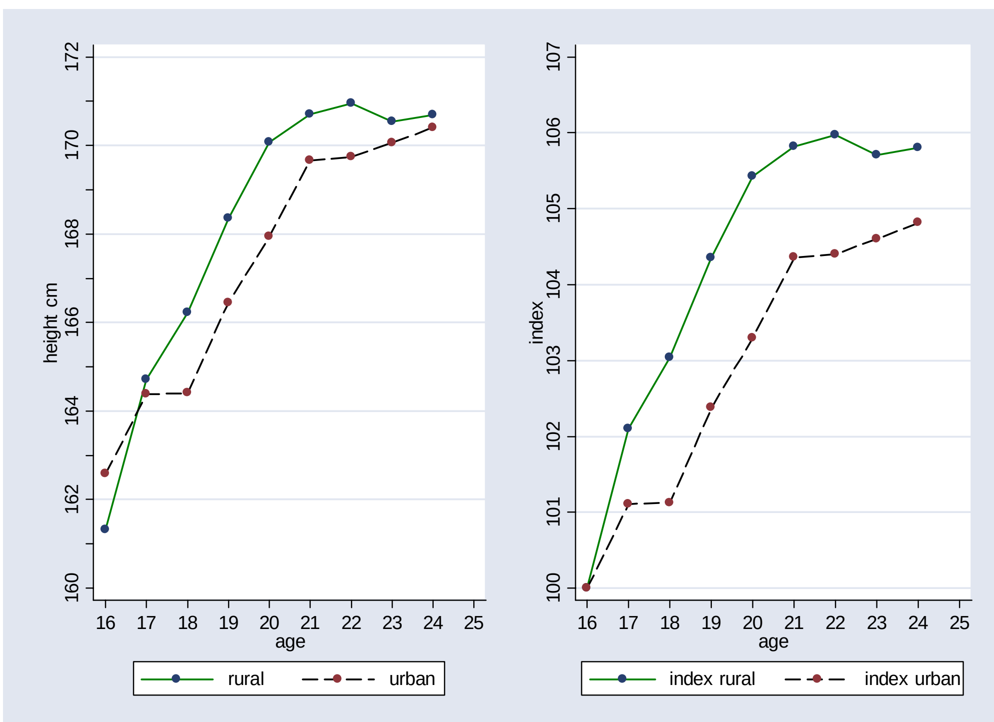

Figure 12. Height-by-age profile for urban and rural populations

Source: see text.

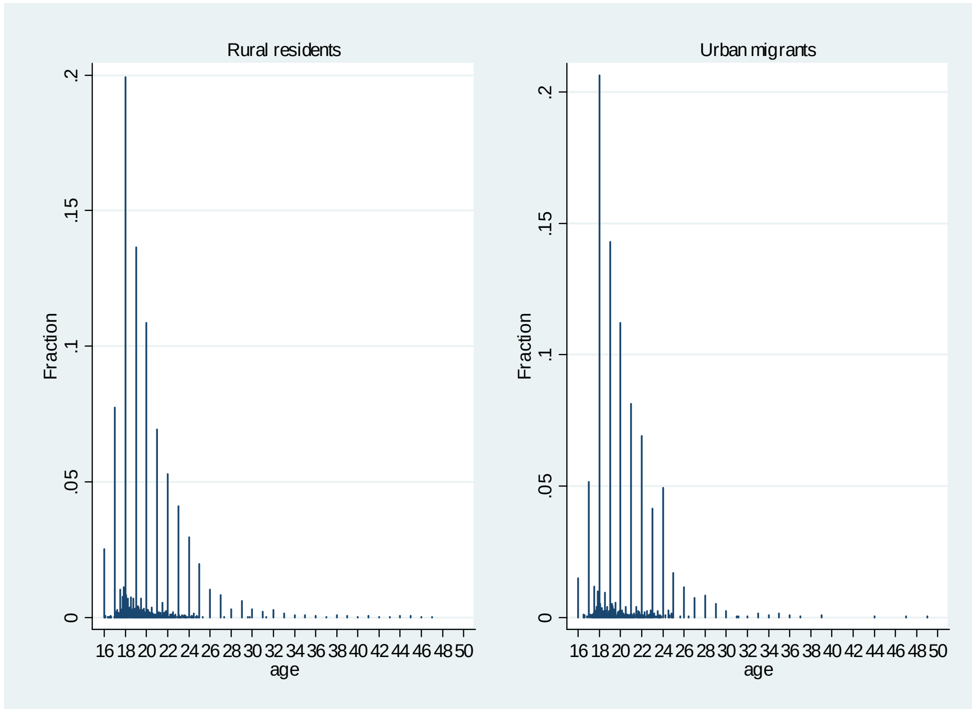

Figure 13. Age distribution of rural residents and urban migrants

Source: see text.

2.4 Enclosures and nutritional status

The findings about nutritional status provided in this article are consistent with the trend in food prices and wage rates estimated for the second half of the eighteenth-century. There is plenty of evidence that food prices rose substantially in the last third of the eighteenth-century; the price of wheat, for instance, increased by 76 percent between 1740-50 and 1785-95.[47] Similarly, Clark presents new estimates of price-indexes for different food items: As shown in figure 14 the trend for all the items is strongly increasing for the whole period 1750-1800. In addition, new figures on farm labor real wages support the view of declining standard of living for the last four decades of the eighteenth-century. Farm labor real wages declined substantially from 1740-49 until 1770-79 across all regions; the wage decline in the southeast and southwest persisted until 1820 (table 5).[48]

[47] Boyer (1990).

[48] Clark (2001); Clark (2007).

We ought not to forget that 35 percent of our sample consists of day laborers, and that 33 percent of them originated from the south (another 15 percent came from the Midlands). Therefore we believe that the economic changes of the English rural-south played an important role in shaping the trend in nutritional status. In this fashion, the parliamentary enclosures of open fields and commons that took place from the 1760s might have played an important role in determining the nutritional status of the British population—besides the substantial increase in prices due to rapid population growth and urbanization. The categories of people mostly touched by the enclosures were day-laborers and cottagers. For the laborers, the effect of the enclosures was typically the loss of common rights and/or allotments.[49] In grain-producing areas where the arable land was enclosed already before 1750, the loss of allotments was a typical phenomenon. The rise in land-value determined by the rise in wheat prices provided an incentive to farmers to take away the land that had been previously allotted to farm laborers.[50] Since the allotments were a primary source of food for the laborers and their family such a loss might have caused a significant reduction in food consumption with a consequent deterioration of the nutritional status. As also pointed out by Boyer (1990) and Humphries (1990), the loss of allotments and commons rights made agricultural laborers more dependent on wages and more sensitive to fluctuations of food-prices. Our estimates fits within this framework as we find that recruits from the south-eastern counties had an inferior nutritional status in the eighteenth-century with respect to all the other regions. In his seminal paper on parliamentary enclosures and labor supply, Chambers (1953) suggested that the loss of land from the enclosures was compensated by an increase in the wage rate and by an increase in the agricultural labor demand. Thus Chambers and other scholars—notably Landes (1969)—rejected the hypothesis that the enclosures created a pool of workers which increased the supply of labor for industry in the early industrialization process. This position has been challenged, among others, by Crafts (1978) and Boyer (1990).

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[49] Humphries (1990) stresses that women and children were the primary exploiters of common rights.

[50] Hobsbawm (1968). See also Clark (1998).

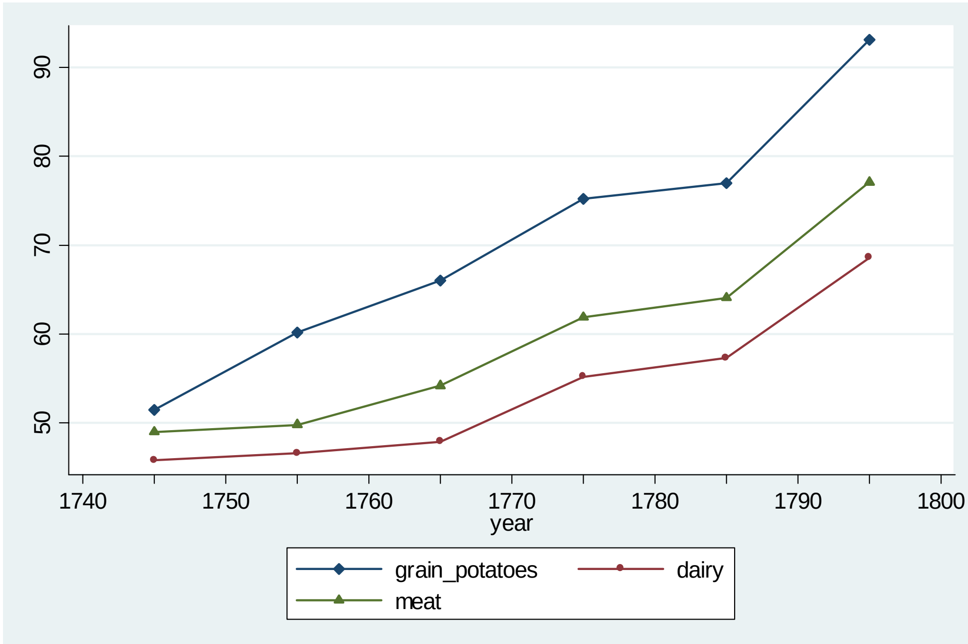

Figure 14. Price indexes of food items

Source: Clark (2007).

The new estimates of Clark (2001, 2007) reject the claim of rising wage rates of farm laborers as a result of enclosures in the second half of the eighteenth-century (table 5). Therefore, the worsening of the nutritional status was in part an endogenous response to the detrimental effect of the enclosures and of rising land-value which deprived laborers from a stable source of food. The price of food, on the rise because of population growth, had both a direct and an indirect effect on average nutritional status as they affected the value of land which became a worthier asset to farmers after 1750 (Clark, 1998).

We test whether our sample represents recruits whose families were affected by the enclosures. Our "identification strategy" consists of exploiting the correlation between enclosures and internal migration. Crafts (1978) showed a significant correlation between enclosures and the rate of migration in counties affected by the enclosures. We test whether this correlation is also present in our sample. Counties most affected by parliamentary enclosures before 1793 were Northampton, Oxford, Huntingdon, and Buckingham. Counties least affected by enclosures were Kent, Essex, Sussex, Suffolk, and Hertford.[51]

[51] See Turner (1981) and Boyer (1990).

