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Well-Being in pre-historic and historic Europe: Roman heyday and Dark Medieval Ages?

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Abstract

For a long-run study on living conditions from pre-historic times onwards sufficient data are very rare: firstly, no ‘conventional’ economic data exist; secondly, no quantitative information on aspects such as infant mortality is available in adequate quantity to study overall welfare. Promising though is an interdisciplinary concept, utilising skeletal material as data source of mean height and applying anthropometric methods in order to determine nutritional status. This approach is employed here to investigate the conditions in Europe in the very long run from pre-historic times onwards, i.e. the 8th century B.C. until the 18th century A.D. The study is based on the data of over 18500 individuals.

Overall, for the centuries A.D. the results of an earlier study (Koepke and Baten 2005; 2008) have been confirmed by the much enlarged data set in the current paper, indicating that there was no pronounced trend in mean height for these centuries. Yet, including the centuries B.C. we found a modest increase in the mean height of about 0.5 cm per 1000 years. However, strong variations between centuries are observable: Conditions of constrained human welfare repeatedly superseded enhanced living conditions during pre-industrial history.

Various potential determinants could explain this finding. One aspect of particular interest is the impact of Roman rule. Contrary to conventional perception we find a decline in mean height at the time of Roman rule and a recovery after the end of the *imperium Romanum.* Other statistically significant determinants include the urbanisation rate, with a negative impact, and the cattle share, as an indicator for milk consumption, with a positive effect. Other variables, such as changes in population density, did not have a decisive impact on the overall long-run development of nutritional status in the course of the centuries under study.

1. Introduction

The purpose of this paper is to provide for the first time a study to fulfill the desideratum of a very long-run overview of the European well-being from pre-historic times onwards.

In general, various different indicators exist in order to assess the dimensions of well-being: the non-economic ones, such as education, and economic ones, such as income inequality captured by the Gini coefficient. However, most of those measures can only be applied to recent centuries and cannot be used to study the development over 25 centuries (and thus see how conditions might have changed in the course of the centuries) because contemporary written sources are rare. Moreover, where they do exist, they often cannot be taken as objective accounts of the living conditions (due to the ancient writers' own agenda resulting in intentional formulations). Adequate economic data, such as on GDP or on prices and price development are not available to any sufficient extent.[1] Furthermore, no quantitative information regarding aspects such as the human development index or infant mortality is available for pre-modern times, which could be used to investigate overall human welfare in the long-run.[2]

[1] It is only recently that data have started to be compiled for Roman times in order to reconstruct the economic growth, and this is only possible to a minor extent even in this specific case (Bowman and Wilson 2009).

For example, an important determinant as indicator for supply conditions would be prices of diet goods, because these 'incorporate' information on the scarcity of goods. But by now no adequate data is available, because historic sources on prices are either temporarily or regionally restricted. Rare references are given on single aspects in ancient or medieval sources (for example, Szaivert and Wolters 2005). It is impossible to find information on a homogenous everywhere consumed good that could have been used as numéraire. Moreover, although rough ratings are possible (Allen 2009) numbers like the ones from Diocletian's price edict are problematic to analyse, because the numbers represent inflicted restrictions; or are only valid for single small regions (for example the indications on *ostraca*). Furthermore, the adequate consideration of the inflation in the course of the first millennium A.D. is problematic. For the purpose to study the effect of price development (with considering the complexity of inflation, comparability of 'good basket') only very recently a large venture has been started ('Cologne Tableau'), which one time will solve also this complex topic. It was started with a DFG-project on 'Econometrics of the Central European Neolithic'.

[2] Concerning, for example, human capital no sufficient data is available to reconstruct the level of schooling etc. for the long run. This is in contrast to later centuries, for which A'Hearn, Baten, Crayen (2006), or De Moor and van Zanden (2008), and others studied numeracy and literacy levels. One exception for Roman times are *elogii* on tombstones bring some information on age-heaping, analysed by Duncan-Jones (1990), but these data probably are flawed (see critique by de Moor and van Zanden 2008, 8).

