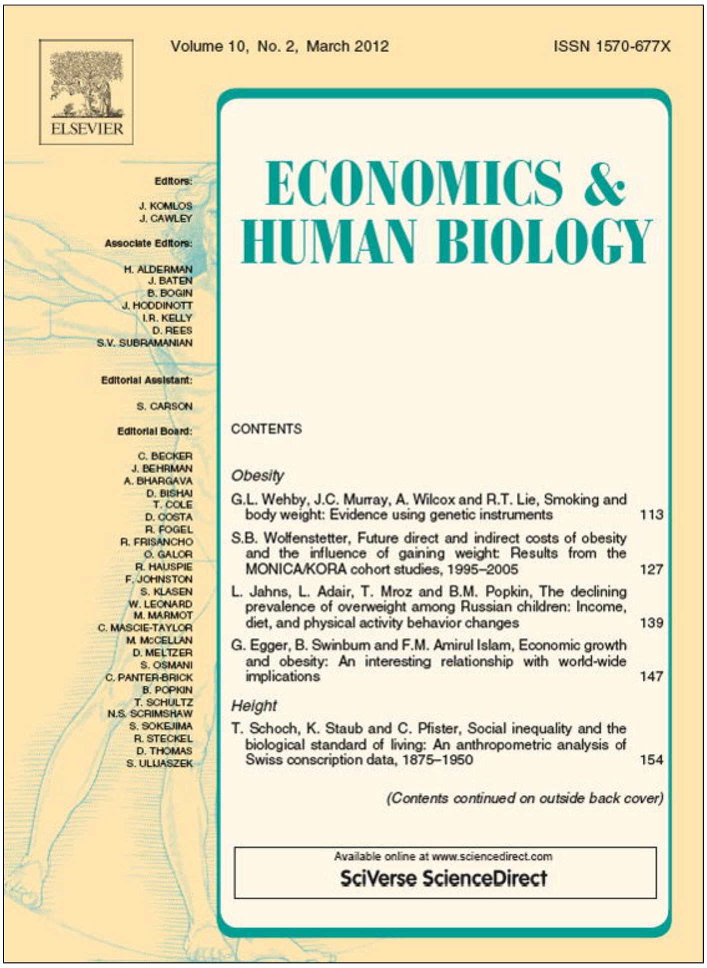
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Social inequality and the biological standard of living: An anthropometric analysis of Swiss conscription data, 1875–1950

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ABSTRACT

We analyze the first representative series of individual measurements of the height of Swiss conscripts for the years 1875–1950. We find that average height followed a general upward time trend, but the economic downturn in the 1880s slowed down the increase in rural average-heights while the economic crisis subsequent to World War I had only a minor effect. Moreover, social-class affiliation was the most important determinant of differences in the biological standard of living, with class and regional disparities remaining constant, for the most part, during the observation period. Lower-class individuals' ability to overcome economic stress was limited, with the result that their biological standard of living, as reflected in the cyclicality of deviations from average height, was likely to be affected by cycles in economic activity.

1. Introduction

Scholars have long debated the evolution of living standards both during and after industrialization using traditional data, such as per capita income and real wages, but they have yet failed to reach a consensus. The traditional monetary measures of economic and social performance contribute to an understanding of levels and changes in well-being at the aggregate level but fail to capture several important aspects of the quality of life, such as socio-economic inequality and health in the broadest sense (Steckel and Floud, 1997; Engerman, 1997; Steckel, 1995; Komlos and Baten, 2004; Komlos, 1985). Stature and thus the biological standard of living, on the other hand, permit one to analyze the overall distribution of welfare and thus to discover patterns of inequality among and within groups. Anthropometry also provides the most widespread method for the assessment of nutritional conditions (Expert Committee, 1995). More specifically, by means of measurements not only of height

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but also of chest and upper-arm circumference, one obtains a snapshot of biological well-being and of demographic behavior – for example, household formation and childbearing – cognitive development, and work capacity (Eveleth and Tanner, 1990; Bogin, 1999), and can thereby identify social groups at risk of functional outcomes in terms of morbidity and mortality (Fogel, 1994, 2004; Gorstein et al., 1994; Koch, 2011).

Our approach is to contrast findings established by traditional measures of human welfare with data related to the biological standard of living. We provide the first annual conscript height data for Switzerland at the individual level for the period 1875–1950.[2] We focus on secular trends and trace differences in the biological standard of living among social groups with regard to regional and temporal patterns.

We also analyze the additional anthropometric measurements of chest circumference and upper-arm circumference and establish a multidimensional representation of the human body. These measurements contribute to our understanding of socio-economic, environmental, and lifestyle factors on body proportions and thus on biological well-being. Finally, we turn to cycles in the average-height series, computed for socio-economic and regional populations separately, and analyze patterns of cyclical deviations from a time trend. These height cycles and their co-movement are explored with regard to two measures of business activity: real wages and GDP (Woitek, 2003; Sunder and Woitek, 2005; Brabec, 2005). We follow Bengtsson's (2004) suggestion that because the ability of lower-class individuals to overcome economic stress is limited, their biological standard of living is likely to be affected by business cycles.

2. Standard of living—measuring social performance

Most of the commonly used concepts of the standard of living focus on goods themselves or on the ability to access them, which is generally measured by income. However, both income and goods are inadequate as living-standard measures because needs and wants vary according to personal and societal characteristics (Sen, 1987, 1997). With such measures the distribution within the society and the family is unclear. A study of the biological standard of living in 19th- and 20th-century Switzerland offers the possibility of expanding our knowledge about a country whose anthropometric history has not been extensively studied (Komlos, 1994; Steckel, 1995; Staub, 2010; Kues, 2010).

2.1. The biological standard of living

Height not only serves as an indicator for nutritional well-being but also has been established as an important standard-of-living measure (Komlos, 1989; Komlos and Baur, 2004). Average height is conceptualized as the "biological standard of living", highlighting the distinction from common (usually monetary) concepts of the standard of living (Komlos, 1987, 1989, 1994). The average adult height of a population serves as a measure of the population's nutritional status from birth through adolescence (including episodes of deprivation and catch-up growth), reflecting environmental conditions (Eveleth and Tanner, 1990; Bogin, 1999; Steckel, 2008).[3] Nutritional status is defined as the balance among the intake of nutrients, the epidemiological environment, and claims on nutrient intake, which stem from the basic maintenance (metabolic rate), and from energy consumption for occupational and discretionary activities (Eveleth and Tanner, 1990; Kim, 2000). Genes determine approximately 80% of the variation of the height of an individual; yet differences in average height across most populations are widely attributable to environmental factors. The living environment limits the extent to which individuals exploit their genetic potential (Bogin, 1999; Cole, 2003; McEvoy and Visscher, 2009). Consequently, human growth is related to economic variables such as per capita income and food prices. Height has been found to increase with social status (Steckel, 1983; Komlos, 1994; Baten, 2000). Moreover, nutrition, infection, and immunity are closely related, and changes in one component affect the other two. For example, malnutrition is associated with decreased immunity and increased susceptibility to infections (Lunn, 1991; Cole, 2003). Stunted growth has functional implications for longevity, cognitive development, earnings and work capacity (Fogel, 2004). Physical stature is thus a useful supplementary indicator of well-being (not a substitute for conventional monetary indicators), providing a more nuanced, spatially and socially detailed view of the impact of dynamic economic processes on the quality of life than does income or GDP per capita. Moreover, it is sensitive to the distribution of income whereas GDP is not.

2.2. Anthropometric history of Switzerland

No comprehensive anthropometric study of the development of the biological standard of living in Switzerland has yet been published. Kues (2007) analyzed 2868 attestation records of the British Swiss Legion gathered by the British War Office in London between 1855 and 1856, during the Crimean War, but his sample was not representative of the Swiss population. Rühli et al. (2008) analyzed the 2005 Armed Forces census (birth years 1984–1986), covering approximately 80% of the birth cohort of the 19-year-old male Swiss population. They reported significant height variation both among the Swiss cantons and among occupational groups. Moreover, Staub et al. (2011a) report the findings of Eduard Mallet's 1835 published but today nearly forgotten study of the average height of Genevan conscripts. Mallet found that 20-years-old conscripts of Geneva, born between 1805 and 1814, were relatively tall for the time, being taller than those of France and Belgium. Staub et al. (2011b) show that in 2009,

[2] For the second half of the 20th century, see Kues (2010).

[3] Considerable attention has been paid to the first three years of life, deemed the most influential (Lunn, 1991; Steckel, 1983; Baten, 2000).

a 19-year-old Swiss conscript was on average 178.17 cm tall—a full 14.8 cm taller than his 1878 counterpart (Staub, 2010).

3. Data, recruitment and regions

Military-conscription record lists are representative in that they enable us to analyze the country's young male population as a whole, since the subpopulation of conscripts is almost identical with that of the entire 19-year-old male population.[4]

3.1. Military recruitment in Switzerland, 1875–1950

In the course of the foundation of the Swiss Confederation, in 1848, the system of universal male conscription was proclaimed in the constitution and led to a military organization that specified that all young men were to be called to arms in the year they turned 19. Regional military authorities compiled annual conscription lists of the relevant cohort of resident males with Swiss citizenship.[5] This recruitment procedure began in 1875 and remained virtually unchanged until 1950 (Kurz, 1985).[6]

Conscripts were required to appear before regional military-draft councils, which ruled on any claims for exemption or deferment and conducted physical examinations to ascertain whether a conscript was fit for military service and met certain formal requirements, such as a minimum-height standard (Kurz, 1985). Those whose physical condition was deemed insufficient but the possibility of improvement existed were declared subject to re-examination and their conscription was deferred to a subsequent draft.[7] The diagnostic findings and the measurements of height, chest circumference, and upper-arm circumference (by 1882) for all conscripts – whether exempted, deferred, or capable of serving – were recorded in annual registers called *Sanitarische Kontrolle* (medical examinations), along with each conscript's full name, year of birth, place of residence, and (in detail) occupation.[8]

Between 1875 and 1914 the conscription process also included a *Pädagogische Prüfung*, or educational test (Lustenberger, 1996).[9] All conscripts judged fit for service – in regard to both their physical fitness and their educational level – and therefore denoted as recruits were assigned to a military unit. Their personal data were transcribed into the *Rekrutierungskontrolle* (recruits' control book). Estimations based on samples from the *Rekrutierungskontrolle* must therefore take into account truncation problems.

3.2. Population definition and geographical regions

In the 19th and 20th centuries, Switzerland underwent large-scale social and economic changes in connection with industrialization, urbanization, and the expansion of the service sector. To capture these transformations, we analyze data from three cities, Basel, Bern, and Zurich, and from the rural canton of Bern.[10] The three cities exhibit distinct development patterns and particular occupational and economic structures (Head-König, 1998). By the start of the 19th century Zurich was already the country's largest and economically most important city. Up until 1850 Basel-city – which comprises the city of Basel and two tiny rural municipalities – had grown at a similar rate, but its population never reached that of Zurich's. Instead, having begun as a typical trading town, Basel became a major chemical and pharmaceutical center. In contrast, by 1850 the city of Bern had fallen behind Zurich and Basel in both population growth and economic potential. The employment structure of Bern was dominated by small-scale industry, in particular the public-service sector and merchants (Head-König, 1998).

To contrast the trajectories of welfare in the three cities, we consider the canton of Bern, a typical rural region. The canton of Bern encompasses a dozen small towns, but the overwhelming majority of its municipalities are small and rural that failed to modernize, on account of a lack of employment opportunities and commercial production that was not competitively priced for the global market (Pfister, 1995).

The definition of the population is identical for all of the cantons. The frame population comprises all those Swiss males called to arms at the age of 19 in the canton in which they resided that had not previously been called to arms.[11]

[4] For instance, in Basel, 386 19-year-old males were called to arms in 1878 (year of birth 1859). The same birth cohort counted 372 21-year-old Swiss males in the 1880 census (Kinkerlin, 1980). The data in the conscription records are almost identical with those for the entire Swiss male population. The difference in the counts between conscription and the census may be due to migration or death.

[5] Swiss citizenship is acquired uniquely by descent through father.

[6] There was one brief exception, during World War II, when the normal age of recruitment was decreased from 19 to 18 years, the recruitment standards remained unchanged.

[7] Most deferments were for an insufficiently robust constitution, a condition judged by chest circumference and typically associated with above-average height. However, other causes of deferment may have been correlated with below-average stature, since poor nutrition renders an individual susceptible to disease (Mühleberg, 1951).