Table 5. Farm labor nominal wage rate by macro-region

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

Note: index equal to 100 for decade 1770-79.

Source: Clark (2001).

We run a binary probit model for migration, constrained to the cohorts born before 1793 for the counties mentioned above. A dummy variable for the counties most affected by the enclosures is used in order to test our hypothesis. We control for age, time trend, occupation, and recruitment during the French Wars. The regression sample contains 1,134 observations, with 65 percent of migrants. Results from the probit estimation are reported in table 6. The coefficient for the counties affected by the enclosures is positive and highly significant. The estimates show that for a recruit born in the counties most affected by the parliamentary enclosures the predicted probability of being a migrant was 10 percent higher with respect to those born in the least affected counties. Certainly, the model estimated is not exhaustive—as usual economic determinants for migration are missing—and therefore we do not take the results as conclusive. Nonetheless, taking into account the occupational and geographical composition of the sample and the significant correlation between migration-counties and enclosure-counties, we are fairly confident that the recruits in this sample represent families of the rural-south affected to some extent by the parliamentary enclosures.

Table 6. Binary probit model for migrants

Dependent var.: binary for migrant	Coefficient	Standard error
Constant	0.588	0.186
Enclosures	0.467***	0.096
French Wars	-0.043	0.114
Age controls	yes	
Cohorts controls	yes	
Occupation controls	yes	
Observations	1,134	
Pseudo R-squared	0.064	

Note: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Source: see text.

The decline of the cottage industry that took place across the two centuries, especially in the south, represents another potential explanation for the north-south divide in nutritional status. It plays an important role not only because it was a complementary employment opportunity for agricultural laborers, but also because cottage industry represented an important source of employment for women and children. The negative correlation between poor relief expenditures and earnings from cottage industry reveals the importance that the latter had in the financial support of the family (Boyer, 1990). We argue that the decline of the cottage industry in the south contributed to the deterioration of nutritional status and constitutes an additional explanation of the north-south divide in the biological standard of living.

The decline in heights found for the nineteenth-century, as already pointed out by Steckel and Floud (1997), is likely due to the timing of industrialization and the high level of urbanization. In fact, the share of population living in urban centers in the middle of nineteenth-century was already more than 50 percent (Steckel and Floud, 1997).[52] As a counterfactual, countries like France with a very low level of urbanization did not experience a decline in nutritional status as the one estimated for Britain (Weir, 1997). Living in urban centers meant lower

[52] Saxony, the pioneer region of German industrialization, is another example of early industrialization with high level of urbanization accompanied by decreasing heights. See Cinnirella (2007).

quality of food at a relatively higher price. In addition, low levels of sanitation—as the germ theory of disease was widely accepted only toward the end of the nineteenth-century—contributed to a low level of nutritional status.

2.5 Conclusion

Our new estimates show that average nutritional status declined substantially in the second half of the eighteenth-century. Physical stature recovered slightly only for the cohorts born between 1805-09 and 1810-14. The 1820s, 1830s, and part of the 1840s were also years of decline in terms of biological standard of living. There are remarkable differences with the previous study of Floud, Wachter and Gregory (1990), especially about the trend in nutritional status of the period 1780-1820. The authors' claim of an improving standard of living during the phase of early industrialization finds here no empirical support. Instead, our results are more in line with those presented by Komlos (1993a) and successively supported by other alternative evidence. We show that the decline in heights during the second half of the eighteenth-century is consistent with recent estimates of food prices and new established trend of farm labor wages (Clark, 2001; Clark, 2007). Similarly to Boyer (1990) and Humphries (1990), we hypothesize that parliamentary enclosures and the decline of cottage industry can partially explain the fall in physical statures estimated in this article.

The trend in nutritional status estimated for the nineteenth-century shares many similarities with the one of Floud *et al.* (1990). The estimated pattern corroborates the results of the studies of Nicholas and Steckel (1991), Johnson and Nicholas (1995), and Komlos (1993a, 2004). According to our estimates the decline in heights started soon after the Napoleonic wars, whereas the estimates of Floud *et al.* place the beginning of the decline around the end of the1820s. In any event, the decline in nutritional status during the hungry thirties and forties is confirmed. Therefore the trend in height during the second and third quarter of the nineteenth-century also supports a pessimistic view of the standard of living of the British working class during the industrial revolution. Yet, also the more cautious estimates of real wages by Feinstein (1998)—which allow for unemployment and short-time working—maintain that from 1778/82 to

1853/57 there was an increase in real weekly earnings, though less than 30 percent. Thus, the early industrialization puzzle characterized by increasing real wages and declining heights seems to find confirmation also here. However, in order to get a better understanding of the trend in nutritional status we believe that the focus should be shifted from the individual to the family level. In fact, the following question should be addressed: Was the increment in the real wage large enough to allow for a sufficient sustenance of the family in a framework of high (and rising) fertility?[53] Our estimated pattern of nutritional status between the 1820s and the 1860s suggests a negative answer: The increment in the real wage was not large enough.[54] The evidence we provide here about the delay with which workers reached their final height in the nineteenth-century points to a similar conclusion. Certainly the deterioration of the average nutritional status is not mono-causal. The effects of high relative price of food, poor housing, public health, or food adulteration, which are all variables difficult to account for, can partially explain the declining trend in heights showed by the regression analysis. The same applies for the large incidence of child labor in the industrializing British society (Horrell and Humphries, 1995). We showed that the nutritional advantage for those who (probably) had been students—therefore with few or no child labor experience—was large and equal to 1.25 cm in the eighteenth-century and 1.84 cm in the nineteenth-century. Those estimates could be interpreted as quantifications in terms of nutritional status of the trade-off between education and child labor.

In conclusion, the early industrialization puzzle is probably not so puzzling when we consider the family unit rather than the single individual. The puzzle arise when we mistakenly compare a measure (the real wage) which affected just one component of the family (the wage-earner) with a measure (height) which is the result of a complex system of interactions which involves the family unit and the surrounding disease environment.[55] The height that we observe is the

[53] Throughout the long eighteenth century the Gross Reproduction Rate (GRR) rose by 36 percent. The combined effect of a decline in stillbirth rate and the fall in the mean-age of marriage account for three quarters of the rise in GRR (Wrigley 2004, p.75).
[54] Also Feinstein (1998, p. 650) stressed that allowing for demographic change, the standard of living of the average family might have been reduced by 10 percent.
[55] Height is also a more accurate measure than the real wage for this period because *(i)* there are more sources of error in measuring wages (e.g. limited regional and industrial coverage), *(ii)* height can focus on children and youth for whom there are no real wage indexes.

endogenous response to the socio-economic dynamics within the family nucleus. The average heights of the period 1820-1870, despite any increase in the real wage, simply mirror the inability or impossibility to maintain an adequate nutritional status in the working-class families where the recruits were nurtured. Whatever the rise in the wage rate during this period, we provide substantive evidence that it was not enough to maintain a given nutritional status of children and youth. Or in alternative, a trade-off between quality and quantity of children might have influenced the decision of the families. It could be the case that working class families of the eighteenth- and nineteenth-century were deliberately willing to have more children at the cost of a lower average nutritional status.[56] Institutions like the *English Poor Law* might have provided incentives in this sense. Evidence that in 1832, despite the increase in farm labor wages, 80 percent of rural south-eastern parishes continued to pay child allowances seems to be in favor of this hypothesis.[57] However, this study provides substantive evidence of a generalized decline in average nutritional status in Britain during the hundred years between 1750 and 1850, shedding new light on the standard of living debate and uncovering the negative effects brought about by the early industrial revolution.

[56] Extra-marital fertility could also play a role. But according to Wrigley (2004) the increase in illegitimacy fertility increased overall fertility only by about 4.7 percent. The large rise in overall fertility was mostly due to fall in stillbirth rate and mean-age of marriage. See also footnote 53.
[57] Boyer (1990), p.49.

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Chapter 3

Body Height, Wage Discrimination, and Occupational Sorting: A Cross-European Analysis

3.1 Introduction

There is a large and growing body of literature which focuses on the effect of physical appearance on earning potential. This strand of literature stems from the overwhelming empirical evidence which report a consistent wage advantage for workers who are *(i)* more beautiful then average (Hamermesh and Biddle, 1994), *(ii)* of normal weight[1] (Cawley, 2000a and 2000b; Behrman and Rosenzweig, 2001), *(iii)* taller than average (Case and Paxson, 2006). In the first part of this article we shall focus on the relationship between physical stature and wages. While there is a vast recent literature about the effects of weight on labor market outcomes (Brunello and D'Hombres, 2007; Paraponaris *et al.*, 2005; Cawley,

[1] There is evidence of wage penalties for people overweight and/or obese.

2000b), studies about the relationship between height and wages are less numerous. Moreover, the most comprehensive studies of wage differentials by height concentrate mainly on US and Britain,[2] whereas studies which focus on continental Europe are rather scarce (Hübler, 2006; Heineck, 2005).

Generally, estimates of log-wage equations show that an inch increase in height (ca. 2.5 cm) is associated with a wage increase in the range of 2-5 percent (Cawley, 2000b; Behrman and Rosenzweig, 2001; Judge and Cable, 2004; Persico *et al.* 2004; Case and Paxson 2006; Heineck, 2005). About the causes of such wage premium the literature in applied psychology provides some possible explanations. Judge and Cable (2004) develop a theoretical model of physical height and career success offering two not mutually exclusive reasons: social-esteem and self-esteem. By social esteem the authors mean the (positive) evaluation and regard of other people around. This social norm probably derives from the evolutionary advantage associated to tall people as they tend to be stronger due to higher leverage. Therefore physical stature is generally linked to power, capability, and it is viewed as the result of a protracted healthy behavior. The perception of a positive evaluation from the society might also influence own self-esteem. Therefore tall people, who feel widespread positive external feedback, might also develop a more distinct self-confidence. Social-esteem and self-esteem, as also stressed by Judge and Cable, constitute important assets in the labor market especially nowadays where the so-called "soft-skills", and individual traits such as motivation, are an important determinant of labor market success (Dunifon and Duncan, 1998; Atkinson, 1964).[3] Using the Judge and Cable terminology, height is more related to "subjective performances" than "objective performances".[4] Similarly, Persico *et al.* (2003) argue that taller people have an advantage in terms of social capital accumulated during childhood. They suggest that teen height matters the most as it is positively associated with

[2] There are also country- and industry-specific studies such as Dinda *et al.* (2006).