In order to reconstruct mortality rates, the archaeological data is not representative enough. Firstly, it is impossible to estimate infant mortality rates correctly, because of the bad preservation conditions of neonatal and infant bones (Kölbl 2004). Secondly, it is also problematic to reconstruct life expectancy, as Tim Parkin (1992) concluded in his book on this topic: "All the figures … are approximations based on comparative evidence, rather than on the (largely inadequate) ancient statistical data." Moreover, other potential problems arose, which the author subsumes as follows: A) the assumed average life expectancy at birth (25 years) might be too optimistic. However, high infant mortality disguises the number of people who potentially will live well past this age (life-expectancy-at-birth is not a median, but a mean). B) The

An achievable alternative however, is to explore mean height as an indicator for nutritional status (net nutrition) and health of a population as a key proxy for the development of well-being. This basic fact that mean height is a good proxy for living conditions is independent of time and therefore a good indicator to use.

This anthropometric method is particularly important for studying welfare in archaeological periods, because in contrast to the problematic poor records for other welfare-related data, skeletal material – which is the base, used to determine human height for pre-historic times – exists in comparably large amount and bears the necessary consistency.[3]

Wing and Brown (1979, 87) already stated that "stature estimation (of fairly complete skeletal populations) can be used to examine long-term changes in resource availability and nutritional intakes, and to test the possibility of status differences within a population". However, up to now hardly anybody has employed the opportunity arising from the anthropometric methodology in order to study living conditions in Europe in an overview in the very long-run and thus to learn about pre-modern periods. The method only was applied in small-regionally or even locally, and temporal restricted analyses.[4] This changed with our study on Europe in the last two millennia conducted by Koepke and Baten (2005).

In this context of studying European conditions in the very long-run we have already contributed to a topic of particular scholarly interest, namely, whether the Roman

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rough estimates neither allow us to account for possible inter-, or intra-regional differences (across sex, or socio-economic classes), nor for possible variation in the course of the centuries.

[3] Means one has the possibility to make the data consistent. However, in order to get this consistency for a systematic comparison one first has to standardise the data to make the estimates internally consistent (see below).

[4] By now a great number of studies were conducted which deal with modern times, especially the pre-industrial and more recent periods. All of them emphasised the informative value of mean height as proxy, and detected an interaction with various economic conditions (for example technical progress in agriculture or medicine, or free trade: Baten 1999). However, on the contrary no extensive regional and temporal – means several periods over-spanning, long-term overview – anthropometric study of the nutritional status in pre- and early historic Europe was conducted by now. The only few existing works mostly focus on osteological-anthropological aspects, and cater for either a single European region or a single period (such as Huber 1968; Bennike 1985; Grupe 1986; Haidle 1997; Kunitz 1987; Lalueza-Fox 1998; Schröter 2000; Brothwell 2003; Maat 2003; De Beer 2004). Furthermore all of them are based on a small number of observations only. Lalueza-Fox (1998) even compared data reconstructed by different models. For example, Steckel (2004b) studied Scandinavian data finding a considerable decrease in mean height since the Middle Ages. Maat (2003), and Brothwell (2003) recently confirmed this finding for the Netherlands. Until recently antiquity was hardly considered by now in an overview (see Jäger et al. 1998). Exception was provided by Angel (1984) with his work on Greek regions in ancient Roman times, for which he found decreasing mean height, and recently Kron (2005), Cardoso and Gomez (2009); Barbiera and Dalla-Zuanna (2009). By now, the only very long-term study of a dimension comparable to the present study was rendered by Steckel and Rose (2002) for the Americas from pre-historic times onwards.

impact as well as the conditions during medieval times influenced well-being positively or negatively. However, our work only presented a first attempt to deal with these questions. The discussion still stands as to whether the Roman period was ‘golden’, and the subsequent period could be called the ‘Dark Ages’ (Ward-Perkins 2005).