[8] All biometric characteristics are measured in centimeters (cm). The height and chest-circumference data were rounded to the nearest half centimeter (but for some years to 0.2 cm). An examination of the height distribution indicates a propensity to round to the nearest integer value. The datum for the upper-arm circumference was rounded to the nearest integer value.

[9] The educational examination consisted mainly of tests of literacy and numeracy skills and the basics of civics, history, and geography.

[10] The choice of the three cantons is mainly motivated by the fact that only 15 of the 26 Swiss cantons have preserved conscription data. Moreover, among these 15 cantons only the cantonal archives of Fribourg, Geneva, Valais, Basel, Bern, and Zurich have kept records of sufficient scope and duration. In addition, financial constraints obliged us to omit the French-speaking cantons.

[11] Since the population frame comprises only those conscripts being recruited for the first time (that is, excludes those being re-examined), the samples are independent. Consequently, we do not have to deal with correlation structures among the samples, which would otherwise arise.

3.3. Sample design and data collection

Because the data for Basel are from the *Sanitarische Kontrolle*, preserved in the cantonal archive,[12] the samples do not suffer from truncation and other selection-bias problems. The sample design consists of a series of simple random samplings without replacement with a fixed sample size of $n = 150$ for each year of measurement (1875–1935). Because the sample size is fixed, the sampling fraction varies with the population size. The sampling fraction, about 40% during the 1880s, begins to decrease at the start of the 20th century when the city's population increases. This sampling design was also used for Bern canton and city.

Because the *Sanitarische Kontrolle* volumes have not been preserved in Bern's cantonal archive[13], our Bern-canton samples derive from the extant *Rekrutierungskontrolle* volumes spanning the years 1875–1938. As a result, all of the height measurements (and those for chest and upper arm circumference) suffer from truncation.

The data for Zurich are based on annual samples from the *Rekrutierungskontrolle*, preserved in the city archive.[14] Height measurements are available for the years 1904–1950. For each year, we applied a Bernoulli sampling scheme (BER)[15] with an expected sample size $n = 200$. In addition, we obtained another annual series; our purpose in doing so was to define differences in the biological standard of living between conscripts with working class occupations, and students and merchants. These additional samples are based on a BER sampling design stratified according to social class (by means of the "occupation" classification) with an expected sample size of $n = 25$ for each the two classes and the year of measurement. For analysis, the annual samples from the two sources were merged in order to broaden the database, leading to an over-representation of the aforementioned classes. However, because the sample-selection process depends only on social-class affiliation (in the exploratory samples), an inverse-probability-weighted estimator with weights according to a post-stratification on the social class will be (approximately) design-unbiased (Särndal et al., 1992). Post-stratification was carried out by stratifying on the social class and the year of measurement, thereby using data from four complete conscription registers of the yearly population of recruits, as recorded in the Rekrutierungskontrolle. These enumerations were distributed equally over the entire period.[16] Given the post-stratification weights, we applied a Horvitz–Thompson-type maximum pseudo-likelihood approach to the truncated regression models (Schoch, 2009).[17] Moreover, in Section 5, we use data from a unique complete enumeration of the 1914 birth cohort (year of measurement 1933) recorded in the Zurich *Sanitarische Kontrolle*.

3.4. Data preparation and coding

By means of the job titles, each of the conscripts was assigned to a social stratum on the basis of the classifications established by Schüren (1989). The social hierarchy comprises six levels, each defined by a distinctive interaction among wealth, prestige, and power. This concept of class affiliation enables a more precise classification than does one based on occupation alone. Moreover, because intergenerational social mobility in the late 19th and early 20th centuries was limited,[18] the social status of a conscript is (on average) a good proxy for his social background and thus an indication of the family environment. Consequently, the social standing of a conscript at the time of measurement permits inference with regard to his nutritional experience during his growing years. We reduced the six social strata proposed by Schüren (1989) to three: his strata 1 and 2 constitute the lower class, 3 and 4 constitute the middle class, and 5 and 6 constitute the upper class.[19] This reduction guarantees a sufficient number of observations in each stratum.

4. Social inequality and the biological standard of living

As early as the end of the 19th century, Switzerland's GDP put it among the wealthiest nations in Europe

[12] Address: Staatsarchiv des Kantons Basel-Stadt, Martinsgasse 2, CH-4001 Basel. www.staatsarchiv.bs.ch.

[13] Address: Staatsarchiv des Kantons Bern, Falkenplatz 4, Postfach 8428, CH-3001 Bern. URL: www.be.ch/staatsarchiv.

[14] Address: Stadtarchiv Zurich, Neumarkt 4, Haus zum unteren Rech, CH-8001 Zurich. URL: www.stadt-zuerich.ch/stadtarchiv.

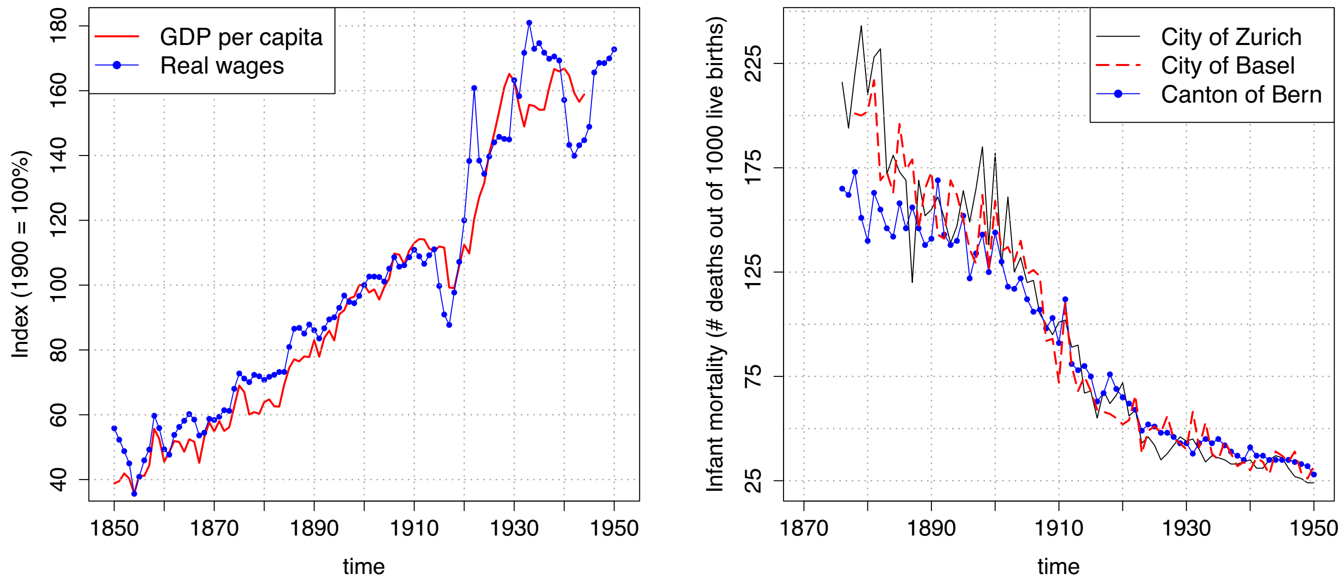
[15] In finite population sampling, BER is (in contrast to the usual simple random sampling) a sampling process where an independent Bernoulli trial (experiment with only two outcomes) determines whether an element becomes part of the sample. Because each element of the population is considered separately for the sample, the sample size is not fixed but follows a binomial distribution. Due to the independence of the sampling between the units, the samples can be drawn according to a fully list-sequential procedure. As a result of the sequential drawing BER is extremely simple and time-saving; see e.g., Särndal et al. (1992).

[16] Due to the fact that social affiliation at the beginning of the 20th century was quite stable (see also Footnote 18) post-stratification on population values, smoothly interpolated between the enumerations, seems to be a reasonable approach.

[17] Because the data from the BER and the stratified BER sample have been merged, the probability for a particular conscript being sampled is not the same for all conscripts. This is to say that the sample inclusion probability depends on whether a conscript has been sampled into BER or the stratified BER sample (and for the latter, also on the strata). As a result, all standard estimators (such as e.g., least squares regression) are biased since they are based on the assumption of independent and identically distributed data. A Horvitz-Thompson-type maximum pseudo-likelihood approach (with weights from a post-stratification), on the other hand, yields approximately unbiased estimators (Schoch, 2009).

[18] Intergenerational social mobility - calculated according to the relationship between the social status (on a six-unit scale, ranging from 1:lowest to 6:highest) of the conscript and that of his father (measured at the time of the son's conscription) - was very limited for the city of Basel in 1877. The measure of association for ordinal data, Goodman and Kruskal's γ, takes a value of 0.51. In 1909 it is 0.42, indicating a relaxation of the class barriers. The analysis of the mobility table shows a slight upward mobility for the upper middle class and also – but to a lesser extent – for the lower middle class in 1909. That social mobility in the late 19th and beginning 20th century was limited becomes apparent when one compares it with that of modern societies: Kaelble (1997) reports a Goodman and Kruskal's γ of 0.109 for Germany in the 1980s. It is noteworthy that the values of Kendall's τ_b are very similar. (Data: register of the schoolboys in the canton of Basel-city. Method: see Hout (1986).)

[19] According to Schüren (1989), students (5.31% of the population during the period 1875–1950) were assigned to the upper class.



(a) Trajectories of GDP per capita and real wages, 1850–1950

(b) Trajectories of infant mortality, 1850–1950

Fig. 1. Temporal trajectories of traditional measures of human welfare: GDP per capita, average real wage, and infant mortality. *Panel a):* Annual GDP based on Maddison (2001) and annual average real wages from Studer and Schuppli (2008). *Panel b):* Annual average of infant mortality data from Siegenthaler (1996).

(Siegenthaler, 1985; Maddison, 2001). Between 1850 and 1950, GDP per capita and the real wages (of skilled workers) follow a similar trend (Fig. 1) and increase by a factor of two but are temporarily interrupted by World War I (Studer, 2008). Aside from the war-induced decline, GDP per capita and real wages continue to increase steadily until the 1930s and are almost stationary during World War II. In addition annual infant mortality rates[20] for the cities of Basel and Zurich and for the predominantly rural canton of Bern indicate a biological component of the standard of living (Steckel, 2008). Infant mortality rate was lower in the rural canton of Bern until about 1900, but the annual pattern shows less of a decrease than that experienced by Basel and Zurich (Fig. 1). By 1902, the improvements are similar for all regions and annual variation disappeared.[21] Thus conventional (monetary as well as biological) measures of living standards describe a steady improvement – except during the two world wars – in overall well-being in Switzerland (with both measures showing an acceleration after the First World War).

4.1. Biological standard of living: time-series perspective

We computed the annual average height for the cities of Basel, Zurich, and Bern and for the rural canton of Bern accounting for the complex samples and truncation due to a minimum height requirement of 157 cm where necessary (Fig. 2). It is evident that all annual height series, except the one for Basel-city, which also has a significantly higher level, show only a slight increase until the year of measurement 1905 (year of birth 1886). By 1905, these curves diverge: Bern and Zurich begin to increase at a considerably higher growth rate than before. By 1931 (year of birth 1912), the Zurich and Basel series are equal, whereas Bern is close but did not close the gap. In fact, the rural areas of canton of Bern experienced a smaller annual rate of increase than those of Zurich and Basel and by 1905 fell clearly below the urban series. On average, height of men from Zurich increase at the fastest rate (by 1.61 cm per decade), followed by those the city of Bern, 1.19 cm, and the rural part of Bern-canton, 1.02 cm.

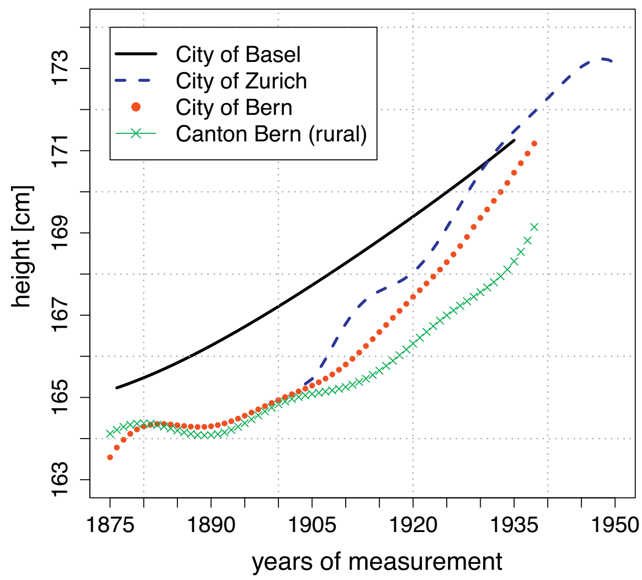


Fig. 2. Secular trends (yearly averages) of the canton Bern (1875–1938), Basel (1875–1935), and Zurich (1904–1950); all series were smoothed by local polynomial regression.