[3] Soft-skills are those non-technical characteristics typical of our personality (responsibility, self-esteem, honesty) that influence also how we interact with other people. In this fashion, Dunifon and Duncan (1998) found that there is an effect of motivation on earning potential after controlling for differences in completed schooling, parental background, and cognitive skills.

[4] Objective performances are defined as job or task-outcomes and results; subjective performances are related to how others evaluate performance. See Judge and Cable (2004), p. 430-431.

participation in "social activities" which in turn enhance teen's capability to interact and socialize, all assets highly rewarded in the labor market.

Yet, height is also related to "hard-skills" such as educational attainment or cognitive abilities. In fact the association between height and educational attainment is undisputed in the literature (Tanner, 1989; Lynn, 1989; Kretchmer, *et al.*, 1996). We shall also provide some evidence on the existence of such a relationship. However, the channels through which such a correlation works are not clear. Possible explanations not mutually exclusive concern infant nutrition, genetics and chemical channels, and mother behavior during pregnancy. The hypothesis that taller people earn more because more intelligent has been put forward by Case and Paxson (2006) whose conclusions about the height wage premium are as straightforward as different from the suggestions of Persico *et al.* (2003): "On average, taller people earn more because they are smarter".[5] Their evidence is based on a strong correlation between height and cognitive tests measured when children are 3 years old. Better prenatal and childhood nutrition, which result in higher physical stature, enhances individual cognitive abilities. That makes taller people more productive and therefore with higher earning potential.

Nevertheless, the hypothesis of wage discrimination by height cannot be rejected *a priori*. Employers, especially for certain managerial positions, might have a preference for taller workers as body height signals stronger leadership, stronger motivation, and self-esteem. Self-fulfilling prophecies can reinforce this phenomenon (Hübler, 2006).[6] In this paper we shall not answer the question why taller people have more schooling or perform better in cognitive tests, but rather, we shall employ this correlation to try to understand whether the impact of body height on wages is due to unobservable characteristics which enhance productivity or more in general due to discrimination. In the first part of the article we shall test existence and magnitude of wage differentials by height; the second part will be devoted to the study of the role that height plays in occupational sorting.

[5] Case and Paxson (2006), p. 2.

[6] Short individuals who predict social and economic disadvantages might decide to invest less in human capital as they feel their returns are lower.

3.2 The dataset [7]

In order to investigate the effect of physical stature on wages and the role that height plays in occupational sorting, we use the Survey of Health, Ageing and Retirement in Europe (SHARE) which collects information on health and various socio-economic variables for circa 31,000 individuals aged 50+ across 11 European countries (Figure 1).[8] Since we have a quite heterogeneous sample we divide the countries into three more homogeneous macro-areas: Nordic (Sweden, Denmark, and the Netherlands), Continental (Germany, Belgium, Austria, and Switzerland), and Mediterranean countries (Spain, France, Italy, and Greece). This grouping aims to combine countries with similar socio-economic and, above all, labor market characteristics.[9]

The dataset at our disposal provides the following advantages: Beyond the usual demographic variables it offers detailed information on earnings from employment in the year 2003 and accurate information about conditions in which the job is performed. Since the main target of this survey is to study the health conditions of the European population, besides self-reported height and weight, there are numerous variables which state the individuals' health status and, very importantly, scores on cognitive tests. The cognitive functions tested in the survey can be grouped into three categories: memory, verbal skills (henceforth fluency), and numeric ability. Regarding the memory test, people

[7] This paper uses data from release 2 of SHARE 2004. The SHARE data collection has been primarily funded by the European Commission through the 5th framework programme (project QLK6-CT-2001-00360 in the thematic programme Quality of Life). Additional funding came from the US National Institute on Ageing (U01 AG09740-13S2, P01 AG005842, P01 AG08291, P30 AG12815, Y1-AG-4553-01 and OGHA 04-064). Data collection in Austria (through the Austrian Science Foundation, FWF), Belgium (through the Belgian Science Policy Office) and Switzerland (through BBW/OFES/UFES) was nationally funded. The SHARE data collection in Israel was funded by the US National Institute on Aging (R21 AG025169), by the German-Israeli Foundation for Scientific Research and Development (G.I.F.), and by the National Insurance Institute of Israel. Further support by the European Commission through the 6th framework program (projects SHARE-I3, RII-CT-2006-062193, and COMPARE, CIT5-CT-2005-028857) is gratefully acknowledged. For methodological details see Boersch-Supan and Juerges (2005).

[8] The dataset originally included also Israel but since many variables were still not available for that country we focused only on Spain, France, Italy, Greece, Switzerland, Austria, Germany, Belgium, the Netherlands, Denmark, and Sweden.

[9] We shall see that this grouping is also meaningful when considering physical stature.

were asked to remember a list of ten words previously presented; about fluency, interviewees were asked to list as many names of animals as they could think of in one minute.

Figure 1. European countries in the survey

Source: The figure is taken from the survey on-line documentation. See www.share-project.org.

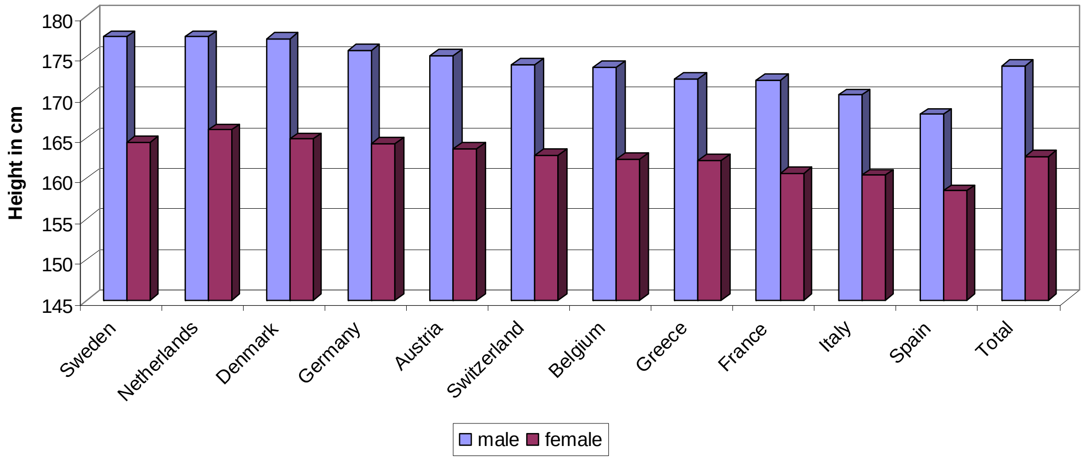

Figure 2. Average height by gender in 11 European countries, 2004

Table 1. Descriptive statistics of variables of interest

Variable	Mean	Std. deviation	Mean	Std. deviation
	Men		Women	
Age	55.2	3.82	53.8	4.63
Years of educ.	12.2	3.81	12.3	3.69
Tenure	21.1	12.39	17.0	11.66
Height (cm)	176.3	7.33	164.6	6.38
Weight (Kg)	82.9	12.79	68.1	12.08
BMI	26.7	3.84	25.1	4.22
Score memory	4.0	1.78	4.6	1.89
Score verbal	22.1	7.51	22.6	6.84
Score numeracy	3.9	0.98	3.6	0.98
Metropolitan	0.34	0.47	0.37	0.48
Town	0.43	0.49	0.42	0.49
Village	0.23	0.42	0.21	0.41

Note: The minimum score for the memory test is 0, the maximum is 10; for the verbal score the minimum is 0 and the maximum is 90; for the numeracy score the minimum is 1 and the maximum is 5.

Eventually for the numeracy test, the interviewer asked four different questions of increasing difficulty:[10] The scores on these four questions have been successively summarized into a single variable for numeric ability. Descriptive statistics for cognitive test scores and other demographic and anthropometric variables of interest are shown by gender in table 1. Figure 2 instead shows average heights by country and gender in our sample: as well-known, people in the Nordic countries are taller than in Southern Europe. Though people start shrinking after age 50, there is no reason to believe that the shrinking rate varies systematically among countries. Therefore our results will not be affected by the process of shrinking. Furthermore there are no systematic differences in age composition between countries.

3.2.1 Height and cognitive functions

There is broad evidence about the relationship between height and educational attainment on one side, and cognitive functions on the other (Tanner, 1989; Kretchmer *et al.*, 1996; Case and Paxson, 2006).[11] Evidence from our sample confirms previous finding. In table 2 we show the relationship between height and years of education by gender and macro-area. In particular, we compare mean heights for low- and high-education groups where these groups are defined according to the years of education with respect to the median. There is a clear gradient in height as people in the high-education group are systematically taller than the other group.[12]

We also find a positive association between height and cognitive abilities.

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[10] The questions about numeracy skills in the survey are the following: 1) If the chance of getting a disease is 10 per cent, how many people out of 1,000 (one thousand) would be expected to get the disease? 2) In a sale, a shop is selling all items at half price. Before the sale, a sofa costs 300. How much will it cost in the sale? 3) A second hand car dealer is selling a car for 6,000. This is two-thirds of what it costs new. How much did the car cost new? 4) Let's say you have 2000 in a savings account. The account earns ten per cent interest each year. How much would you have in the account at the end of two years?

[11] See Case and Paxson (2006) for an exhaustive review of the literature.

[12] The estimation of an exploratory model of the type $education = a + \beta\ height + \varepsilon$ controlling also for gender, age and age squared, shows that the association between height and educational attainment is stronger in Mediterranean countries ($\beta = 0.14$) than in Nordic ($\beta = 0.05$) or Continental countries ($\beta = 0.08$).