In order to assess overall well-being, over a long period of time, research concentrated on ‘traditional’ economic indicators, and on the discussion as to whether or not Roman times meant an improvement in economic welfare in comparison to underdeveloped societies (Finley 1973). Although it is still not completely verified whether, for example, in Roman times technological innovations were introduced or only some diffusion of technology took place, the newest research indicates that Roman times brought unprecedented economic growth (Bowman and Wilson 2009).

In this context, it is important to consider, however, that well-being is a complex concept that also includes non-monetary measures (e.g. Boarini et al. 1996). This means we have to differentiate between economic living conditions and health-related conditions, as it has been accomplished in several publications on Roman times recently (Kron 2005; Barbiera and Dalla-Zuanna 2009; and others: listed in Scheidel (2010)). Up to now the studies mostly indicate that “the population of the imperial heartland appears to have been fairly short” (Scheidel 2010, 6); however according to some researchers, Roman conditions seem to have been comparably favourable (e.g. Kron 2005). A problem with these studies conducted in recent years is that the scholars mainly concentrated on the region of modern Italy during antiquity. However, in order to assess the actual Roman effect more properly it is necessary to expand the data to other European regions and to extend the study period a long way back in time for comparison. It is also helpful to apply quantitative methods in order to avoid being solely dependent on a visual impression of the development of mean height. These aspects are provided here for the first time.

The study brings two new main contributions: firstly, we present an overview of the development of nutritional status further back in time in order to provide additional knowledge on well-being in the very long-run, namely from the early Iron Age onwards. Secondly, the data set is temporally pro-longed and regionally enlarged to a wide extent. This allows us, in particular, to control for possible changes in nutritional status due to the Roman impact far more precisely. Thus, this study is a significant refinement of the earlier one (Koepke and Baten 2005a) to verify our previous results.

The following questions concerning the course of the 8th century B.C. until the 18th century A.D. have been dealt with among others in this study for the first time: How did conditions develop in different European regions in the course of these 25 centuries? Which were periods of ameliorated conditions? And what are the determinants of nutritional status during these periods?

The paper is structured in the following way: We start with a brief introduction to the anthropometric methodology, followed by the presentation of the data set. In the subsequent third part hypotheses concerning possible explantory variables for net nutrition are discussed. In section 4 our findings are presented, comprising firstly, the temporal development of human mean height in Europe and secondly, our regression results depicting the actual impact of the potential determinants.

2. Methodology and Data

2.1. Nutritional Status and Mean Height

The anthropometric approach is rooted in the close interrelation of welfare, nutritional status and mean height (and health). The differences in mean height in a homogenous population are driven by environmental factors (Bogin 1999; Mascie-Taylor and Bogin 1995; Silventoinen 2003; Curtis et al. 2005)[5]: Nutritional status affects stature growth during the pre-natal period, childhood and youth.[6] Of special importance is nutrition during the lactation period, the weaning period, and the adolescent growth spurt, because this is when the growth velocity is the highest, resulting in especially high nutritional requirements (Poskitt 1999; Scott and Duncan 2002).[7] Consequently, adult final height is the cumulative output of factors concerning living conditions during the whole growth period (Eveleth and Tanner 1976; Tanner 1981; Bogin 1988; Baten 1999; Baten 2000; Stinson 2000). Chronic malnutrition leads to reduced growth and somatic growth can be permanently impaired because the body gives priority to survival over growth. Thus the attainment of the possible genetic height potential, which is equal for

[5] Moreover, even genetics are determined by living conditions to some extent: see Jablonka and Lamb (2005).

[6] That not only the first years of life, but also foetal conditions are of importance, one can conclude from: De Onis et al. 1998; Gopaldas and Gujral 1995; Hindmarsh et al. 2008; Langley-Evans and Carrington 2006; Leiarraga 2002; Li et al. 2003; Martin-Gronert and Ozanne 2006; Roseboom et al. 2006; Wu et al. 2004.