[20] Infant mortality rate is defined as the number of deaths of children below one year of age per 1,000 live births.

[21] These findings are in line with those of Head-König (1998), who shows that in 19th-century Switzerland infant mortality was generally higher in urban than in rural regions.

Heights in Basel show an average increase of 0.78 cm per decade.

The overall increase in average height was primarily due to a radical change in the typical diet of the Swiss population during the second half of the 19th century. In particular, the share of animal protein in the diet had begun to increase in the 1880s, when the massive import of cheap grain led to a substantial increase in the availability of meat. At the same time, Swiss farmers shifted the focus of production from grain to dairy products (Pfister, 1995). Overall, the daily average per capita calorie consumption increased by 18% between 1870 and 1912 (Brugger, 1985). Parallel to this dietary alteration was the establishment of a public health-care system, improved public sanitation, an increase in immunization, and improvements in work and housing conditions (Guberan, 1980; Höpflinger, 1986).

We next examine the evolution of the average-height series using the years of birth as periodization. We can identify three factors for the differences in the biological standard of living between Basel, Zurich, and Bern, and the canton of Bern. First, the economic downturn in 1880–1888 (corresponding to the years of measurement 1899–1907) caused a drastic decline in the sale of agricultural products, which in turn led to a rise in unemployment among farm workers (Gruner and Wiedmer, 1987; Pfister, 1995) and thus prevented any improvement in the biological standard of living. Furthermore, the crisis resulted in extensive migration from the countryside (Ritzmann-Blickenstorfer, 1997), whereupon the cities of Bern and Zurich, and to a lesser extend Basel (as a result of more severe restrictions on migration, (Lorenceau, 2006)) were affected. Rural–urban migration led to a surplus of short, young lower-class men in Bern and Zurich, and thus to a reduction in the average height there. Second, the diet of city dwellers contrasted sharply with that of the rural population: by the 1870s the average city dweller consumed considerably more animal protein (cf. Gruner and Wiedmer, 1987; Tanner, 1999). This increase in meat consumption may account for the increase in the biological standard of living in Bern and Zurich, closing the gap between them and Basel subsequent to the economic upturn in 1887–1888 (years of measurement 1906–1907), in contrast to the canton of Bern. Moreover, a decline in the birthrate, along with the dissemination of middle-class family ideals raised per capita resources, which could be expended on food and health care, to the benefit of children (Höpflinger, 1986; Easterlin, 2000). Third, the considerably large infant mortality in the cities, which lasted until the end of the 19th century, may have entailed a selection effect on average height. This by eliminating those infants who, being unhealthy, would have been, as a rule, relatively short had they survived, may have contributed to an increase in average height (Bozzoli et al., 2009).[22]

There were no serious declines in average height throughout the observation period (Fig. 2): unexpected, since GDP per capita and real wages declined steeply during World War I, especially toward its end, when large

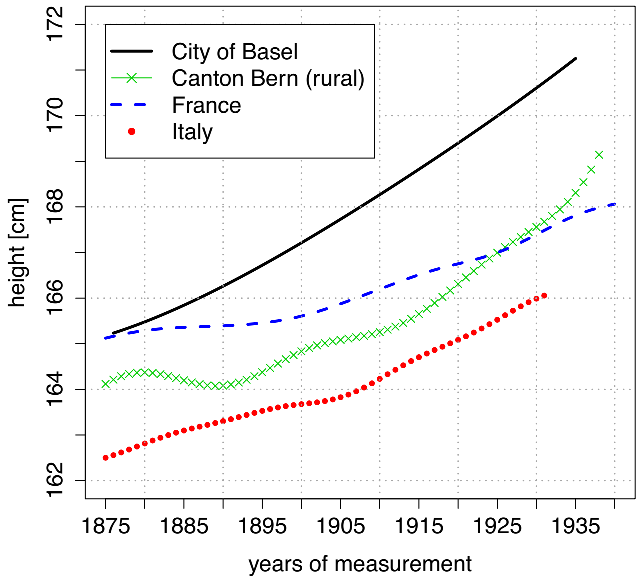


Fig. 3. Secular trends (yearly average) of Switzerland, France (van Meerten, 1990), and Italy (Federico, 2003); all series were smoothed by local polynomial regression.

portions of the population suffered from poor nutrition (Gautschi, 1988). In the city of Bern, these alterations in nutritional status had negative consequences for the overall health and, by extension, the biological growth of schoolchildren. Annual physical examinations, conducted from 1913 to 1935 by the school medic, of all 14-year-old boys and girls in the city indicate that during each of those years the percentage affected by rickets and the number of those shorter than 148 cm spiked in 1918 (Staub, 2010). However, there is considerable evidence that nutritional deficiencies were not sufficiently severe to impinge upon physical growth of the 19-year-old conscripts; moreover, catch-up growth must have eliminated the consequences of any such deficiencies. Supporting such a theory is the fact that despite the economic crisis milk and milk products remained available and affordable.[23] Moreover, government programs during the post-war era were devoted to maintaining the nutritional status of schoolchildren from families at risk of poverty, minimized malnutrition and contributed to catch-up growth.[24] Furthermore, mortality induced by the crisis (the increase in the infant-mortality curve in the canton of Bern around 1918, Fig. 1) may have been selective, affecting not just infants but also frail youth, while sparing those who were healthy and therefore tall (Bozzoli et al., 2009). Thus, one can safely conclude that the crisis of WWI

[22] We are grateful to an anonymous referee pointing this out.

[23] Until 1918 the Swiss government heavily (cross-) subsidized milk production through the export of cheese, thereby making milk affordable (Moser and Brodbeck, 2007).

[24] In 1917 and 1918, for example, the city of Bern tripled the pre-war scope of its welfare programs for schoolchildren (6 to 14 years of age); henceforth more than 30%, selected by the school medic according to need, benefited from additional daily school lunches (of milk, bread, and soup) during the winter and summer holidays at municipal camps, providing the children with plenty of outdoor exercise as well as a healthful diet (Staub, 2010).

caused an increase in infant mortality but not a decrease in the overall biological standard of living, because both catch-up growth and mortality-induced selection compensated for the negative consequences of the crisis.

A comparison of Italian (Federico, 2003) and Swiss height data indicates that the four Swiss groups examined here tended to be taller. Furthermore, men in Basel were about as tall as those in Belgian cities.[25] In addition, the biological standard of living was considerably higher in Basel-city than France (Fig. 3).

Evidently, no urban height penalty existed in 19th century Switzerland (Fig. 1), the conscripts from rural areas of canton Bern never have been taller than the conscripts from the city of Bern in the period under consideration. In general, the absence of an urban height penalty may be due to the moderate size of Swiss towns, the absence of large slums, and proximity to the milk-producing areas in the Alps (as in Bavaria; viz. Baten (1999)). In addition, the vibrant trading towns attracted the mobile element of the rural middle and upper classes, which undoubtedly contributed to an improvement in urban biological standard of living. There is overwhelming evidence that in the late 19th century many towns in central Europe – e.g., Bavaria (Baten, 1999), Belgium (Alter et al., 2004), Spain (Martìnez-Carriòn and Moreno-Làzaro, 2007), and thus Switzerland – typically did not suffer an urban height penalty.

4.2. Biological standard of living: a cross-sectional perspective

Our next analysis is based on cross-sectional regression models, with height as the dependent variable. In the case of the Basel conscription data (neither truncation nor selection effects), the regression coefficients are estimated by OLS. In the case of the conscription data of the canton of Bern (rural and urban), the estimates are obtained from the truncated normal regression model (A'Hearn, 2004; Komlos, 2004), because the height distribution suffers from left-truncation at the minimum-height requirement of 157 cm. For the conscription data in Zurich, the regression estimates are obtained by means of a Horvitz-Thompson-type truncated maximum pseudo-likelihood estimation strategy, in order to account for the non-iid data structure (post-stratification along the social strata) and the truncated height distribution (Schoch, 2009).

In Basel, the biological standard of living differed significantly among the social strata; members of the upper class were on average 3.0–5.1 cm taller than those of the lower class (column I in Table 1 and Fig. 4).[26] It is remarkable that the height differentials remained

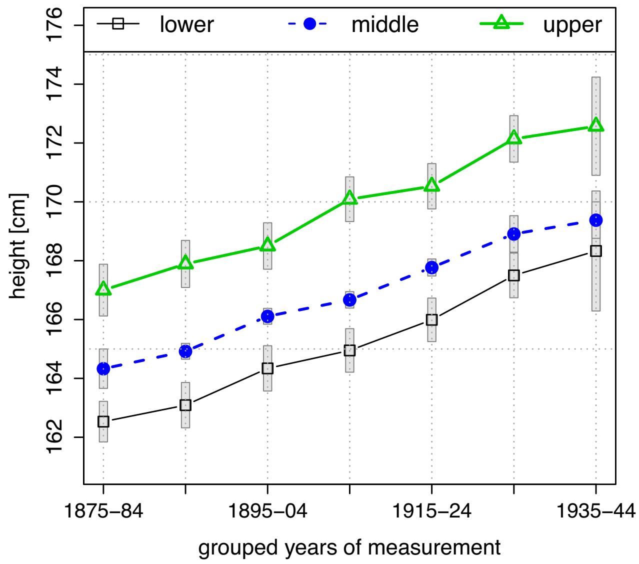


Fig. 4. Class-specific time trajectories of average height (1875–1935). The data are predictions from the models in Table 1. The bars denote 95% confidence intervals.

throughout the period under consideration. However, the curve of the lower class is slightly steeper than that of the upper class, meaning that it experienced the largest overall height gain (6.75 cm compared with 4.96 cm for the middle class), implying that economically disadvantaged men gained more from the economic improvement. Because of their low income but high income elasticity of the demand for food, the lower class enjoyed an increase in per capita food consumption compared to that of the upper class (Engel's law), who, long had sufficient financial means to ensure a balanced diet. Generally, class disparities in the biological standard of living did not disappear in the city of Basel but decreased slightly because of improvements in public health care, nutrition, and the living environment.[27]

For the city of Zurich, we obtain a similar pattern (column IV, section E in Table 1): the lower-class series shows the greatest height gain, by 6.6 cm over the observation period, followed by that of the upper class, 6.4 cm, and that of the middle class, 6.3 cm. Indicating that class disparities in the biological standard of living remained essentially unchanged. The average height of lower-class men exhibits a sharp rise of 3.6 cm between the periods 1925–1934 and 1935–1944 (section E, column IV in Table 1) whereas middle- and upper-class heights show only a modest increase (1.3 cm and 0.7 cm, respectively): an unexpected result in light of the fact that during World War II the measurement age decreased from 19 to 18 years, and that lower-class men had a relatively low developmental tempo. The best explanation

[25] The Belgium series is a compilation of the cities of Limbourg, Verviers, and Tilleur from Alter et al. (2004). These cities were chosen since they have a production and settlement structure comparable to that of the Swiss cities under consideration (especially Basel).

[26] Example: for the period 1905–1914, the height difference between the upper and lower class is on average 5.94 cm (with all other variables held constant at their average). The computations based on Table 1 are: [upperclass] + [upperclass] × [period1905_14] − [underclass] × [period1905_14] = 4.47 + 2.90 − 2.96 = 4.41.

[27] In addition, the Basel data permit us to estimate what would have been the effect of draft selection on average height if we had used recruitment instead of conscription data. Indeed, draft selection varied according to social class; a relatively high proportion of the lower class was rejected, and this group's average height was below that of those accepted (Table 1; class-specific number of excluded and deferred individuals are not shown).

Table 1
OLS and truncated-ML models for height.