Table 2. Mean height (in cm) by educational attainment

Country	Low education	High education	Observations	Low education	High education	Observations
		Men			Women	
Denmark	176.3	178.8	763	164.0	166.0	932
Sweden	176.1	178.5	1,391	163.8	165.1	1,613
Netherlands	176.0	178.9	1,350	164.4	167.3	1,579
Austria	173.3	176.7	780	162.8	164.1	1,105
Switzerland	172.9	175.7	445	160.4	164.0	525
Belgium	172.7	174.9	1,723	161.1	163.3	2,075
Germany	172.0	177.1	1,372	162.7	165.1	1,618
France	170.7	174.5	1,344	159.8	161.7	1,765
Greece	170.3	174.1	1,242	159.6	163.9	1,645
Spain	166.3	170.1	988	156.0	160.8	1,396
Italy	166.2	172.2	1,130	158.6	161.4	1,423
Total	172.1	175.5	12,528	161.0	163.9	15,676

Note: Low and high education are defined in terms of the median of years of education.

In order to show that, we consider the scores on numeracy test which are ordered on the basis of five increasing values: score 1 is a "bad" outcome while score 5 is a "good" one. We calculated the average height for each of the five scores by country (fig. 3). The positive association between height and numeracy skill is clear: tall stature is associated with high scores in numeracy, while short stature is associated with poor performances. With the exception of Austrian men, differences in mean height between score 1 and score 5 are always statistically significant. This result is corroborated by the analysis of the other two tests on cognitive functions, namely memory and fluency. The correlation coefficient of height and memory scores is 0.218 for men and 0.216 for women; for height and fluency is 0.266 for men and 0.217 for women, for all countries altogether. When we compare the correlation coefficients of height and cognitive tests for the three macro-areas the following pattern emerges: Reading table 3 horizontally one can see that the correlation coefficients in the Mediterranean countries are always larger than in the other two areas, both for men and women. Therefore the established association between physical stature and educational attainment on one side, and numeracy skills on the other is confirmed in this data set. It is also important to note that there are considerable differences in the test performances between macro-areas and gender. In table 4 we report the distribution of the results for numeracy following the scale of five values previously defined. The differences in performance are quite striking: the Mediterranean countries score significantly worse than the other two areas. Among the male population, in Nordic and Continental countries circa 4 percent of the sample scored poorly in the numeracy test; in Mediterranean countries the share is above 10 percent. The proportion of people who scored "good" in Mediterranean countries (14 percent) is less than half of that of Nordic men (32 percent). A similar pattern can also be identified among females. Within each macro-area men perform significantly better than women in numeracy score.[13]

We also need to define when an individual can be considered short or tall. Physical stature is a country-specific variable: An individual whose stature is 1.80m is considered tall in Italy but of average stature in North-European countries. In what follows, when not otherwise specified, we shall consider a person short when his/her stature is below the reference median, tall when above. The reference median is defined by country and gender.[14]

Table 3. Height and cognitive tests by gender and area

	Nordic countries	Continental countries	Mediterranean countries	Total
Numeracy test				
Men	0.165	0.162	0.258	0.261
Women	0.125	0.181	0.214	0.235
Fluency				
Men	0.175	0.160	0.203	0.265
Women	0.125	0.142	0.136	0.217
Memory				
Men	0.139	0.140	0.214	0.220
Women	0.106	0.153	0.202	0.216

Note: All the correlation coefficients are significant at 1% level.

[13] We tested difference of means for all countries and found that men always outperform women.

[14] We also used three height categories (short, medium, and tall) on the basis of number of standard deviation from the mean. The results illustrated throughout the article are valid also with such specification.

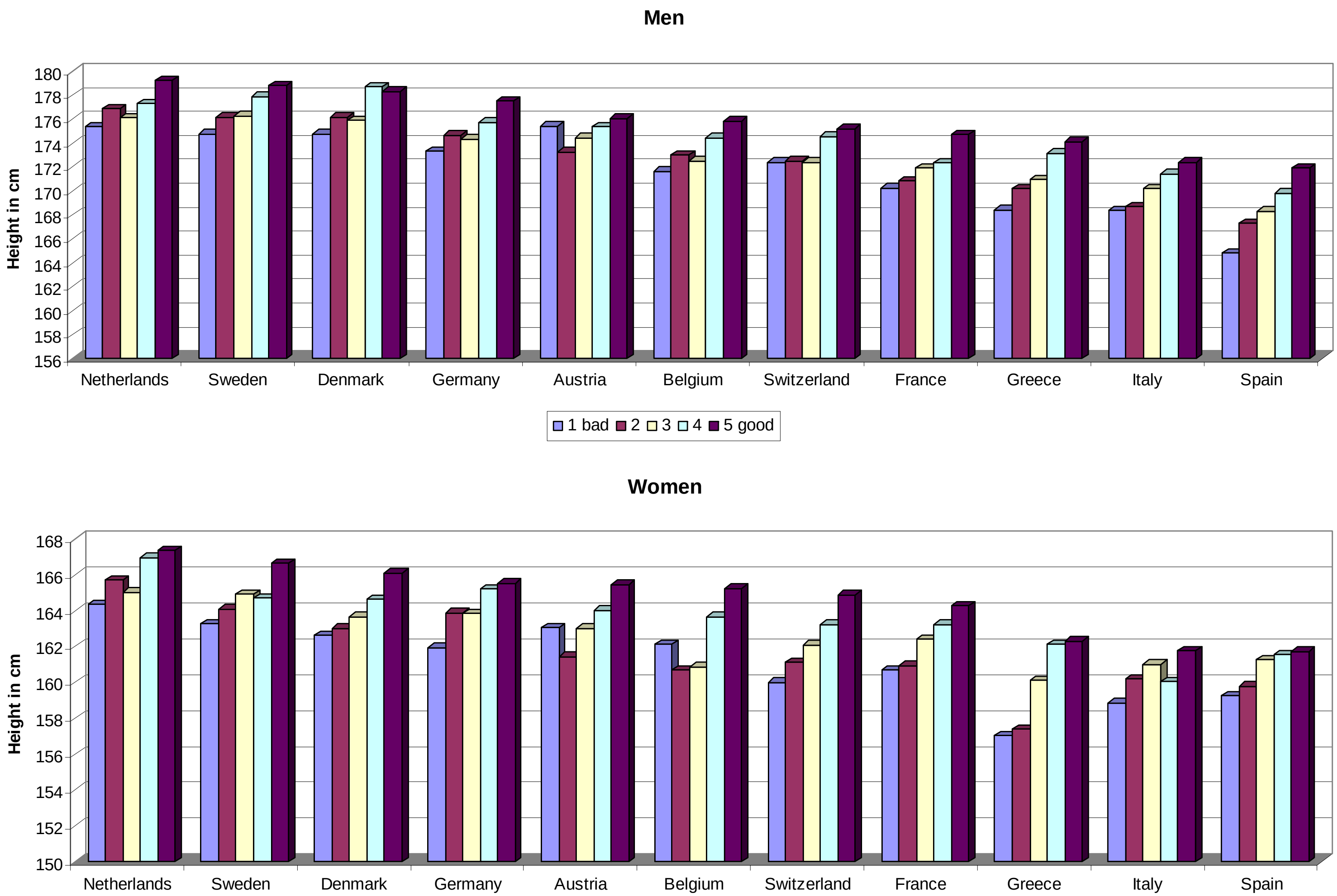

Figure 3. Mean height by score on numeracy test

Table 4. Distribution of scores on numeracy test (percent)

Macro-area	Score					Total
	1 (bad)	2	3	4	5 (good)	
Men						
Nordic	3.96	6.64	28.00	29.74	31.67	100
Continental	3.56	7.87	23.75	41.41	23.41	100
Mediterranean	10.58	14.73	33.93	26.62	14.14	100
Total	6.37	10.16	28.86	32.45	22.15	100
Women						
Nordic	5.49	15.17	34.12	28.19	17.04	100
Continental	6.55	15.07	30.13	34.81	13.43	100
Mediterranean	16.69	26.14	31.91	18.93	6.33	100
Total	10.30	19.49	31.89	26.76	11.57	100

Source: see text.

3.3 Compensating wage differentials

In order to measure wage differentials by height we start from the hedonic model of wages which postulates that wage differentials compensate for the conditions and demands under which a job is performed (Cahuc and Zylberberg, 2004; Rosen, 1974). Wage heterogeneity could stem from the different conditions under which the same typology of job is performed. The model explaining wages can then be described by the following log-level equation:

$$\ln W_i = \mathbf{x}_i \beta + \mathbf{z}_i \theta + \delta h_i + \alpha_i + \varepsilon_i \quad (1)$$

where W_i is the hourly wage of an individual i, $\boldsymbol{x}$ is a vector that includes the individual-specific characteristics (age, experience, gender, education); $\boldsymbol{z}$ includes job-specific characteristics such as working time (e.g. part-time vs. full-time), type of contract (e.g. short term vs. long term), degree of responsibility, level of independence, time pressure, level of security, and flexibility; h indicates physical stature; α_i indicates unobserved abilities of individual i such as intelligence or cognitive abilities. The coefficients β, θ and δ are parameters to estimate. A standard way to account for unobserved ability is to use longitudinal data and estimate the first-difference of equation (1), allowing for arbitrary correlations between individual unobserved heterogeneity and the set of regressors. In this paper we shall account for unobserved ability using test scores on cognitive functions. Therefore least squares estimates of equation (1) will yield consistent and unbiased estimates of δ when including α_i (or a proxy for ability).

We want to test whether height has a positive impact on wages because it is a biological marker for higher cognitive skills or whether there is wage discrimination. In general, we speak of "statistical discrimination" when individuals with identical abilities on the basis of some *a priori* belief are treated differently only because of membership in a different demographic group. If taller people earn more exclusively because they are more productive, once accounting for cognitive functions δ should be (or tend to) zero. Otherwise, if the coefficient of height is still different from zero we should conclude that there is a height-wage-premium which cannot be referred to differences in individual abilities. Clearly, the extent of statistical discrimination depends on the degree of accuracy with which we can account for the individual unobserved heterogeneity under the assumption that the model is fully specified.

Other elements that could potentially influence the estimates of wage differentials by height are the industry and the worker's occupation. In a perfectly competitive market with perfect information and mobility of workers, with given productive abilities and working conditions, wage determination should be independent of the industry of employment. Nevertheless there is abundant empirical evidence on persistent wage differentials between industries.[1] There is a vast literature which argues that inter-industry wage differentials are largely due to unobserved worker abilities (Murphy and Topel, 1987; Abowd *et al.*, 1999; Goux and Maurin, 1999). Since unobserved abilities have been shown to be correlated with physical stature, accounting for industry fixed effects could further reduce, if not eliminate, any residual height wage-differential. The model explaining wages is then described by this new equation:

$$\ln W_i = \mathbf{x}_i \beta + \mathbf{z}_i \theta + \delta h_i + \gamma_j + \alpha_i + \varepsilon_i \qquad (2)$$

[1] See Cahuc and Zylberberg (2004), p. 295-298 for a summary of the literature on inter-industry wage differentials.

where γ_j is a fixed effect for industry *j*.