[7] Of special danger is the 'malnutrition-diarrhea-cycle', particularly for weaning toddlers (Scrimshaw 2000: Scrimshaw et al. 1968; Molla and Molla 1999).

European people, is suppressed, and therefore results in lower adult final height (Henry and Ulijaszek 1996; Cameron 2002).[8]

Since children's living conditions "reflect … the state of a nation's public health and the average nutritional status of its citizens" (Eveleth and Tanner 1976, 1) the nutritional status as indicated by mean height can be used as a sensitive indicator for well-being and living environment of the whole population: It is an important factor of welfare for any population in any society at any time (see WHO 1995).[9] However, the anthropometric approach is all the more important for studies on 'archaeological' centuries as no other adequate data is available to study welfare in the very long-run (see above).

2.2. Data for the Nutritional Status of Pre- and Early Modern Europeans and Possible Issues

The main sources of information on the nutritional status of pre- and early historic people are human bone remains, gathered from skeletons from archaeological excavations.

The data set we compiled consists of 18,502 individuals from 484 excavation sites across Europe. The earliest birth cohorts lived in the eighth century B.C.; no individual

[8] When discussing nutritional status and well-being, one has to keep in mind that adequate nutritional status is not only decisive for a body to gain height, but that nutritional status during growth shapes adult life conditions, as well (Fogel and Costa 1997; Grantham-McGregor 1995; Bogin 1996; Bogin et al. 2001; Rotberg 2000; Gluckman and Hanson 2004; Ulijaszek 1996). Nutritional status is also of importance for the physical and cognitive body functions to develop and perform well (Grantham-McGregor et al. 2007; Walker et al. 2007a). As a consequence, nutritional status can affect human capital accumulation (Gautschi and Hangartner 2006; Stinson et al. 2000; Fogel 1994). Another important factor is that human capital has an effect on working capability and productivity (Margo and Steckel 1982; Spurr 1983; Fogel 1994; Strauss and Thomas 1998), and therefore influences well-being (Stinson 2000). As a negative outcome this may result in an "intergenerational transmission of poverty" (Thomas and Strauss 1992). Moreover, inadequate nutritional status during (early) growth (and thus lower adult height) seems to have, in particular, an impact on morbidity later in life, such as on cardiovascular, bronchial and respiratory, or cholesterol and diabetic disease susceptibility in adulthood (Uljiaszek 1996; Stinson 2000, 457 f.; Koletzko et al. 2005).

[9] Mean height is also used as an indicator for nutritional status for today's populations (De Onis and Habicht 1996), as well as historic populations all over the world, emphasising the importance of this proxy. However, the anthropometric approach was mainly applied on the more recent centuries so far. It is utilised in economic history, but also in medical science and palaeo-medical research: Armelagos 1990; Baten 1999; 2000; Cohen 1989; Floud et al. 1990; Floud and Harris 1997; Fogel et al. 1983; Grupe 1990; Harris 2000; Horrell, Humphries and Voth 1998; Horrell, Meredith, and Oxley 2009; Inwood, Oxley, and Roberts 2010; Komlos 1998; Komlos and Cuff 1998; Larsen 1997; Leonard 2000; Li et al. 2007; Lopez-Blanco 1995; María-Dolores and Martínez Carrión 2011; Moradi 2009; 2010; Moradi and Baten 2005; Oxley 2004; Schwekendiek 2008; Scott and Duncan 2002; Schofield et al. 1991; Shepard and Pařízková 1991; Steckel 1995; 2009; 2010; Steckel and Floud 1997; Steckel and Rose 2002; Walker et al. 2007, etc .

was born later than 18th century A.D.[10] The data are widely distributed in time and region, belong to all social classes, and include information on both men and women.