Models	(I) Basel$^{(a)}$ coef.	se	(II) Bern rural$^{(b)}$ coef.	se	(III) Bern urban$^{(b)}$ coef.	se	(IV) Zurich$^{(c)}$ coef.	se
(A) Fitness for service								
Fit for service	reference		–	–	–	–	–	–
Excluded	-3.59***	0.58	–	–	–	–	–	–
Deferred	-2.91***	0.54	–	–	–	–	–	–
(B) Fitness for service × social class								
Excluded × under class	reference		–	–	–	–	–	–
Excluded × middle class	2.23***	0.63	–	–	–	–	–	–
Excluded × upper class	2.81***	0.89	–	–	–	–	–	–
Deferred × under class	reference		–	–	–	–	–	–
Deferred × middle class	2.44***	0.63	–	–	–	–	–	–
Deferred × upper class	3.12***	0.89	–	–	–	–	–	–
(C) Urbanization								
Living in rural region	reference		–	–	–	–	–	–
Living in urban region	1.79***	0.33	–	–	–	–	–	–
(D) Social class								
Under class	reference		reference		reference		reference	
Middle class	1.85***	0.62	1.38***	0.38	1.66**	0.81	2.66***	0.53
Upper class	4.47***	0.82	1.57***	0.49	4.64***	1.71	6.48**	0.68
(E) Social class × years								
Under class × 1875–1884	reference		reference		reference		–	–
Under class × 1885–1894	0.40	0.70	−0.05	0.37	−0.39	1.04	–	–
Under class × 1895–1904	2.01***	0.77	0.37	0.39	0.54	1.12	–	–
Under class × 1905–1914	2.96***	0.74	0.40	0.42	0.85	1.28	reference	
Under class × 1915–1924	4.20***	0.73	1.50***	0.50	1.27	1.71	1.91*	0.76
Under class × 1925–1934	6.75***	2.03	2.67***	0.57	1.62	1.94	2.46**	0.81
Under class × 1935–1944	–	–	2.39***	0.79	4.31	4.26	6.11***	0.77
Under class × 1945–1950	–	–	–	–	–	–	6.62**	0.85
Middle class × 1875–1884	reference		reference		reference		–	–
Middle class × 1885–1894	0.61**	0.27	−0.80**	0.40	−0.05	0.42	–	–
Middle class × 1895–1904	1.77***	0.27	−0.26	0.39	0.99**	0.41	–	–
Middle class × 1905–1914	2.30***	0.28	0.26	0.38	1.01**	0.41	reference	
Middle class × 1915–1924	3.38***	0.29	1.81***	0.41	2.14***	0.63	1.25***	0.25
Middle class × 1925–1934	4.96***	0.62	2.14***	0.39	3.80***	0.61	3.61***	0.23
Middle class × 1935–1944	–	–	4.27***	0.54	5.32***	0.90	5.29***	0.22
Middle class × 1945–1950	–	–	–	–	–	–	6.37***	0.26
Upper class × 1875–1884	reference		reference		reference		–	–
Upper class × 1885–1894	1.01	0.79	0.25	0.58	1.29	1.85	–	–
Upper class × 1895–1904	1.50*	0.79	0.92*	0.56	2.27	1.73	–	–
Upper class × 1905–1914	2.90***	0.75	0.54	0.54	2.94*	1.75	reference	
Upper class × 1915–1924	3.57***	0.76	1.18**	0.55	3.95*	2.20	1.81**	0.63
Upper class × 1925–1934	5.31***	1.67	2.81***	0.56	2.29	2.61	3.98***	0.60
Upper class × 1935–1944	–	–	3.40***	0.71	5.17	3.34	4.77***	0.63
Upper class × 1945–1950	–	–	–	–	-	-	6.45***	0.82
Constant	162.5***	0.69	164.2***	0.71	164.2***	0.75	164.1***	0.52
Sample size n	8807		6145		2328		9538	
Adjusted R^2	0.141		0.121		0.103		0.140	

Notes: (a) OLS estimates; (b) truncated-normal maximum likelihood estimates; (c) Horvitz-Thompson truncated-normal maximum pseudo-likelihood estimates; × denotes interaction effects; se denotes standard error.
* Significance at the 10%-level.
** Significance at the 5%-level.
*** Significance at the 1%-level.

for this sharp height increase of the lower-class conscripts lies in the economic upswing in the 1920s, subsequent to the postwar economic crisis and indicating catch-up growth, after two decades (1905–1924) of exceedingly modest growth.[28]

In Section 4.1 (Fig. 1), we reported that the biological standard of living was greater in urban regions of the canton of Bern than in the rural regions by the year of measurement 1905 (years of birth 1886). We now turn our attention to class-specific differences in the biological standard of living between rural and urban populations (columns II and III in Table 1; truncated ML estimates plotted in Fig. 5). First, members of the upper class living in an urban environment were significantly taller than middle-class men in general and upper-class men from the Bern countryside during the period under investigation (except for the years 1925–1934 and 1935–1944, for which the samples are very small, and the coefficients not

[28] The series for the cantons of Bern and of Basel-city terminate in 1938 and 1935, respectively: thus no decrease in the age of measurement.

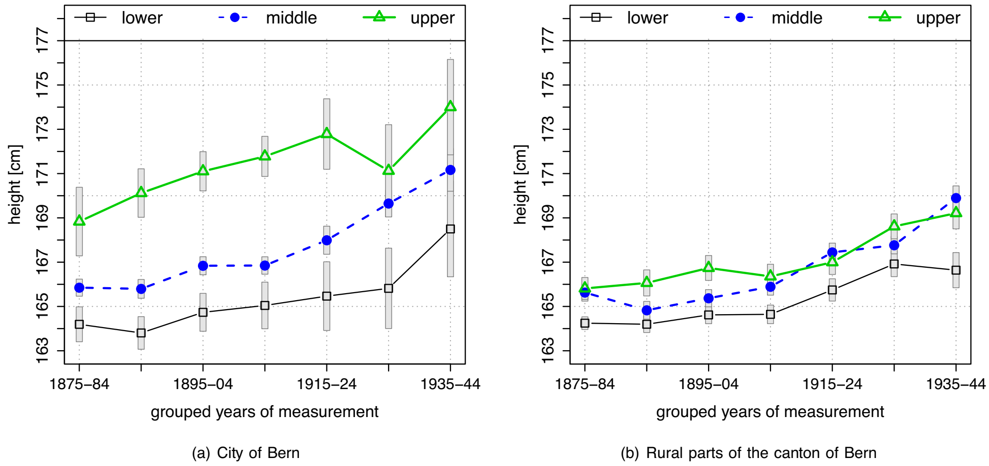


Fig. 5. Class-specific time trajectories of average height for the rural and urban parts of the canton of Bern (1875–1938). The data are predictions from the models in Table 1. The bars denote 95% confidence intervals.

significantly different (columns II and III in Table 1). Second, the curve of the urban upper class is the only one that declines while the biological standard of living of conscripts from all other social strata, both urban and rural, did not do so. Third, the living standards of the rural upper class and the urban middle class were similar throughout the observation period. On the other hand, during the years of measurement 1885 and 1904 (years of birth 1866 and 1885) the living standard of the rural middle class was significantly lower than that of either the urban middle class or the rural upper class; moreover, it declined during the 1880–1888 economic downturn. By 1904 (year of birth 1886), which marks the end of the downturn, the middle class caught up with the upper class in the agrarian countryside. This finding supports the argument that the 1880–1888 economic downturn was primarily due to difficulties in the marketing of agrarian products and led to a sharp rise in unemployment among farm workers, and a modest one among townsmen (Pfister, 1995; Ritzmann-Blickenstorfer, 1997). In contrast, the regression analysis shows that the average height, already extremely low, of lower-class conscripts, both urban and rural, was not affected by this economic downturn. In addition, the time trajectories of the coefficients in Fig. 5 for the lower class is almost congruent for townsmen and villagers, except during the period 1935–1944 (but the two series do not significantly differ). These findings indicate comparable living standards for young lower-class villagers and townsmen.

5. Body shapes and the current nutritional status

The most commonly used physical measurements, for both children and adults, are height and weight, followed by chest circumference (Eveleth and Tanner, 1990). During the entire period under study, 1875–1950, the latter was an important measurement for the military-draft councils, helping them to identify those conscripts with an insufficiently robust constitution. To ascertain precise measurements, the military authorities established, with the *Instruction über die Untersuchung und die Ausmusterung der Militärpflichtigen* (1875), strict instructions regarding measurement of the conscript's chest circumference.[29] Beginning in 1887 (1882 in the case of Basel) the draft councils also used the upper-arm circumference in order to determine the conscript's military-service eligibility.

Together the three major anthropometric measures – height, chest circumference, and upper-arm circumference – contribute to our understanding of body shape. In the absence of weight data, these measures serve as surrogate indicators of current nutritional status. Chest and upper-arm circumference are sensitive to immediate environmental conditions while height provides a history of nutritional status during the growing years. Moreover, because they feature muscle and fat, an adult's upper arms and chest may diminish in size in response to adverse environmental conditions, whereas height is strictly additive (except during old age). Thus, these two additional anthropometric measures are valuable indicators of body composition and proportions. Recent research indicates that malnutrition beginning in the prenatal period of life, and continuing throughout childhood, influences an individual's adult body proportions (Bogin, 1999; Bogin et al., 2001; Bogin, 2006).

This analysis is based on the conscript population of Zurich in 1933 (birth year 1914) because these data do not suffer from systematic selection bias or from problems due to truncation (Fig. 7).[30] We study the joint distribution of height, upper-arm, and chest circumference for the lower and the upper classes. Because the growth profiles of body dimensions such as height and chest circumference are not independent of one another – after the age of 14, a young man's chest circumference increases at a faster rate than

[29] The measurement had to be conducted by an experienced doctor with a measuring tape over both acromastia, the chest being bare, after a normal exhalation. For measurement problems associated with chest circumference, see Eveleth and Tanner (1990) and Ulijaszek and Lourie (2005).

[30] Since most deferments were for an insufficiently robust constitution, a condition judged by chest circumference, estimation based on the data of recruits rather than conscripts would have resulted in a serious overestimation of the average chest circumference.

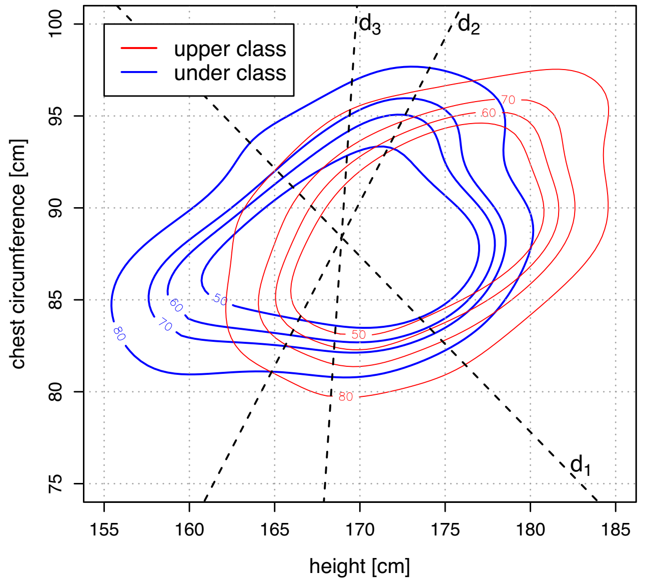


Fig. 6. Class-specific kernel density estimates of height, chest and upper arm circumference (Zurich 1933 consription data; $N = 1795$; Epanechnikov kernel).

does his height – their proportions trace non-linear trajectories (Eveleth and Tanner, 1990; Bogin, 1999).[31] Non-parametric models and techniques are well suited for our purpose because they avoid restrictive (a priori) assumptions regarding the functional form and instead allow a data-driven analysis (Silverman, 1986; Härdle et al., 2004). We focus on the shape of the joint-density-function estimates of the underlying anthropometric variables conditional on years of measurement and social-class affiliation. The computations are discussed in Appendix B.1. The results of the analysis are presented visually (Hyndman, 1996). We plot the contour lines of the joint distribution as summary measures to highlight the features of distributional shape and the nature of any changes in this shape across different groups. Aside from the identification of features from a bivariate distribution, it is of particular interest to quantify the directions in which these lie (Appendix B.1).