We estimate equation (2) with OLS, where the dependent variable is log-hourly wage. The survey provides detailed information about the last gross payment received, the effective number of hours worked per week, and the frequency of payments. Therefore we are able to generate a variable for hourly wages which is deflated for country-specific purchase power parity (PPP) expressed in Euros. In more detail, the explanatory variables used in the hedonic wage model are the following:

- Individual-specific variables *(**x**)*: age (and its squared), years of education (plus a dummy variable for tertiary education which will be used alternatively to "years of education" when correcting for sample selection), tenure, and marital status. It is important to note that, contrary to many other studies in labor economics which use the concept of "potential experience", we can rely on effective years of tenure.
- Job-specific variables *(**z**)*: dummy variables for the typology of contract (fixed term, part-time), and several other controls such as degree of independence, possibility to acquire new skills, colleague support, responsibility, job security, future prospects.
- Dummy variable for height (h_i), Body Mass Index (BMI) and health status.[2]
- Industry fixed effects (γ_j): 13 controls for industrial sectors classified according to the NACE Codes created by the European Union.
- Cognitive abilities (α_i): we defined dummy variables for over-performance in memory and numeric test;[3] fluency is used as a continuous variable.
- Controls for place of residence (metropolitan area, town, village) and country fixed-effects.

[2] BMI is defined as weight/height^2, with height measured in meters and weight in kg.
[3] Regarding the memory test: Results above the median (3 words listed) are regarded as over-performance; about numeracy: the dummy takes on value one if the score is either 4 or 5.

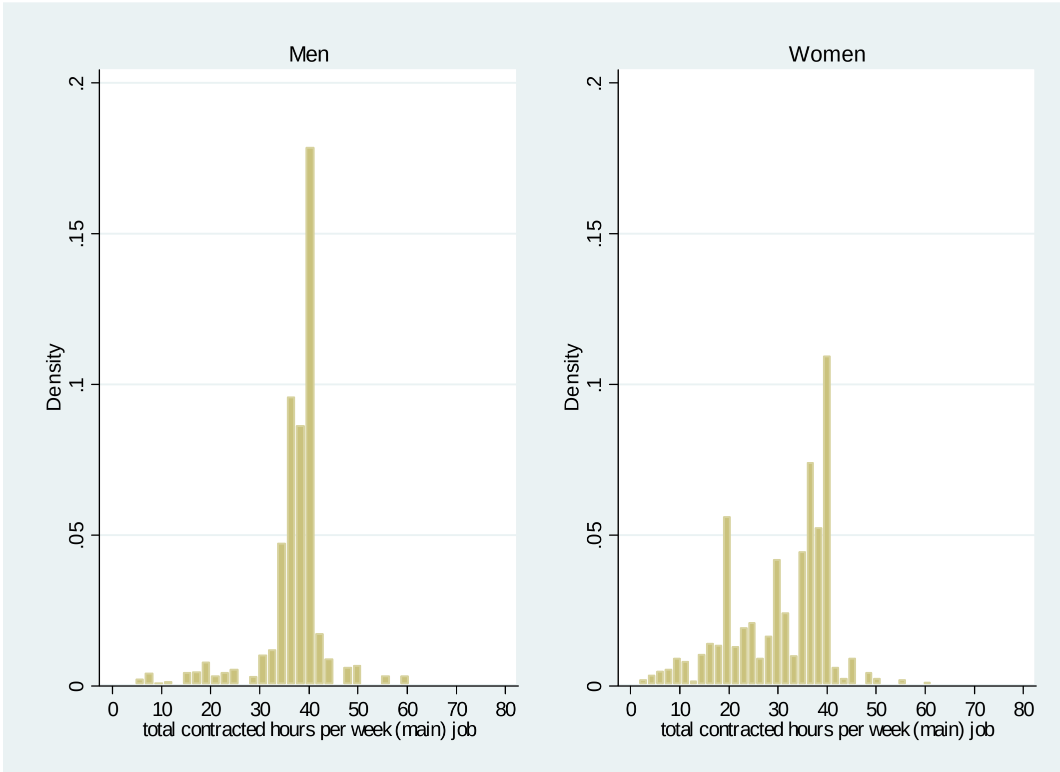

Figure 4. Distribution of contracted hours per week by gender

In addition to the variables specified above, we also have eight controls for occupation classified according to the International Standard Classification of Occupations (ISCO). These control variables, to some extent, capture the amount of skills embedded in the different tasks; therefore it is important to account for them in order to obtain unbiased estimates of the height wage differential.

Since we want to investigate returns to physical stature and the existence of potential discrimination in the labor market, we constrain our sample to employees and civil servants. Homemakers, self-employed, pensioners, and permanently disabled people are excluded from the analysis.[4] The hedonic wage model is constrained to working-age people strictly below 65 years. In order to avoid that results are driven by outliers, we focus exclusively on part-time and full-time employees discarding atypical employees who reported below 20 and above 60 "total contracted hours per week". In figure 4 we report the distributions of the contracted weekly hours for men and women.

[4] Female homemakers will be re-considered when we address the issue of sample selection.

General results are obtained pooling the 11 European countries. We adjust the standard errors for clustering, where the countries are the clusters. In this way we allow for correlation of the observations within country but we maintain independence of the observations between countries. We account for physical stature using a dummy variable which takes on value one if height is below the reference median, zero otherwise.

3.3.1 Height premium in the male labor market

Estimates of the hedonic wage model (2) for male employees are reported in table 5. We present three different specifications which differ from each other on account of the inclusion of cognitive functions and eight controls for occupation. In the first specification, where we do not control for cognitive abilities and occupations, short men earn on average 9.1 percent less than people above the reference median and the coefficient is highly significant. The coefficient becomes smaller when we introduce controls for cognitive skills in regression II (8.4 percent). The effect of height decreases further to 7.3 percent (p-value = 0.092) when we eventually introduce controls for occupations. Then, least squares estimates of the hedonic wage model show that controlling for cognitive functions and occupations reduces the magnitude of the height-wage-premium; nonetheless, a significant positive impact of height persists suggesting that physical stature is capturing other unobservable characteristics which have a direct impact on wages, or alternatively, that there is wage discrimination by body height.

Due probably to the particular age composition of the sample the effect of age is not different from zero. The relationship between wages and tenure is concave, yet the squared effect is negligible: an additional year of tenure determines circa a 1.3 percent increase in hourly wage. The effect of an additional year of education ranges from 1.5 percent—when we account for cognitive functions in regression III—to 2.3 percent in the first regression. Among the job-specific variables there is a strong positive effect for jobs with high degree of responsibility and jobs which allow improving individual skills. There is a strong negative effect on wages for jobs which are physically demanding. About the industrial fixed effects, with respect to the reference category of banking, we find systematic lower wages for the agricultural, trade, and health industry.[5]

Table 5. Hedonic wage model for men (OLS)

Dep. var.: log-hourly wage	Regression I	Regression II	Regression III
Individual specific			
Age	0.043	0.044	0.054
	[0.076]	[0.076]	[0.076]
Age squared	-0.000	-0.000	-0.000
	[0.001]	[0.001]	[0.001]
Tenure	0.013***	0.013***	0.012***
	[0.004]	[0.004]	[0.004]
Tenure squared	-0.000**	-0.000**	-0.000**
	[0.000]	[0.000]	[0.000]
Years of education	0.023***	0.020***	0.015***
	[0.005]	[0.005]	[0.005]
Married	-0.006	-0.002	-0.013
	[0.038]	[0.038]	[0.038]
Anthropometric variables			
Short (below median)	**-0.091*** **	**-0.084*** **	**-0.073** **
	[0.029]	[0.029]	[0.029]
Underweight	0.001	-0.001	0.021
	[0.359]	[0.359]	[0.362]
Overweight	-0.003	-0.002	-0.008
	[0.031]	[0.031]	[0.031]
Obese	-0.032	-0.036	-0.045
	[0.043]	[0.043]	[0.043]
Health low	0.007	0.013	0.019
	[0.047]	[0.047]	[0.047]
Health medium	reference group	reference group	reference group
Health high	0.057*	0.051	0.049
	[0.031]	[0.031]	[0.031]
Cognitive functions			
Memory		0.025	0.015
		[0.030]	[0.031]
Fluency		0.005**	0.004**
		[0.002]	[0.002]
Numeracy		0.012	0.006
		[0.032]	[0.032]
Job-specific variables	yes	yes	yes

[5] Due to sample size, estimates of equation (2) by macro area do not yield significant results.

Dep. var.: log-hourly wage	Regression I	Regression II	Regression III
Industry controls	yes	yes	yes
Place of residence	yes	yes	yes
Country fixed-effects	yes	yes	yes
Occupation controls	no	no	yes
Constant	0.939 [2.112]	0.806 [2.110]	0.676 [2.106]
Observations	2,014	2,014	2,014
R-squared	0.21	0.21	0.22

Note: Robust standard errors in brackets adjusted for clustering, where the countries represent the clusters.

* p < 0.10, ** p < 0.05, *** p< 0.01.

3.3.2 Height premium and sample selection in the female labor market

The estimation of the hedonic wage model for women yields different results compared to men. As can be seen in table 6, there is no height effect already in regression I.[6] There is neither age nor tenure effect. Instead, education seems to play a slightly larger role for women than for men. Regarding the job-specific characteristics, we observe similar results as for men, namely a wage advantage for those jobs with higher level of responsibility and a negative effect of industry such as education, trade, and the health sector.

Thus, the estimates of the hedonic wage model for women suggest that there is no effect of height on wages. A well-known problem of the previous OLS estimates regards the fact that we only observe the wages of those who participate in the labor market. If unobserved characteristics of those who do not work, for instance homemakers, are correlated with earning potential, the OLS coefficients are generally inconsistent (Heckman, 1979).