For determining height the length of the femur was used as it is the best predictor of stature and fortunately, it is also the best preserved long-bone. In order to reconstruct height from skeletal material over 40 different models were developed by different authors for the different long bones, and are in use in current research. Thus, in order to enable us to consolidate large numbers of data from different sources, we got rid of inconsistencies by recalculating the data to the basic femur length and based on this, standardise the heights reconstructed by the various methods originally used (Scheidel 2010). This way we ensure the crucial comparability of the data.

A basic requirement to reconstruct the height of an individual correctly is the knowledge of its sex and age at death. The sex needs to be known, since the correlation between bone length and height is sex specific, resulting in different transformation formulas. Correspondingly, we restricted the data to individuals that could be sexed satisfactorily. Secondly, the age is necessary to be known, since only the height of fully grown individuals should be compared with respect to nutritional status. Thus the study was restricted to humans aged 23 or older at the time of death.[11]
The archaeological background results in a certain dating insecurity; but we made sure to only take the definite dated observations (proof dating in one century) into account, and excluded individuals of uncertain dating, in order to reconstruct the development of the nutritional status. The temporal resolution of the final data set is a hundred years. Since the birth century is used as the unit of the analysis, this may result in an additional small uncertainty due to the assessment of the age of death of the individuals. Furthermore, the dating of graves in an archaeological context can be problematic. The problem of dating vagueness (birth century) was tackled by marking the imprecise data with a dummy variable and controlling for them by excluding them from the analysis. In the same way we also considered a possible bias due to varying burial customs (inhumation versus cremation). [12] Actually, whether we compare the temporal

[10] Some researchers only reported average height of the excavated individuals; 5041 separate height measurements are available.
[11] Because the growth period can be prolonged until this age due to inadequate nutritional status: see Tanner 1981; Komlos 1985; Moradi and Guntupalli 2004. In general, this actually is the age associated with the ephipysis of the claviculae, which takes place whenever longitudinal growth is finalised.
[12]In additon to imprecise dating, the effect of cremation has to be checked because the custom of cremation is not consistently distributed over time. Although results based on the commonly used

development of mean height based on the whole data or solely on the reduced one without the potentially problematic data does not make an important difference in the results concerning the development over time.

Moreover, the work with archaeological data sources naturally bears further caveats, such as the degree of preservation, measurement errors, and the equations for reconstructing the height from the bones. However, the effects of preservation are already taken into account in the height determination methods and therefore measurement errors should be low since the data used have been measured by trained archaeologists, and we created the new algorithms to standardise the data from different conversion methods.

The final data have been subdivided into three main European regions: Mediterranean Europe, Central-Western Europe, and North-Eastern Europe. The definition of the borders is based on basic natural-, and cultural-environmental aspects.[13] This sub-division enables us to control for different possible regional-dependent reasons for the development of the nutritional status. Together with the chosen time frame of the study, these regions allow us to tackle in particular the question of changes in nutritional status with the transition to Roman times, and during Roman times until the decline of the *imperium Romanum* in the West and the transition to early medieval times.

The data are given as mean height, both for men and women separately, and then combined and adjusted for female height (see Koepke and Baten 2005a; 2008). Of the compiled data we only considered those centuries for the study for which we could collect more than 35 individuals per major region (see Table 1).

The resulting development of the mean height in the long-run can be taken as reliable because we made sure to exclude uncertain data (see above) and ascertained that there is no large bias regarding the 'representativity' of the population, means we only took

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reconstruction model for cremated bones (cf Rösing) are combinable with inhumated bones reconstructed by the model used as algorithm basic (cf Breitinger/Bach) (thanks for friendly communication Prof. Wahl, Landesdenkmalamt Baden-Wuerttemberg & University Tuebingen), one has to have in mind that actually heights reconstructed on the cremated bone remains are siginficantly smaller than inhumated remains.