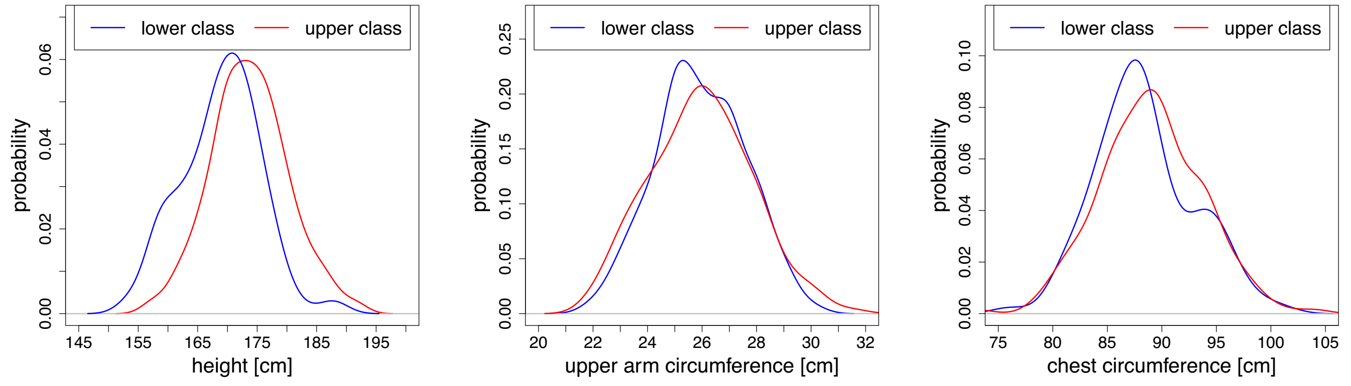
In Fig. 6 we plotted the contours of the bivariate density estimates for the variables height x chest circumference, conditional on social class. Since height and chest circumference are positively correlated, a taller conscript tends to have a larger chest circumference (and vice versa). Accordingly, in a scatter plot of these data, the positive correlation would come into notice as a regression line (through the origin) with a positive slope. Yet, this positive slope is evidence of the positive association of height and chest circumference, but it says nothing about the dispersion of the points around the line. If these data were bivariate normally (cf. Fig. 8) distributed (more generally if they were from an elliptically contoured distribution), the data points (more precisely any proportion of the data) fit into ellipses, which kind of surround the line of a regression through the origin. The shape of the ellipses serves as a representation of the dispersion or the shape of the distribution. Conversely, if the (plotted) contour lines are not elliptically shaped, we would conclude that the data are not elliptically symmetric (or multivariate normally) distributed.

Focusing on the global features in Fig. 6, one sees that while the two social strata share roughly the same chest circumference, upper-class men are, on average, taller. Of particular interest in this regard is the fact that, while the upper-class contours are typical of a (more or less) elliptically symmetric distribution, the joint-density estimates for the lower class deviate significantly from this pattern (see also the bimodal distribution of chest circumference for the lower class, Fig. 7). To emphasize the non-elliptical shape, we repeated the contour plot for the lower class and superimposed the theoretical contours that would result if the data were bivariate normally distributed (Fig. 8). This characteristic is clarified by the plotted directions (d_1, d_2, d_3) in Fig. 6, which are close to but distinct from the principal components (not displayed) and represent more evidence of the non-normal joint distribution. Taking a closer look at the shape of the lower-class contours, one sees a bulge in direction d_1 (in the lower right corner of the display; also in Fig. 8, comparing the contours of the theoretical and empirical distribution) which is evidence of the non-elliptical shape of the distribution. If the data were bivariate normally distributed, the contours would be ellipses whose major axis would run from the lower left to the upper right part of the plot (i.e., the slope of the major axis would be similar to the slope of a regression line through the origin). The bulge comprises a large number of conscripts who are quite tall but of a narrower chest circumference – that is, physically weaker – than those located in the upper part of the d_2-direction. This indicates that adverse living conditions affect body proportions.

In addition to the relationship between height and chest circumference, we analyze the joint density for upper-arm and chest circumference by means of non-parametric methods. In Fig. 9, the contours of these joint-density estimates are plotted using a diagonal bandwidth matrix to allow for possible multi-modal distributions. The highest-density regions plotted as contours for the lower-class men indicate a bimodal distribution. Most of the joint density (e.g., the 50% contours) is divided into two islands. The larger island is located in the middle and the lower-left corner of the plot; the smaller one, in the upper-right corner, stands for lower-class men whose upper-arm and chest circumference, indicators of physical strength, are similar to those of the strongest upper-class conscripts. The professional occupations of most of the conscripts in this small island involved considerable physical activity (gardener, butcher, carpenter, etc.). The contours for the upper class describe a unimodal joint-density distribution, although a diagonal bandwidth matrix was used in the estimation procedure, indicating that the joint distribution for the upper-class men is a (more or less) typical bivariate normal.

The contour plot of upper-arm circumference and height for upper-class individuals shows a unimodal, elliptically symmetric distribution (Fig. 10). The contours

[31] See also Cole et al. (2008) for patterns of nonlinear growth.



(a) Height (b) Upper arm circumference (c) Chest cirumference

Fig. 7. Contour plot of the bivariate kernel density estimates of height versus chest circumference (Zurich 1933 conscription data; $N = 1795$; kernel: Epanechnikov; bandwidth selection: unconstrained smoothed cross-validation).

of lower-class individuals are similar, except for a bulge at the lower end of the height dimension, indicating that this class is associated with lower height values. Comparison of upper-arm circumference with height distribution is not as informative, since it can be reduced to little more than the (univariate) distribution of height differences.

In summary, class affiliation exerts a strong influence on an individual's physique through the intermediary of living conditions, but this does not mean that lower-class living conditions produce an inferior physique. One's physique is partly determined by the local living environment, but one's biomechanical efficiency of movement and performance in daily activities are partly determined, in turn, by one's physique (Bogin et al., 2001). Thus habitual physical activity, adaptation to the work environment, and traditional occupations bring out certain physical characteristics (Singh and Singh, 2007).

6. Cycles in the height series

Aside from class-specific differences in the levels of the biological standard of living, short-term height-series cycles – defined as periodical deviations from the long-run trend – that are specific to class and to the living environment have been discovered. Their relationship to business cycles has also been examined (Woitek, 2003; Jacobs and Tassenaar, 2004; Sunder and Woitek, 2005). There is considerable evidence that socio-economic groups have distinctive responses to business cycles (and particularly to variations in income and consumption) that are reflected in their distinctive average-height cycles. Members of the upper class were less susceptible to temporal changes in the living environment (e.g., lower-income

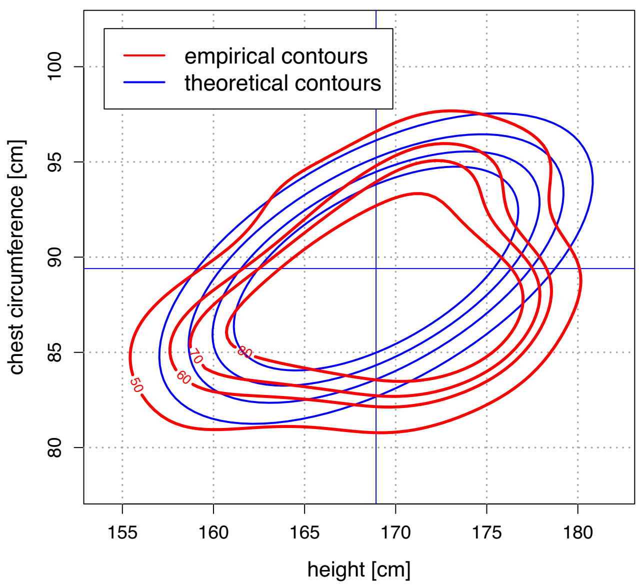


Fig. 8. Repetition of the contours for height versus chest circumference of the lower class from (Fig. 6), superimposed by the theoretical contours that would result if the data were bivariate normally distributed (the theoretical distribution is based on: mean height = 168.9 cm, mean chest circumference = 88.4 cm, variance of height = 43.9, variance of chest circumference = 20.6, covariance between height and chest circumference = 15.1).

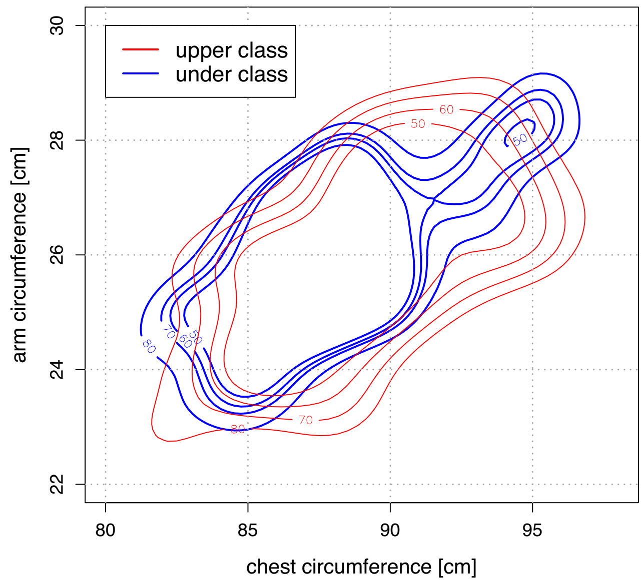


Fig. 9. Contour plot of the bivariate kernel density estimates of chest versus upper arm circumference (Zurich 1933 conscription data; $N = 1795$; kernel: Epanechnikov; bandwidth selection: unconstrained smoothed cross-validation).

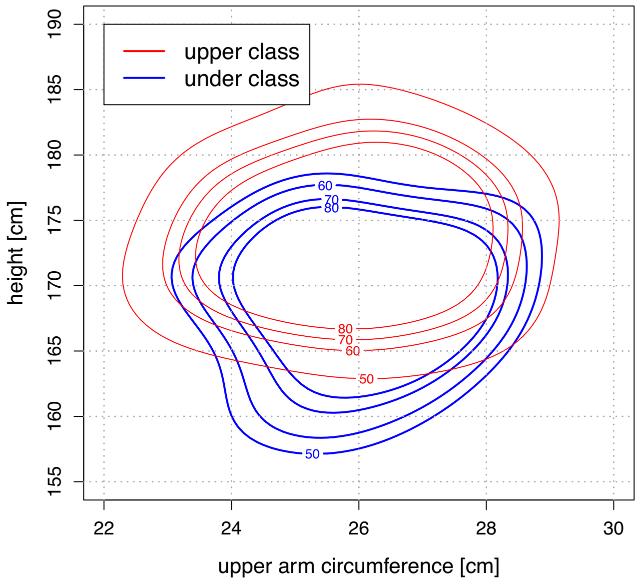


Fig. 10. Contour plot of the bivariate kernel density estimates of height versus upper arm circumference (Zurich 1933 conscription data; $N = 1795$; kernel: Epanechnikov; bandwidth selection: smoothed cross-validation with bandwidth matrix constrained to be diagonal).

elasticity in the demand for food) and had a variety of means to insulate themselves from short-term fluctuations (Bengtsson, 2004). The extent of short-term fluctuations and cycles in the class-specific average-height series (that co-move with business cycles) thus serves as a measure of the impact of economic stress on the class in question and offers a new perspective on living standards.

We focus on the cyclicality of the mean-height time series for members of different social strata (Sunder and Woitek, 2005), on height differences between urban and rural populations (Brabec, 2005), and on the correlation between the height cycles and certain economic variables. By means of spectral analysis, we relate these variables to the birth-year height series of the respective conscripts' cohort. We first fitted (vector-) autoregression, (V)AR, processes to the detrended series (using the filters of Hodrick and Prescott (1997), Baxter and King (1999), and the Hanning/Hamming window (Iacobucci and Noullez, 2005)) and then computed the corresponding spectrum of the estimated model (Appendix B.2). Employing spectral analysis, we focus on 7–10-year business cycles (Juglar cycles), upon which 3–5-year cycles (Kitchin cycles), are superimposed. We also account for cycles of 10–15 years, 5–7 years, and 2–3 years in order to obtain an impression of the overall shape of the spectrum. The cyclicality patterns are studied by means of spectral measures (Hart et al., 2009).

6.1. Data on business measures

In the absence of a single index of economic activity pertaining to socio-economic conditions in Switzerland during the late 19th and early 20th centuries, we use real wages and national GDP because real wages reflect changes in budget constraints, and thus changes in the quality and quantity of food purchased, and annual real-wage data are available for each of the three cities under consideration (Studer and Schuppli, 2008). We also use data on the real wages of carpenters, masons, and laborers in the canton of Basel (Schuppli, 2005). The carpenters' series represents real wages for individuals with significant skills. The masons' series is an aggregation of the wage level of men whose standard of living tended to be somewhat below that of the carpenters. The real wages in the laborers' series are the lower-class average. To supplement the results based on real wages, we also consider Swiss GDP data (1851–2005) (Studer, 2008).