[6] In a recent study about the German labor market Heckman (2005) also found no significant effect of height on wages for the female sub-sample.

Table 6. Female wage regression (OLS)

Dep. var.: log-hourly wage	Regression I	Regression II	Regression III
Individual specific			
Age	0.017	0.019	0.013
	[0.037]	[0.037]	[0.037]
Age squared	-0.000	-0.000	-0.000
	[0.000]	[0.000]	[0.000]
Tenure	0.004	0.004	0.004
	[0.005]	[0.005]	[0.005]
Tenure squared	0.000	0.000	-0.000
	[0.000]	[0.000]	[0.000]
Years of education	0.029***	0.027***	0.018***
	[0.005]	[0.005]	[0.006]
Married	-0.024	-0.024	-0.025
	[0.035]	[0.035]	[0.035]
Anthropometric variables			
Short (below median)	**-0.042**	**-0.041**	**-0.047**
	[0.030]	[0.030]	[0.030]
Underweight	0.109	0.104	0.100
	[0.115]	[0.115]	[0.114]
Overweight	-0.036	-0.034	-0.037
	[0.033]	[0.033]	[0.033]
Obese	0.032	0.031	0.031
	[0.044]	[0.044]	[0.044]
Health low	-0.029	-0.027	-0.031
	[0.053]	[0.053]	[0.053]
Health medium	Reference group	Reference group	Reference group
Health high	0.082***	0.076**	0.063**
	[0.032]	[0.032]	[0.032]
Cognitive functions			
Memory		0.018	0.015
		[0.035]	[0.035]
Fluency		0.004*	0.004*
		[0.002]	[0.002]
Numeracy		0.016	-0.002
		[0.032]	[0.032]
Job-specific variables	yes	yes	yes
Industry controls	yes	yes	yes
Place of residence	yes	yes	yes
Country fixed-effects	yes	yes	yes
Occupation controls	no	no	yes

Dep. var.: log-hourly wage	Regression I	Regression II	Regression III
Constant	1.433	1.326	1.472
	[0.968]	[0.969]	[0.969]
Observations	1,947	1,947	1,947
R-squared	0.20	0.20	0.21

Note: Robust standard errors in brackets adjusted for clustering, where the countries represent the clusters.

* p < 0.10, ** p < 0.05, *** p< 0.01.

Therefore it is possible that the working women previously analyzed do not constitute a random sample. Indeed, in the current dataset circa 2,500 women of working age (below 65 years) reported to be homemakers.[7] Therefore we want to test for sample-selection and, in case, correct the least squares estimates for women using the inverse mills ratio (IMR).

Let's assume that the employment and wage equations are given by:

$$E_i^* = \mathbf{H}_i\gamma + \varepsilon_i \tag{3}$$

$$W_i = \mathbf{X}_i\beta + u_i \tag{4}$$

where E^* is a latent variable associated with being employed and $\boldsymbol{H}$ is a vector of determinants of labor force participation.[8] W is the employee log-wage and $\mathbf{X}$ is a vector of determinants of market wages. Errors ε_i and u_i are assumed to follow a bivariate normal distribution (0, 0, σ_ε, σ_u, ϱ). Since wages are observed only if $E^* > 0$, the expected wage of an employee is given by

$$E(W_i \mid E_i^* > 0) = \mathbf{X}_i\beta + \theta\lambda_i \tag{5}$$

where $\theta = \rho\sigma_u$, $\lambda_i = \phi(\mathbf{H}_i\gamma)/\Phi(\mathbf{H}_i\gamma)$, $\phi(\cdot)$ is the standard normal density function, and $\Phi(\cdot)$ is the standard normal C.D.F. *Lambda* is the IMR which decreases monotonically with the probability of participating in the labor force.

[7] Conversely, only 30 men reported to be homemakers.

[8] Please note that γ of equation (3) is not the industry fixed effect of equation (2).

From equation (5) it is clear that a simple OLS regression of W_i on $\boldsymbol{X}_i$ would omit the term $\theta\lambda_i$ leading to biased estimates of β. Usually one obtains estimates of the probability of participating in the labor force from probit estimations of the selection equation (3). Thereafter, the IMR is constructed and included in equation (5) which is estimated through OLS.

In general, the non-linearity of λ_i is a sufficient condition to identify the selection model even if the basic model (4) and the selection equation (3) have the same regressors. Nonetheless this solution is considered to be sub-optimal and therefore we specify some additional identifying restrictions. We generate a variable for "other sources of income" in the household. This variable includes all the annual income of other household members. Additionally, we have a variable for the number of children at home which is often used as an identifying restriction in the literature on female labor supply. For the remaining we include a dummy variable for marital status, health and anthropometric variables, and the variables for cognitive abilities. Following Neuman and Oaxaca (2004), age and its squared are included only in the selection equation whereas tenure and its squared are retained in the basic regression. The logic is that wages are determined more by seniority than age. On the other hand, age is more likely to play a role in determining whether to participate in the labor force. The variable "years of education" is used in the selection equation, whereas a dummy variable for tertiary education is used in the wage equation. Finally, country fixed effects and place of residence are included in both equations as country location can play a role both in determining wages and in the decision to participate.

The estimate of the coefficient theta associated with the IMR suggests that there is indeed sample selection among women. The coefficient is negative and highly significant (θ = -0.352). This result implies that *(i)* the female sub-sample analyzed in the previous section is not a random sample and the OLS estimates are biased and inconsistent; *(ii)* since lambda is a monotonic decreasing function of the probability of participating in the labor force, individuals with a higher probability of participating tend also to earn higher wages. Variables which have a strong positive impact on the probability of participating in the labor force are age and education. In contrast, to be married and an increasing number of children at home significantly reduces the probability of being in the labor force.

Also the place of residence plays an important role as women residing in large metropolis are more likely to work compared to towns or villages. Finally, low health status is negatively associated with the probability of being in the labor force, while other income in the family does not have a significant effect.

Correcting for sample-selection changes our parameter of interest in the hedonic wage model as now short female workers earns circa 5 percent less than those above the median (*p*-value = 0.076). Physical stature seems also to play a role in the selection equation: taller women are more likely to select into the labor force and tend to earn higher wages.

Table 7. Female log-wage equation adjusted for sample selection

	Dependent variable: log-hourly wage	Selection equation
Individual specific		
Age		0.437***
		[0.045]
Age squared		-0.005***
		[0.000]
Years of education		0.060***
		[0.007]
Children at home		-0.103***
		[0.029]
Other income		0.001
		[0.000]
Tenure	0.004	
	[0.004]	
Tenure squared	-0.000	
	[0.000]	
Tertiary education	0.039	
	[0.041]	
Married	0.013	-0.274***
	[0.036]	[0.055]
Anthropometric variables		
Short (below median)	**-0.053***	**0.076***
	[0.030]	[0.044]
Underweight	0.076	-0.012
	[0.116]	[0.181]
Overweight	-0.013	-0.065
	[0.033]	[0.048]
Obese	0.044	-0.046
	[0.044]	[0.062]
Health low	0.059	-0.426***
	[0.054]	[0.063]
Health high	0.044	0.009

	Dependent variable: log-hourly wage	Selection equation
	[0.032]	[0.048]
Cognitive functions	yes	yes
Job-specific variables	yes	no
Industry controls	yes	no
Place of residence	yes	yes
Country fixed-effects	yes	yes
Occupation controls	yes	no
Constant	2.238***	-9.836***
	[0.169]	[1.218]
Censored observations	5,002	
Uncensored observations	1,947	
Observations	6,949	

Note: Standard errors in brackets.

* p < 0.10, ** p < 0.05, *** p< 0.01

3.4 Height-wage-gap and discrimination

Least square estimates show that after accounting for cognitive functions there is still a consistent wage premium for workers whose physical stature is above the reference median. In order to test whether the height premium stems from differences in endowments or in coefficients we employ the Blinder-Oaxaca decomposition (Blinder, 1973; Oaxaca, 1973), which consists of estimating wage equations separately for short and tall workers. Let's consider $W_{T,i}$ and $W_{S,j}$ the log-hourly wage of, respectively, a tall person *i* and a short person *j*.

$$\ln W_{T,i} = \mathbf{X}_{T,i}\beta_T + \varepsilon_{T,i} \quad (6)$$

$$\ln W_{S,j} = \mathbf{X}_{S,j}\beta_S + \varepsilon_{S,j} \quad (7)$$

The difference between the average values of the wage logarithms can be decomposed as follows:

$$\overline{\ln W_T} - \overline{\ln W_S} = (\overline{\mathbf{X}}_T - \overline{\mathbf{X}}_s)\hat{\beta} + \overline{\mathbf{X}}_T(\hat{\beta}_T - \hat{\beta}) + \overline{\mathbf{X}}_S(\hat{\beta}_S - \hat{\beta}), \qquad (8)$$

$$\textit{where} \ \ \hat{\beta} = \alpha\hat{\beta}_T + (1-\alpha)\hat{\beta}_S \quad \textit{and} \quad \alpha \in [0,1]$$

In the general specification of equation (8), α constitutes the relative weight of the non-discriminatory group and $\hat{\beta}$ is interpreted as the vector of the returns on observable variables in a competitive market. Consistently with much of the literature on wage-discrimination we adopt the wage structure of the "tall" workers as the reference group (Neuman and Oaxaca, 2004). That implies α = 1 and the decomposition in (8) becomes

$$\underbrace{\overline{\ln W_T} - \overline{\ln W_S}}_{\textit{wage gap}} = \underbrace{(\overline{\mathbf{X}}_T - \overline{\mathbf{X}}_S)\hat{\beta}_T}_{\textit{explained part}} + \underbrace{\overline{\mathbf{X}}_S(\hat{\beta}_T - \hat{\beta}_S)}_{\textit{unexplained part}} \qquad (9)$$

where the first term of the decomposition represents the explained part of the wage-gap which measures the contribution of the endowments.[9] The second term is the unexplained part which measures the difference of returns to a given variable assessing then the difference in treatment for a given variable. The extent of discrimination in the wage-gap between tall and short workers depends on the magnitude of the unexplained part.