6.2. Univariate analysis

We first fitted univariate AR-models to the different series and computed the spectral density. The shares of total variance, which are attributed to the relevant frequency bands, for the height series and the economic measures are reported in Tables 2 and 3, respectively. We detect a robust cyclicality structure in the height series, in that the order of the AR-models is not zero (Table 2). Moreover, the Hodrick–Prescott filter (HP) shows the highest share of total variance in the high-frequency bands (i.e., in the 2–3- and 3–5-year ranges). In addition, 14 of the 18 cases in the 2–3-year and 3–5-year (Kitchin) bands are significant. In the case of the 2–3-year cycle, all but one of the height series of the HP filter display a significant cyclical structure, the exception being the lower class in Zurich. There are only two cases of dominant or significant patterns in the lower-frequency (i.e., 7–5, 7–10, and 10–15) bands. Like the HP filter, the modified Baxter–King filter (BKM) shows a dominant cyclical structure for the high-frequency bands, but it puts greater emphasis on the 2–3-year range. The Hamming/Hanning window filter (HW) displays a cyclical pattern that is very similar to that of the BKM, but it puts greater emphasis on longer cycles.

As for the differences between urban and rural living environments, we find that they were negligible in the canton of Bern, with the exception of the total variance share in the 2–3-year band: evidence that the average height of conscripts from the rural part of the canton of Bern was distinguished by stronger cycles with high frequency than was the average height of their urban counterparts, regardless of which filtering method is used.

The results for both the BKM and HW filter (and the HP filter except for the 5–7-year range) display distinct class-specific cyclicality patterns. Lower-class men feature a large and significant variance share in both the 3–5-year and the 5–7-year cycles, whereas that of the upper-class men is significant only in the latter. Moreover, the magnitude of the share in the 5–7-year band is distinctly higher for the upper class, indicating a greater exposure in this frequency band. In addition, the middle class fits perfectly between the two other socio-economic strata. As for the Juglar cycle (7–10 years), there is little difference among the total variance shares of each of the socio-economic strata (except for the HW-filter and the Basel series).

Generally speaking, the lower class features the greatest exposure to short- and medium-term cycles, while the mean height of members of the middle and upper classes

Table 2
Univariate results, share of total variance of the height series for different filtering methods.

	Hodrick–Prescott Filter					Modified Baxter–King Filter					Hanning/Hamming Window Filter				
Period ▷	2–3	3–5	5–7	7–10	10–15	2–3	3–5	5–7	7–10	10–15	2–3	3–5	5–7	7–10	10–15
Basel (1875–1935)															
All	0.42*	0.37*	0.15*	0.03	0.01	0.37	0.44*	0.16*	0.02	0.01	0.39*	0.44*	0.10*	0.03	0.01
Under class	0.46*	0.48*	0.05	0.01	0.01	0.31	0.44*	0.21*	0.03*	0.01	0.33	0.42*	0.15*	0.04	0.02
Middle class	0.51*	0.36*	0.10	0.01	0.00	0.34	0.31*	0.28*	0.05	0.01	0.35	0.26	0.19*	0.13	0.02
Upper class	0.61*	0.29	0.07	0.01	0.00	0.42*	0.31*	0.16*	0.05	0.02	0.36	0.21	0.12	0.17*	0.07*
Bern (1875–1938)															
Urban	0.54*	0.36*	0.08	0.01	0.01	0.37	0.30	0.21*	0.09*	0.02	0.38*	0.32*	0.18*	0.09*	0.02
Rural	0.66*	0.26	0.07	0.01	0.00	0.42*	0.25	0.20*	0.09*	0.02	0.29	0.41*	0.21*	0.08	0.02
Zurich (1904–1950)															
All	0.53*	0.31*	0.14*	0.01		0.34	0.26	0.32*	0.06	0.02	0.34	0.23	0.32*	0.08	0.03
Under class	0.38	0.56*	0.05	0.01	0.01	0.26	0.50*	0.20*	0.03	0.01	0.26	0.47*	0.21*	0.05	0.01
Upper class	0.67*	0.20	0.12	0.01	0.00	0.42*	0.17	0.33*	0.06	0.02	0.46*	0.14	0.32*	0.07	0.02

Notes: (i) Periods measured in years. (ii) Empty cells indicate that the order of the underlying AR model is 0. (iii) * share of total variance is greater than the respective interval length, relative to the length of the overall business cycle interval [2;15].

Table 3
Univariate variance shares for economic measures (modified Baxter–King filter).

	Period (years)				
Economic measures	2–3	3–5	5–7	7–10	10–15
GDP (1851–1950)					
GDP	0.01	0.24	0.42*	0.23*	0.09*
Real wages in Basel (1850–1950)					
Carpenters	0.20	0.23	0.40*	0.12*	0.04
Masons	0.23	0.42*	0.18*	0.10*	0.07
Laborers	0.18	0.33*	0.22*	0.20*	0.07

Notes: * Indicates that the share of total variance is greater than the respective interval length, relative to the length of the overall business cycle interval [2;15], see Table 2 for further explanations; *Data:* GDP data: Studer (2008), real-wage data: Schuppli (2005).

was more affected by the medium-term cycles. In contrast with the short- and medium-term cycles, the variance shares of the highest-frequency band (i.e., the 2–3-year range) reveal a graduated rise in magnitude in parallel with class level, no matter which filtering method is used. This may be due to high sampling variability (i.e., a large standard error), due, in turn, to the particularly small sample size of the middle- and upper-class time series.

As for GDP and real wages, the results of the three filtering methods are very similar (Table 3). For GDP (1851–1950), 5–7-year and (to a lesser extent) 7–10-year cycles dominate the spectrum. In particular, the real-wages results are as expected, insofar as short-term business cycles have no significant effect on the carpenters' series—a compilation of wages for individuals with significant skills (especially craftsmen), relatively stable conditions of employment, and permanent or regular long-term employment contracts. On the other hand, average real wages for laborers and to a somewhat lesser extent for masons exhibit higher short-term fluctuations because of typically short-term employment conditions and a more variable course of business and order volume.

6.3. Bivariate analysis

While these findings reveal several aspects of cyclicality in the height series, we cannot determine whether observed cycles in these series reflect underlying economic conditions unless we relate them to other variables that not only reflect fluctuations in economic activity but also feature strong associations with height itself: a situation that prompts one to ask: Is there a frequency band that dominates business-related cyclical behavior, and if so, what is its direction and strength?

We fitted VAR models to the filtered series (Table 4). While the predictive quality of the models varies considerably, there is a clear pattern. First, the R^2 tends to take the largest value for the overall height series (series "all" for Basel, Bern, and Zurich). Second, for the social strata, the magnitudes tend to follow the inverse of the social rank: the lower-class series have the highest values, the upper-class series tends to be lower.[32] In addition to R^2, we report the maximum absolute eigenvalue, $\max|\lambda|$, of the parameter matrix in the companion-form representation of the estimated models to give an impression of the persistence of the shocks. According to the $\max|\lambda|$ values in the last column of Table 4, shocks to lower-class residents of Basel are much more persistent than those to the upper class insofar as the eigenvalues are larger (closer

[32] The only exception is the model for the Basel conscripts' and the carpenters' real-wage series. In this case the upper-class height series exhibits a slightly larger R^2 than does that of the middle class. This is explained by the fact that the carpenters' real-wage series is dominated by individuals (especially craftsmen) with significant skills and an above-average standard of living.

Table 4
Diagnostics for the bivariate models

Height series	Economic measure	R^2	$max\|\lambda\|$
Basel			
All	Carpenters (w)	0.415	0.83
Underclass		0.354	0.83
Middle class		0.215	0.82
Upper class		0.238	0.53
All	Masons (w)	0.406	0.80
Underclass		0.385	0.82
Middle class		0.129	0.57
Upper class		0.081	0.22
All	Laborers (w)	0.474	0.82
Underclass		0.373	0.82
Middle class		0.203	0.71
Upper class		0.179	0.64
Bern			
All	GDP	0.301	0.88
Urban		0.092	0.58
Rural		0.323	0.88
Zurich			
All	GDP	0.494	0.88
Underclass		0.576	0.92
Upper class		0.379	0.83

Notes: The order of the VAR models is determined by AIC; R^2 is reported for the height equation; max $|\lambda|$ is the maximum absolute eigenvalue of the companion-form representation implied by the estimated model; (w) denotes real-wage data.

Table 5
Variance components according to the bivariate analysis (modified Baxter-King filter).

Series	Period	Share	Total	In-phase	Out-of-phase
Bern					
All	7–10	0.055	0.051 **	0.048	0.003
	5–7	0.192	0.191 ***	0.175	0.017
	3–5	0.390	0.389 ***	0.155	0.234
Urban	7–10	0.062	0.062 **	0.011	0.051
	5–7	0.172	0.169 ***	0.002	0.167
	3–5	0.298	0.286 ***	0.124	0.162
Rural	7–10	0.052	0.047 *	0.045	0.002
	5–7	0.183	0.182 ***	0.156	0.026
	3–5	0.397	0.397 ***	0.163	0.234
Zurich					
All	7–10	0.055	0.054 **	0.051	0.003
	5–7	0.114	0.113 **	0.046	0.067
	3–5	0.350	0.348 ***	0.302	0.046
Upper	7–10	0.026	0.025 *	0.024	0.001
	5–7	0.035	0.035	0.017	0.018
	3–5	0.547	0.547 ***	0.508	0.039
Under	7–10	0.066	0.066 *	0.011	0.055
	5–7	0.296	0.295 ***	0.061	0.234
	3–5	0.185	0.184 ***	0.161	0.024

Notes: Variance shares (in or out-of-phase) estimated according to the bivariate VAR models in Table 4.
* Significance at the 10%-level.
** Significance at the 5%-level.
*** Significance at the 1%-level.

to one). For Zurich, on the other hand, shocks to both of these classes were persistent, if small, whereas shocks to the system of urban conscripts in general are far less persistent than those to the rural conscripts in the canton of Bern.[33]

The estimated VAR processes are then transformed to the frequency domain. The analysis of the height series' spectral representation allows us to tackle the cyclical behavior directly. Having identified dominant cycles in the height series which are closely correlated with economic indicators, we would be inclined to explain height cyclicality in terms of business cycles.[34] On the other hand, a particular share of variance in average height may be intrinsically tied to the cyclical exposure to diseases and the spread of diseases (especially contagious ones) and other non-monetary fluctuations that cannot be explained.[35]

In Table 5 we report the results of the variance decomposition based on the VAR-models for the conscripts of the city of Bern and rural surroundings, and those for Zurich (lower and upper classes; GDP). The results for Basel (lower, middle, and upper classes) and the three real-wage series (those of carpenters, masons, and laborers) are shown in Table 6. It is evident that a reasonable proportion of the total variance (column denoted by total) in the cyclical structure lies in the 5–7-year-frequency range (4–30%). As in the results of Brabec (2005), Woitek (2003), and Sunder and Woitek (2005), the highest share of explained variation is in the short-cycle range (19–54% between 3 and 5 years). The longer cycles (2–6%) are clearly less important (Table 5). In the remaining pages we analyze the cyclical behavior in the height series of particular social strata and then turn our attention to differences in the co-movement between the height series and the GDP of urban and rural populations.

6.3.1. Differences between social strata

In order to establish whether there are significant class-specific differences in the cyclical structure of the height series of the Basel conscripts, we report the results of the height series of the lower, middle, and upper classes in connection with all three real-wage series (Table 6).[36] For ease of interpretation, we present a visual display of the results from Table 6 (Basel conscripts) in Fig. 11. Fig. 11a represents the variance shares of the frequency range of 3–10 years that can be explained by the real-wage series. Apparently the contribution of all three wage series is strongest for the lower class, followed by the middle class, indicating that the association tends to be weakest for the upper class. The shortest cycles, with a 3–5-year frequency

[33] The rural and urban height series were fitted as VAR(4) models. We lifted the restriction of maximal order 3, because all information criteria suggested order 4.

[34] On the other hand, a seemingly low correlation between the height series may simply reflect the fact that an underlying time series is composed of a number of cyclical components that are of different amplitudes and timing. While a single frequency band may display strong evidence of a cyclical relationship, when the effects over several frequency bands are considered together, countervailing influences may mask underlying patterns (Hart et al., 2009).

[35] We are grateful to an anonymous referee for clarifying this point.

[36] Since there are minor differences among the various filtering methods, we show results only for the modified Baxter-King filter.

Table 6
Basel conscripts: variance components according to the bivariate analysis (modified Baxter-King filter).

	Real wage carpenters				Real wage masons				Real wage laborers			
	Share	Total	In phase	Out-of phase	Share	Total	In phase	Out-of phase	Share	Total	In phase	Out-of phase
All												
7–10 y	0.020	0.003	0	0.003	0.021	0.018	0.004	0.014	0.022	0.018	0.001	0.017
5–7 y	0.080	0.041 *	0.033	0.008	0.075	0.070 ***	0.006	0.064	0.084	0.065 **	0.046	0.019
3–5 y	0.477	0.376 ***	0.039	0.337	0.468	0.435 ***	0.339	0.096	0.543	0.492 ***	0.316	0.176
Under class												
7–10 y	0.029	0.019	0.018	0.001	0.031	0.030 *	0.001	0.029	0.027	0.026	0.002	0.024
5–7 y	0.121	0.104 ***	0.021	0.083	0.123	0.122 ***	0.087	0.035	0.134	0.132 ***	0.081	0.051
3–5 y	0.478	0.431 ***	0.227	0.204	0.507	0.502 ***	0.245	0.257	0.506	0.491 ***	0.322	0.169
Middle class												
7–10 y	0.046	0.040 **	0.017	0.023	0.051	0.051 **	0.030	0.021	0.054	0.053 ***	0.053	0
5–7 y	0.135	0.129 ***	0.062	0.067	0.104	0.103 ***	0.023	0.080	0.132	0.132 ***	0.102	0.030
3–5 y	0.425	0.416 ***	0.234	0.182	0.392	0.392 ***	0.096	0.296	0.365	0.365 ***	0.058	0.307
Upper class												
7–10 y	0.059	0.057 **	0.054	0.003	0.059	0.059 **	0.026	0.033	0.061	0.061 **	0.045	0.016
5–7 y	0.163	0.161 ***	0.102	0.059	0.086	0.085 **	0.013	0.072	0.108	0.108 ***	0.103	0.005
3–5 y	0.302	0.300 ***	0.019	0.281	0.255	0.255 ***	0.026	0.229	0.275	0.275 ***	0.064	0.211

Notes: Variance share (in or out-of phase) estimated according to the bivariate VAR models in Table 4; *Data:* economic measures from Studer and Schuppli (2008).
* Significance at the 10%-level.
** Significance at the 5%-level.
*** Significance at the 1%-level.

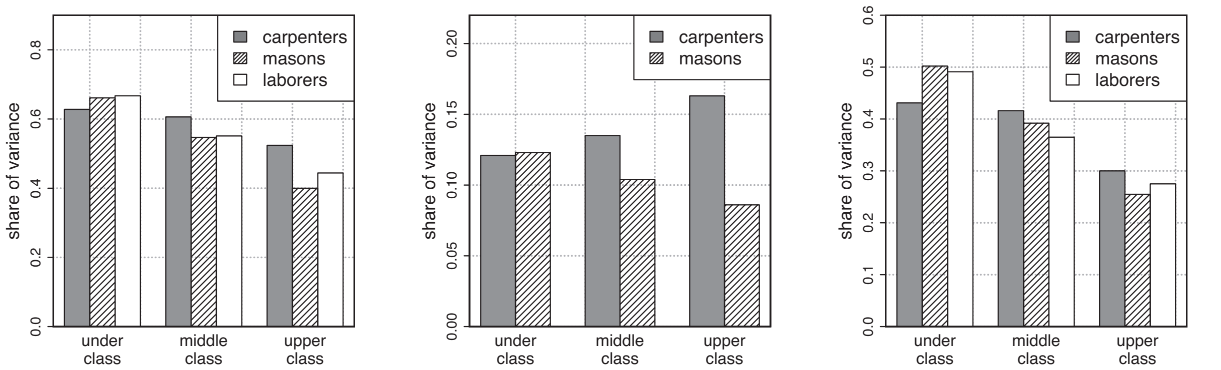
range, display the same pattern (Fig. 11c). For mid-term cycles (5–7 years) one needs to distinguish among the particular real-wage series. In the case of the masons' wages, the explained variance shares decrease with social rank, whereas in the case of the carpenters' wage series the opposite is the case. The association tends to be stronger among the upper than among the middle class. That is to say, each of the three real-wage series stands for an average wage of a particular job profile and represents an income bracket. It follows that these wage series have a different prediction potential for each of the various social strata. Accordingly, the upper and middle classes, in contrast to the lower class, are more responsive to the cyclical behavior of the carpenters' series than they are to that of the masons. Since the dominant cycles of the carpenters' real-wage series lie in the 5–7-year range (Table 3), they have an important impact on the upper-class height series in the 5–7-year frequency band, whereas there is hardly a difference in the Juglar and the Kitchin cycles.

For the Zurich data and GDP, we encounter a similar situation: the explained share of variance in the 3-5-year frequency band is significantly larger for the lower class than it is for the upper class (Fig. 11f) while the upper class is more responsive in the mid-term cycles. These results confirm those established for Basel and the real-wages series. In summary, the average height series for each social stratum exhibits a unique pattern of cyclical association.

We next turn to the issue of whether or not the series are pro-cyclical. Suppose that the peaks and troughs of an influential constituent cycle of the height time series coincide with the respective turning points of a given business cycle; it follows that the height series is both pro-cyclical and in phase with the business cycle. However, two series may be highly pro-cyclical and yet out of phase (or partly in and partly out of phase). In order to address the importance of phase shifts in a frequency band, we apply a variance decomposition proposed by Sunder and Woitek (2005). A particular frequency interval will be decomposed into a fraction that co-moves with the economic series (in-phase): a fraction with which the two cycles are associated but out of phase, and an unexplained remainder (Tables 5 and 6).

To simplify matters, the interesting in- and out-of-phase components in Tables 5 and 6 have been normalized by the corresponding explained variance and plotted in Figs. 11d and 11e. Hence an in-phase share greater than 0.5 (or 50%) indicates that a variable is pro-cyclical (and vice versa). Fig. 11d shows the in-phase variance component over the full frequency range (3-10 years). It is apparent that the average height for lower-class individuals is slightly in phase and pro-cyclical with respect to both the masons' and the carpenters' series insofar as both series feature a variance share of approximately 0.5 (Fig. 11d). In the case of the upper class, the carpenters' series is the better predictor (since it shows a larger variance share than does the masons' series) but is clearly out of phase (i.e., its variance share is smaller than 0.5; Fig. 11d). The situation becomes clearer when one takes into consideration the dominant, 5-7 year, cycles (Table 3), in which the co-movement between lower-class and masons' real wages is apparently in phase (share of 0.71; Fig. 11e). In contrast, the in-phase variance share of the upper class is almost negligible for the masons (share of 0.16; Fig. 11e). On the other hand, this pattern is inverted in the case of the carpenters' wage series: that is, upper-class heights are very responsive to the carpenters' series in phase. The variance shares of the 3-5-year band are not reported because the economic measures show no dominant cyclical structure in this band.

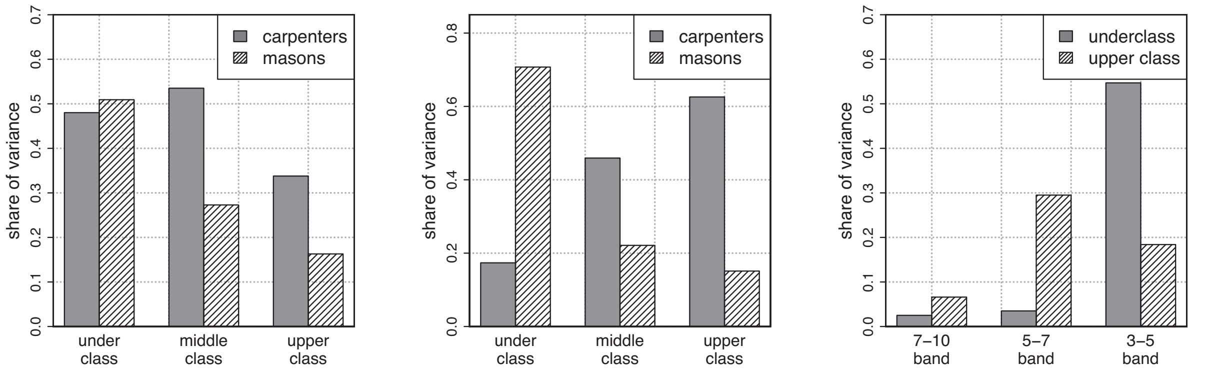
In summary, the average-height series for each social stratum exhibits a unique pattern of cyclical association



(a) Explained variance using the real-wage series (Basel conscripts, 3–10 years frequency range)

(b) Explained variance using the real-wage series (Basel conscripts, 5–7 years frequency range)

(c) Explained variance using the real-wage series (Basel conscripts, 3–5 years frequency range)



(d) In-phase component using the real-wage series (Basel conscripts, 3–10 years frequency range)

(e) In-phase component using the real-wage series (Basel conscripts, 5–7 years frequency range)

(f) Explained variance using GDP (Zurich conscripts, 3–10 years frequency range)

Fig. 11. Visual display of the total explained height variance and the in-phase component in the particular frequency bands, based on the results from Tables 5 and 6.

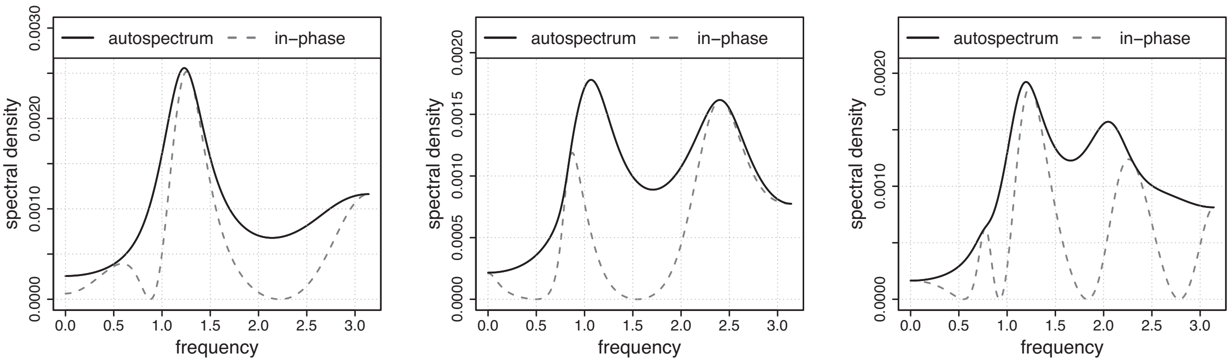
with the respective real-wage series of the underlying job profiles, each of which in turn represents a particular income bracket. The lower-class height series is the one most closely correlated with the laborers' real-wage series. Consequently, we discern that the class-specific average biological standard of living is very closely correlated with the respective real-wage series and thus reflects the underlying economic conditions.

6.3.2. Differences between rural and urban populations

In this section, we turn our attention to differences in co-movement between the height series and GDP for urban and rural populations of the canton of Bern. As we noted in the previous section, shocks to the rural series are more persistent than those to the urban series (Table 4). In order to understand the cyclical behavior of the respective series, we consider the contribution of each cycle to the total variance. The results of the variance decomposition are reported in Table 5. With regard to the explained variance share, the cyclical structures of the two height series, urban and rural, are very similar, except for the dominant Kitchin cycles. It is remarkable that short-term fluctuations in GDP affect individuals living in Bern's rural surroundings more than those who live in the city itself. In the case of the Juglar and the other longer cycles, there is no significant difference between urban and rural heights.

Because the variance decomposition for the particular frequency bands provides only a rough sketch, we plotted the autospectrum and the in-phase variance component for the full frequency range (Fig. 12). The peak of the autospectrum coincides with the in-phase component at a frequency of approximately five years[37] and is both pro-cyclical and in phase with regard to GDP (Fig. 12a). The autospectra for urban and rural populations follow a very similar pattern (Fig. 12b and c). Both autospectra have two influential, constituent cycles, however, each distinguished by a slightly different in-phase pattern. For the urban population, the shorter cycle is clearly in phase, whereas the mid-term cycle is partly in phase and partly out of phase (Fig. 12b). In the case of the rural populations, this pattern is inverted (Fig. 12b). On the other hand, these are minor differences, and may be partly due to phase shifts induced by the filtering methods. In summary, we find two dominant cycles in the average-height series of the rural and urban populations in the canton of Bern during the period 1875–1938 that are both (almost) in phase and pro-cyclical.