We showed that the height wage premium for women appears only when correcting for sample selection. In the presence of sample selectivity the decomposition in (9) takes the following form:

$$\underbrace{\overline{\ln W_T} - \overline{\ln W_S}}_{\text{wage gap}} = \underbrace{(\overline{\mathbf{X}}_T - \overline{\mathbf{X}}_S)\hat{\beta}_T}_{\text{explained part}} + \underbrace{\overline{\mathbf{X}}_S(\hat{\beta}_T - \hat{\beta}_S)}_{\text{unexplained part}} + \underbrace{(\hat{\theta}_T\hat{\lambda}_T - \hat{\theta}_S\hat{\lambda}_S)}_{\text{selectivity}} \qquad (10)$$

[9] Alternative approaches assign some weights to each group: Reimers (1983) proposed to use mean coefficients between low and high outcome groups; Cotton (1988) proposed to weight the coefficients by group size; Neumark (1988) proposed to estimate a pooled model over both groups.

The last term on the right-hand side of the equation measures the contribution of selection effects to the observed height-wage-gap. The extent of discrimination is still explained by the magnitude of the unexplained part.

Table 8 presents the result of the decomposition analysis. There is indeed wage discrimination by body height in the European labor markets and it is larger for female than for male workers. Slightly less than half (ca. 45 percent) of the wage gap between short and tall male workers can be ascribed to discrimination, whereas circa 55 percent of the gap is due to differences in endowments. In the case of women, circa 66 percent of the height wage gap is due to discrimination, whereas only 34 percent is due to differences in endowments. A recent study of Hübler (2006) on Germany also found larger wage discrimination for women than for men, though the magnitude of discrimination estimated there is smaller.[10]

Table 8. Blinder-Oaxaca wage decomposition

	Men	Women
Mean prediction (tall)	2.779	2.554
Mean prediction (short)	2.647	2.489
Raw differential (R)	0.133	0.065
- due to endowments (E)	0.037	0.012
- due to coefficients (C)	0.060	0.043
- due to interaction (CE)	0.036	0.010
Endowments as % total ((E+CE)/R)	55.2	33.8
Discrimination as % total (C/R)	44.8	66.2

Note: Wage decomposition for women is adjusted for sample selection.

3.5 Occupational sorting

According to a model elaborated by Case and Paxson (2006), if the correlation between height and cognitive abilities is large enough, taller individuals are expected to sort into occupations for which cognitive functions are more important, whereas shorter people would select into occupations with more repetitive and possibly manual tasks. Taller people have a comparative advantage for jobs where more intellectual abilities are required, and since

[10] In that case the extent of discrimination for male workers is 28.2 percent whereas for women is 55.3.

workers choose occupations where they can obtain the highest return, occupational sorting is expected in the labor market. Case and Paxson tested occupational sorting using data from the US National Health Interview Survey containing people aged 18-65 years. They found that, compared to "laborers" (a broad category characterized by high level of physical strength and low level of intelligence), a one-inch increase in male height increases the odds of being a professional by 9.5 percent.[11] Hamermesh and Biddle (1994) tested whether physical beauty plays also a role in occupational sorting, that is, whether people with above-average beauty sort into those occupations where the look is likely to enhance productivity. Hamermesh and Biddle cannot provide substantial evidence of occupational sorting by beauty.[12]

We hypothesize that occupational sorting by height can also have other explanations. As suggested by some literature in applied psychology (Judge and Cable, 2004; Dunifon and Duncan, 1998), physical height could capture traits such as leadership and self-esteem which for obvious reasons cannot be included in the regression analysis. On the other side, employers could have *a priori* preferences for taller workers as body height is believed to signal, rightly or wrongly, higher productivity.[13] In this sense, we test whether body height plays a role in occupational sorting once controls for cognitive functions are introduced in the regression analysis. Similarly to Case and Paxson (2006) we define four occupational categories according to the level of intellectual skills required with respect to physical strength. The measures of skill requirements are drawn from the Dictionary of Occupational Titles (DOT). In the first category, which is the one with the highest requirement for intellectual capabilities, we include managers, professionals, and highly skilled technicians. In the second category we included clerks, service-, shop-, market-sales workers, and crafts. In the third category there are skilled agricultural, trade workers and machine operators. In the last category we find unskilled individuals employed in elementary occupations.[14] Regarding our male sample, 52 percent of the workers are in the

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[11] Case and Paxson (2006), p.29

[12] Hamermesh and Biddle (1994), p.1189-1192.

[13] This is related to what Judge and Cable (2004) term social-esteem.

[14] For a more detailed description of the occupations you are referred to the International standard Classification of Occupations (ISCO) at http://www.ilo.org/public/english/bureau/stat/isco/isco88/major.htm.

first category, 27 percent in the second, 14 percent in the third, and the remaining 7 percent in the fourth category. As typically done in such a framework, we estimate a multinomial logit model which allows computing the probabilities of being in each of the four labor outcomes.

$$\Pr(Y = j) = \frac{\exp(\beta_k^j x_k)}{\sum_{j=1}^{4} \exp(\beta_k^j x_k)}, \quad where \;\; j = 1, 2, ..., 4 \;\; and \;\; k = 1, ..., i, ..., K \tag{11}$$

The estimated coefficients are displayed as relative risk ratios (RRR), where category 1 (most intellectual jobs) is the reference group. For example the relative risk ratio for a one unit change in the variable x_i for the occupational category 4 (relative to category 1) would be the following:

$$RRR_i^4 = \exp(\beta_i^4) = \frac{\exp(\beta_1^4 x_1 + ... + \beta_i^4 x_i + ... + \beta_K^4 x_K)}{\exp(\beta_1^4 x_1 + ... + \beta_i^4 (x_i + 1) + ... + \beta_K^4 x_K)} \tag{12}$$

The coefficient is then interpreted as the effect of a unitary change of the independent variable on the probability of being in occupational category *j* with respect to category 1.

3.5.1 Estimates of male occupational sorting

The independent variables included in the occupational sorting model are age, years of education, the usual anthropometric measures of height, BMI, self-reported health status, and the controls for cognitive skills. We also included the industry in which the individual reported to work as we treat the working sector as a proxy for the field of studies of the individual, which in turn is a possible important determinant of occupational sorting.[15] We estimate separate sorting model for employees and self-employed. As we include proxies for intelligence (cognitive functions), an independent effect of height on occupational outcome would suggest an interpretation in favor of height discrimination. Furthermore,

[15] Anyway, the inclusion of the set of industrial sectors does not change qualitatively our results.

the comparison with the group of self-employed might help to understand whether height has an independent effect, or rather, it is the result of a discriminatory behavior from employers.

The coefficients linked to the height variable estimated for the employees group are all highly significant and increase across the occupational categories (table 9).[16] The results are interpreted as follows: for a man whose height is below the median, the "risk" of being in occupational category 2 (or 3) is circa 50 percent higher compared to category 1; the risk of being in category 4 is 87 percent higher. Also the set of coefficients linked to cognitive functions are highly significant and indicate that those with more cognitive skills have higher probability of ending up in positions which require higher intellectual capabilities. Thus, height plays a significant role in occupational sorting, net of its correlation with cognitive functions. Our estimates can then be interpreted in two ways: *(i)* height has an independent effect as it is a proxy for unobserved characteristics such as leadership or self-esteem which play a major role in occupational sorting; *(ii)* there is statistical discrimination as employers have an *a priori* preference for taller workers for positions where leadership and motivations are required. The comparison of the results for employees with those for the self-employed suggests the second explanation, namely that employers discriminate by height. In fact, the estimates for self-employed show that height plays no role in occupational sorting. Admittedly, the sample size for the self-employed is much smaller and also the coefficients for cognitive functions are not statistically significant. Nevertheless, the finding that height plays no role for the self-employed occupational sorting cannot be ignored. In synthesis, we can provide substantive evidence that body height, independently on cognitive abilities, plays a major role in occupational sorting only in the employee group.

The method of recycled predictions provides further help for the interpretation of the results. This method consists of varying the characteristics of interest—in our case body height—across the regression sample and then averaging the predictions.

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[16] Please remember that the four categories were generated according to the amount of intellectual abilities required: category 1 is for the most intellectual jobs, while category 4 is for the most manual jobs.

Table 9. Estimates of occupational sorting model (men)

Variables	Employees			Self-employed		
	Cat. 2	Cat. 3	Cat. 4	Cat. 2	Cat. 3	Cat. 4
Age	1.065	1.533	1.108	0.994	1.054	0.862
	[0.320]	[0.743]	[0.527]	[0.016]	[0.932]	[0.045]
Years of education	0.769***	0.698***	0.673***	0.826***	0.751***	0.868***
	[0.022]	[0.022]	[0.025]	[0.023]	[0.042]	[0.071]
Married	0.686*	0.546***	0.504***	1.232	0.835	0.489
	[0.139]	[0.124]	0.123	[0.313]	[0.290]	[0.272]
Anthropometric variables						
Short (below median)	**1.508*****	**1.508*****	**1.870*****	**1.127**	**0.930**	**1.908**
	[0.183]	**[0.069]**	**[0.292]**	**[0.159]**	**[0.193]**	**[1.341]**
Cognitive functions						
Memory	0.736**	0.623***	0.526***	0.890	1.071	0.272*
	[0.101]	[0.087]	[0.052]	[0.118]	[0.346]	[0.192]
Fluency	0.977*	0.974*	0.947***	0.994	1.014	0.982
	[0.012]	[0.014]	[0.011]	[0.016]	[0.012]	[0.038]
Numeracy	0.777*	0.545***	0.706	1.129	0.932	1.072
	[0.107]	[0.076]	[0.176]	[0.262]	[0.150]	[0.831]
Country fixed effects		yes			yes	
Industry controls		yes			no	
Place of residence		yes			yes	
Health variables		yes			yes	
Observations		2,756			847	
Pseudo R^2		0.256			0.143	

Note: Robust standard errors in brackets. Standard errors are adjusted for clustering where the countries constitute the clusters. The coefficients are presented as relative risk ratios. Given the extremely low number of male underweight people, in this regression they have been put together with people of normal weight.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

We first "pretend" that the whole regression sample is made of short people, holding all other characteristics constant, and we compute the probabilities for each of the four outcomes (column "Short", table 10). Then, we change the value of height "making" all the individuals tall and, always holding the other characteristics constant, we compute the probabilities of each outcome (column

"Tall", table 10). The difference between the two distributions of probability shows the effect of height. As individuals get taller the occupational distribution shifts slightly towards more intellectual jobs. The probability of being in category 1 rises from 48 to 55 percent as physical stature goes from below to above the median. Instead, the probability of falling in the last occupational category diminishes by 3 percentage points, from 8 to 6 percent.

Table 10. Predicted male occupational outcomes among short and tall men

Occupational category	Short	Tall
1 (intellectual)	0.48	0.55
2	0.32	0.28
3	0.12	0.11
4 (manual)	0.08	0.06

Source: Multinomial logit regression of table 9, "Employees" sub-sample.

Since we are pooling 11 European countries which are quite heterogeneous, we test whether height effects change across macro-areas running separate multinomial models. The estimated RRRs for the variable height are displayed in table 11. Almost all the coefficients are statistically significant but the effect of height in the three macro-areas present different patterns. In figure 5 we show how the probability of being in the extreme occupational categories 1 and 4 changes as height varies. [17] The plots are computed for a married man aged 55 with 12 years of education and average score on cognitive tests. The plot on the left shows how the probability of ending up in a more intellectual job increases with height: The curves for Nordic and Continental countries have a steeper slope with respect to the Mediterranean countries. It indicates that the effect of height on occupational sorting is stronger in the former countries. On the right panel, we can see how the probability of being in a more manual occupation decreases as height increases. The negative effect of height is evident in the Continental and in the Nordic countries, whereas the effect is practically zero in the Mediterranean countries. In synthesis, the effect of male height on

[17] In order to generate such plots we run multinomial logit models for the three macro-areas using height as a continuous variable.

occupational sorting is larger in Nordic and Continental countries compared to Mediterranean ones.

Table 11. Relative risk ratio for height by macro-area

Macro-area	RRR (cat. 2)	RRR (cat. 3)	RRR (cat. 4)	Observations
Nordic	1.98***	1.38***	1.76**	988
Continental	1.40***	1.70***	1.96***	957
Mediterranean	1.25	1.60***	1.89***	811

Note: Occupational category 1 is the base group.

* p < 0.10, ** p < 0.05, *** p< 0.01.

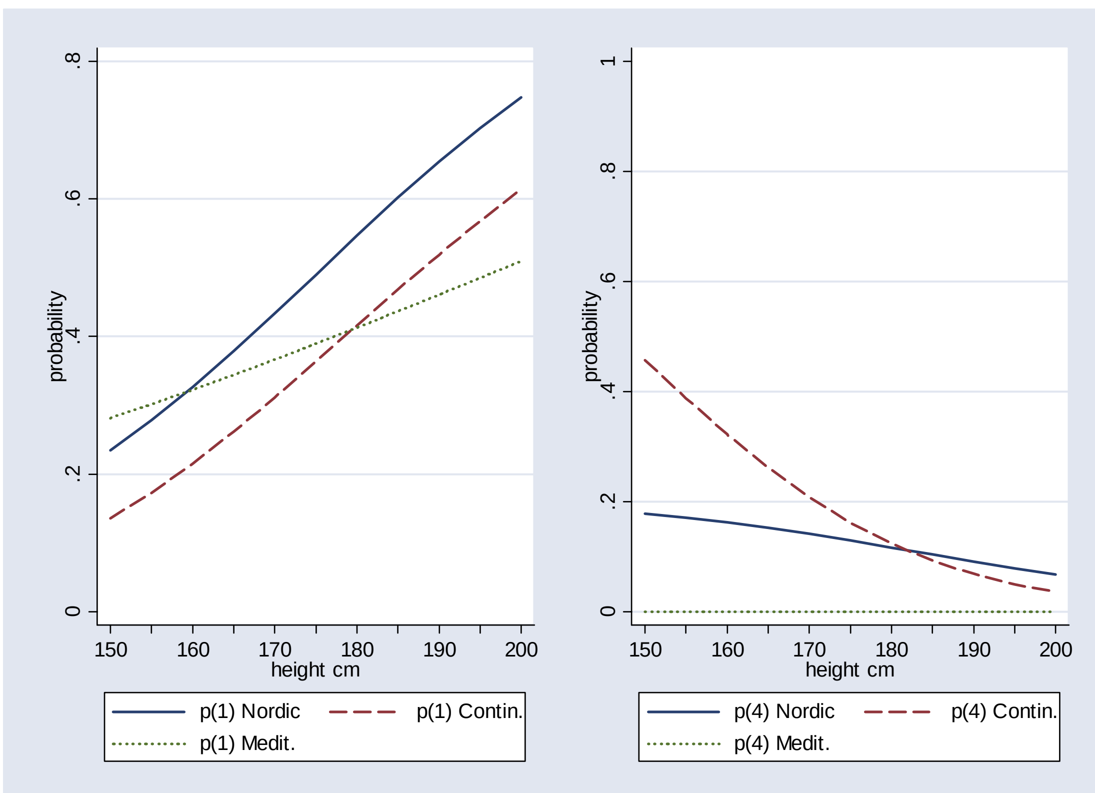

Figure 5. Height and predicted probabilities of category 1 (left panel) and 4 (right panel)

3.5.2 Female occupational sorting

The analysis of occupational sorting for women is affected by two complicating factors: *(i)* the female skill-job-structure and *(ii)* sample selection. With regard to the first problem, female occupations in our sample are concentrated among professionals (e.g. managers and teachers), high-skilled technicians (e.g. administrative secretaries), service workers (e.g. shop assistants), and clerks (e.g. office secretaries). We therefore follow a different scheme than the one adopted for the male sub-sample to select occupational categories by degrees of cognitive abilities. In order to distinguish between more and less intellectual occupations we reduce the occupational outcome to a binary category. The dependent variable of our model takes on value one if the woman's occupation belongs to managerial positions, zero otherwise.

Proceeding in this way we also simplify the second problem, namely sample selection. Correcting for sample selection when the basic regression is a choice model with more than two outcomes is econometrically non-trivial. Instead, having a probit as a basic model simplifies notably the estimation: though the Heckman two-step procedure cannot be applied since the basic model is non-linear, the binary selection equation can still be estimated via maximum likelihood procedure.[18] The identifying variables used in this estimation are those used in the econometric model of section 3.3.2. For the basic regression the controls for industry are here discarded as many of them perfectly predict one of the two outcomes. Due to the small number of women who reported being self-employed we cannot perform separate regressions for the two groups as in the previous section but we focus exclusively on employees. The estimates of table 12 show that height does not play a role in female occupational sorting. This result is robust to different specifications of the dependent variable, namely the inclusion of other professionals in the dependent variable. Therefore height in the female labor market has no effect on occupational sorting. Results of the selection model are similar to the estimates of the log-wage model: age and education have a positive effect on labor force participation, whereas marital status and number of children at home have a negative impact.

[18] See Greene (2003).

Table 12. Binary occupational sorting model with sample-selection (women)

	Dep.var.: prob. of being manager	Selection equation
Other income		0.000
		[0.001]
Children at home		-0.084***
		[0.023]
Age	0.110	0.466***
	[0.075]	[0.076]
Age squared	-0.001*	-0.005***
	[0.001]	[0.001]
Years of education	0.158***	0.088***
	[0.013]	[0.017]
Tertiary education	-0.583***	
	[0.206]	
Married	-0.016	-0.462***
	[0.095]	[0.067]
	[0.112]	[0.054]
Anthropometric variables		
Short (below median)	**-0.132**	**0.074***
	[0.094]	[0.040]
Underweight	-0.625*	-0.080
	[0.369]	[0.122]
Overweight	0.020	-0.013
	[0.050]	[0.042]
Obese	0.079	-0.060
	[0.124]	[0.111]
Cognitive functions		
Memory	0.020	-0.030
	[0.102]	[0.036]
Fluency	0.002	0.012***
	[0.005]	[0.004]
Numeracy	0.236**	0.060
	[0.100]	[0.045]
Country fixed-effect	yes	yes
Place of residence	yes	yes
Health status	yes	yes
Constant	-6.584***	-10.698***
	[2.028]	[1.864]
Observations	5,823	

Note: Standard errors in brackets. * p < 0.10, ** p < 0.05, *** p< 0.01.

3.6 Conclusion

We estimated a hedonic wage model in order to test the existence of wage differentials by height where we account for unobserved ability using a set of test scores on cognitive functions. We show that accounting for industry, occupation, and cognitive functions reduces the impact of male height on wages only by two percentage points, from 9 to 7 percent. A slightly smaller effect is found for women after adjusting for sample selection. The net effect of height on wages has two non-mutually-exclusive possible explanations: *(i)* further than for cognitive skills, height is a proxy for other unobserved characteristics such as leadership and self-esteem which have an independent impact on wages; *(ii)* employers on the basis of some *a priori* belief discriminate in favor of tall workers. Wage decomposition analysis shows that circa 45 percent of the wage-gap between short and tall male workers can be attributed to discrimination, 66 percent in the case of women.

We provide substantive evidence of a positive correlation between physical stature and cognitive abilities. Case and Paxson (2006) argue that the height-wage-differential stems from the fact that the skills associated with taller men (intelligence) have a higher financial reward with respect to the distinctive skills of shorter individuals. We tested whether height plays a role in occupational sorting even after controlling for cognitive skills. Similarly to Case and Paxson (2006) we estimated a model with four occupational categories generated according to the degree of intellectual abilities required. Net of cognitive skills, which resulted as being important determinants of occupational sorting, we show that taller people have a significantly higher probability of being in occupations in which more intellectual abilities, supervisory function, and authority are required (e.g. managers). Instead, shorter workers tend to sort into occupations with more repetitive tasks where less cognitive functions are required (e.g. doorkeeper). The fact that height has an effect on occupational sorting even after accounting for cognitive functions, and the finding that height has no effect for the self-employed, seem to suggest that employers discriminate on the basis of body height. Moreover, separate estimations show that the effect of height on occupational sorting is larger in Nordic and Continental countries compared to Spain, France, Italy, and Greece.

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Ich versichere hiermit eidesstattlich, dass ich die vorliegende Arbeit selbständig und ohne fremde Hilfe verfasst habe. Die aus fremden Quellen direkt oder indirekt übernommenen Gedanken sowie mir gegebene Anregungen sind als solche kenntlich gemacht. Die Arbeit wurde bisher keiner anderen Prüfungsbehörde vorgelegt und auch noch nicht veröffentlicht.

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