[37] The peak of the autospectrum in Fig. 12a coincides with the peak of the in-phase component at the frequency of approx. $f = 1.25$. The corresponding period, τ, (in years) is obtained from $\tau = 2\pi/f = 5.02$ years.



(a) Canton Bern (rural and urban)

(b) City of Bern

(c) Rural part of canton Bern

Fig. 12. Spectral decomposition: Autospectra and in-phase component for the height series of the canton Bern in connection with GDP according to the estimated VAR-models in Table 4 (spectrum range [0;π]).

7. Conclusion

We have presented the first representative analysis of the biological standard of living in four areas of Switzerland 1875–1950 based on individual records of 19-year-old conscripts, using a multifaceted approach to reveal patterns of socio-economic inequality. We find that average heights increased in all four areas: compared to 1875, 19-year-old conscripts in 1935 were approximately 6 cm taller in the city of Basel, 7 cm taller in the city of Bern and 5 cm taller in the rural areas of canton Bern. In addition, conscripts in the city of Zurich were 8 cm taller in 1950 than in 1905. Furthermore, we find no urban height penalty at all: conscripts from rural areas of canton Bern were not taller than their counterparts in the city of Bern. Furthermore, by 1905 (birth year 1886) the biological standard of living in Switzerland was significantly higher among the urban than among the rural population.

Basel, spared the (mainly agrarian) 1880–1888 economic downturn and the resulting rural-urban migration, enjoyed the highest average height until the 1930s, but by 1931 Zurich – in contrast with the still smaller conscripts from the city of Bern – closed the gap. Moreover, the height series of the rural canton of Bern featured a smaller annual growth rate than that of the city itself, and after 1886 (year of birth) deviated significantly and negatively from the urban series: evidence that since the end of the 19th century there was no urban height penalty. The differences between the rural and urban average biological living standards were mainly due to the 1880–1888 economic downturn, which affected the biological standard of living in rural areas more severely, and the fact that the typical urban diet contained far more protein than did the rural one. Furthermore, the economic crisis subsequent to World War I had little if any effect on the biological standard of living of urban and rural populations. A comparison with European countries indicates that the biological standard of living in Switzerland was considerably higher than it was in Italy. By 1925 Swiss conscripts even from rural areas in the canton Bern were on average taller than their French counterparts (as those from the city of Basel had been since 1875).

Turning to the micro level, we find that class affiliation was the most important determinant of one's biological standard of living (a finding that receives further support when we control for the urban/rural living environment in the models). Our data show persistent and significant differences in the class-specific average-height series. The upper class in the city of Bern enjoyed a constantly and significantly 3–4 cm higher standard of living than did either the upper or the middle class elsewhere in the canton. Class and regional disparities in the standard of living remained strikingly constant during the observation period, despite general improvements in public health-care services, nutrition, and the living environment. On the other hand, the fact that the largest overall height gain was among the lower class indicates that it was the disadvantaged who benefited the most from economic improvements.

To broaden our perspective, we used measurements of chest and upper-arm circumference, in the absence of weight data (since they, too, are indicators of short-term nutritional status), in conjunction with non-parametric statistical methods. The cross-sectional analysis showed that adverse living conditions had a major influence on body proportions: We found that lower-class men's measurements were below average when it came to both height relative to chest circumference and chest circumference relative to upper-arm circumference. However, those lower-class conscripts whose occupations featured a high level of physical activity had chest and upper-arm circumferences as large as those of any of the upper-class conscripts. In other words, habitual physical activity, adaptation to work conditions, and traditional occupations brought out physical characteristics typical of each occupational group.

By studying deviation cycles from the annual average-height series, we found that the highest share of total variance (i.e., 29–67%) can be attributed to the short- and mid-range cycles, particularly the latter. The analysis of class-specific differences in the cyclicality indicates that the biological standard of living of lower-class men was particularly sensitive to short-term but also to medium-term economic fluctuations, whereas changes in the mean height of members of the upper class were correlated with medium-term cycles only. In line with the findings in the literature, the average height series of conscripts living in rural regions was most closely correlated with short cycles and the shocks to rural height series were far more persistent than those to urban ones: evidence that rural conscripts were disproportionately sensitive to economic cyclicality.

Furthermore, the average height series for each social stratum displays a unique pattern relative to the respective real-wage series of the underlying job profiles, which in turn represents a particular income bracket. The height series of the lower-class conscripts is most closely associated with their real-wage series and far less so with the wage series of skilled workers. In contrast, the average height series of the upper-class conscripts is closely related to the wage series of the carpenters, that is, of workers with significant skills, relatively stable conditions of employment, and permanent or regular long-term employment contracts. We therefore conclude that the class-specific annual average of the biological standard of living is very closely related to the respective real-wage series and thus reflects underlying economic conditions. The biological standard of living is thus very responsive not only to indicators of economic activity (e.g., real wages and GDP) in general but also to class-specific derivatives of these measurements.

Acknowledgements

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Appendix A. Data prepration/computations

All computations are done in R (R Development Core Team, 2009). To assure satisfactory data quality, because the data are based on primary-data collection by the (error-prone) transcription of several control books, the post-collection process consisted mainly of editing and data cleaning. For the categorical data we applied simple range and plausibility checks. Inconsistent values were set to the most likely. In the case of metric measures - that is height, and upper-arm and chest circumference, we employed the Stahel-Donoho estimate for multivariate outlier detection (Maronna et al., 2006). These outliers were then replaced by estimates from a multivariate regression (hot deck imputation). For the samples of the cantons Bern and Zurich, outliers were removed visually, because we were interested only in the height distribution. The number of outlying and missing observations was negligible (fewer than one in a thousand).

Appendix B. Technical appendix

B.1. Multivariate density estimation

Let $\mathbf{X} = (X_1, \ldots, X_p)^T$ denote a p-vector random variable with a well-behaved density, f. Suppose that $\mathbf{x}_i = (x_{i,1}, \ldots, x_{i,p})^T$ are realizations, $i = 1, \ldots, n$. The kernel density estimator is defined by

$$\hat{f}_{\mathbf{H}}(\mathbf{u}) = \frac{1}{n}\sum_{i=1}^{n}\frac{1}{det\,(\mathbf{H})}K\left\{\mathbf{H}^{-1}(\mathbf{u}-\mathbf{x}_i)\right\}, \tag{B.1}$$

where $\mathbf{H}$ is a nonsingular, positive, and typically unconstrained bandwidth matrix. In case the density function is supposed to show a multi-modal shape, we use a diagonal bandwidth matrix. The choice of the kernel function $K(\cdot)$ is not crucial; we use an Epanechnikov kernel. More attention has to be payed to the choice of a bandwidth selection criterion. We use the smoothed cross validation criterion (SCV) proposed by Hall et al. (1992) because the plug-in method by Silverman (1986) revealed strong over-smoothing (this is well-known in the literature, see e.g. Härdle et al. (2004)). In particular, we employed the formulation of SCV method established by Duong and Hazelton (2005) and the algorithm proposed (an implemented) by Duong (2007).

Besides the identification of features from a bivariate distribution it is of particular interest to quantify the directions in which these lie. In case of elliptical distributions this can be done by computing the principal components. With non-elliptical distributions the projection has the potential disadvantage to blur together features that may actually be separated in the joint density. Our approach is to find directions from the mean (or a similarly defined location) which maximize $\int_0^\infty f(c \cdot \nu)\mathrm{d}c$, where f is the underlying density function, $\nu = (\nu_1, \nu_2)$ is a unit vector and c a positive scalar (Bowman and Foster, 1993). Since we are only interested in directions, we re-parametrize the problem at hand through polar coordinates from the estimated location. Each observation $i = \{1, \ldots, n\}$ is represented in terms of radius and angle, (r_i, θ_i), and interesting directions correspond to modes of the marginal distribution of the angle θ. An estimator of this marginal density is given by $\hat{g}(\theta) = \frac{1}{n}\sum_{i=1}^{n} V(\theta - \theta_i; h)$, where $V(x|\mu, h) = 1/(2\pi I_0(h))exp[h\cos(x-\mu)]$ denotes the von Mises density function of the random variable x on the circle with location parameter μ, concentration parameter h, and I_0 is the modified Bessel function of order 0 (cf. Fisher, 1995). Since the main interest is in the distribution of the modes over the support, the scaling constant of the von Mises can be ignored (Bowman and Foster, 1993). The interesting directions – represented by the modes – of $\hat{g}$, evaluated at each direction θ_i using a smoothing parameter h following the plug-in rule by Taylor (2008), are determined by virtue of a visual displays (not shown).

B.2. Spectral analysis

The starting point of the spectral analysis is to detrend the non-stationary time series using various filtering methods, because each of the commonly used filtering methods causes specific, artificial cyclical structure which may alter the final cyclicality analysis (cf. Canova, 1998). Thus, phenomena which can be obtained for several filtering methods are considered robust. We compare the results of the Hodrick–Prescott filter (Hodrick and Prescott, 1997) with a smoothing weight $\lambda = 6.25$ according to Ravn and Uhlig (2002), the (modified) Baxter-King filter (Baxter and King, 1999; Hart et al., 2009), and the Hanning/Hamming-window filter (with $a = 0.54$) (Iacobucci and Noullez, 2005). For the bandpass filters the upper range was set to 15 years. Given the filtered series, the population spectrum is estimated according to Burg's maximum entropy approach (cf. Pristley, 1981), which is more stable in case of very short time series than the standard smoothed periodogram estimator (Woitek, 2003; Sunder and Woitek, 2005). Thus, the key is a (covariance-stationary) multivariate vector autoregression (VAR) process. According to Hamilton (1994), let a VAR of order p be defined as $\mathbf{y}_t = \mathbf{c} + \sum_{j=1}^{p} \Phi_j \mathbf{y}_{t-j} + \boldsymbol{\varepsilon}_t$; $t = \{1, \ldots, T\}$; $j = \{1, \ldots, p\}$, where $\mathbf{y}_t$ is a $(n \times 1)$ vector of dependent variables, Φ_j are $(n \times n)$ time-independent parameter matrices, $\mathbf{c}$ denotes a $(n \times 1)$ vector of constants, and ε_t is a $(n \times 1)$ vector error term. For convenience, the error terms follow the usual assumption: $\mathbb{E}[\boldsymbol{\varepsilon}_t] = \mathbf{0}$, $\mathbb{E}[\boldsymbol{\varepsilon}_t, \boldsymbol{\varepsilon}_t] = \Sigma$ (symmetric positive definite), and $\mathbb{E}[\boldsymbol{\varepsilon}_t, \boldsymbol{\varepsilon}_s] = \mathbf{0}, \forall t \neq s$. Finally, we assume that $\boldsymbol{\varepsilon}_t \sim \mathcal{N}(\mathbf{0}, \Sigma)$ and that p lags are sufficient to summarize the dynamic correlations between elements of $\mathbf{y}$. Thus, the population spectrum of the covariance-stationary VAR(p) process is $\mathbf{s}_y = 1/(2\pi)\Phi(\omega)^{-1}\Sigma\Phi(\omega)^{-\star}$, $\omega \in [-\pi, \pi]$, where $\Phi(\omega)$ is the Fourier transform of the matrix lag polynomial $\Phi(L) = \mathbf{I} - \Phi_1 L^1 - \ldots - \Phi_p L^p$; L is the lag operator and $\star$ denotes the complex conjugate transpose.

The order p of the VAR process (or AR process in the univariate case) is chosen according to the information criteria of Akaike, Hannan-Quinn, and Schwartz. In case all the criteria show different orders, we chose the smallest order to ensure a parsimonious parameterization. For univariate AR models we set the maximal order to 5, and in the VAR case to 3. In order to draw inference under the AR and VAR models, we adopted a series of Monte Carlo experiments: (1) generation of uncorrelated white noise series with the same variance and length as the underlying time series, (2) AR(p) or VAR(p) model were fitted to the simulated series. (3) Finally, we calculated the spectral measures. Steps 1–3 were repeated 10,000 times. The resulting distribution of the spectral measures allows then to judge the null hypothesis of no cyclical structure.

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