[13] The "Mediterranean Europe" in our sample includes Italy, Southern France, Spain, Portugal and the Balkans. "Central-Western Europe" refers to the UK, Benelux, Northern and Eastern France, Western Germany, Southern Germany, Switzerland, and Austria. "Northern and Eastern Europe" subsumes those regions that had only limited contact with the Roman Empire and its provincial economy: Scandinavia, Poland, Northern and Eastern Germany, and Hungary, the latter being included here because the large region east of the Danube was not fully integrated into the Roman imperial economy.

those cemeteries into account that included the whole population and not just some noblemen's graves. Moreover, the height data can be seen as representative due to their large number and their random collection from a large number of cemeteries from all over Europe.

Despite those issues the positive aspects of the method clearly dominate: the analysis of bones is of special interest for archaeological periods. Skeletal data contribute powerfully to the knowledge of former living conditions. And the data are sufficiently adequate to draw reasonable conclusions and to check hypotheses, whose accuracy could not be controlled for before.

3. Potential Explanatory Variables of the European Nutritional Status from 8th century B.C. until the 18th century A.D.

The first question concerns which variables (may) have an influence on the nutritional status and thus mean height. And this gives rise to the second question: How to get information on these potential explanatory variables for the long-run from 8th century B.C. until the 18th century A.D.?

Nutritional status is defined as the interaction of nutrient consumption (quantity and quality) and the negative effects of exposure to parasites, disease stress, and physical workload (Steckel 2009; 2010; McKeown 1983; Al-Dabbagh and Ebrahim 1984; Scott and Duncan 2002; Ulijaszek 2006). The nutritional status is adequate if the quality and quantity of diet is sufficient for the metabolic needs while offsetting any possible negative effects resulting from the other three main influencing factors. The quality and the quantity of food, as well as the other three direct determinants, parasites, disease and work load, depend on a wide range of indirect determinants, which therefore must be taken into account as possible explaining variables of mean height.

This study concentrates on the basic variable 'food quality and quantity'. The first aspect to consider is that this is a multilayered determinant. One has to distinguish between food production and consumption in order to define instances of adequate dietary intake.[14] These factors in turn are affected by various different aspects. For

[14] In addition to this necessary differentiation, food quality and quantity is not only determined by the mentioned other main direct determinants of nutritional status, but those are also complexly interwoven with each other. For example, diseases influence nutritional status on different levels: they affect digestion, but also food production. Also the exposure to parasites is closely interconnected to both, diet

example, insufficient food production can result from a variety of factors, from climatic conditions – or even weather changes – and limited agricultural productivity, to political problems (particularly war). Additionally, many possible causes of food poverty and deprivation exist, other than shortage in food production. Food allocation depends, for example, on transport, storage, and destruction due to parasites. Moreover, research on famine has found that massive hunger crises often arise despite aggregate food supplies being no less adequate than usual (Sen 1984; doubted by Ó Gráda 2009). Underlying reasons for differences in nutritional status of a population can be a variation in access to food for people of different social groups within a population and also for different people within a household.[15] In particular, if gender inequality is present this will result in unequal support and allocation between the concerned groups, affecting the mean height of overall population in the end (Osmani 1992; Osmani and Sen 2003); and this effect might vary in different times and regions.

For the centuries under study we assume that no significant changes in child labour seem to have taken place (Bradley 1991; Hindman 2009, esp. Hendrick in Hindman 2009, 33; Horn and Martens 2009), an also no decisive progress was made in health care and sanitation ('germ theory' was only introduced in the 19th century) with the consequence that disease environment and parasite exposure did not improve remarkably and generally everyone was prone to a similar disease load (Scheidel 2010). Some variation might have occurred due to differences in sanitary conditions or the availability of drinking water; and further exceptions in the temporal development are epidemic plagues, when a disease or parasite exposure affects the whole population. We tested these factors by dummies.[16] However, due to missing exact data concerning the health and work load conditions we were not able to test for them in more detail.
Those potential determinants that we hypothesise to be of relevance for the nutritional status, and which are actually testable for the periods under study, are discussed below.

3.1. Natural Factors

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and disease environment. Infectious diseases caused by infestation rank among the most common diseases in human beings (Frauendorf 2001; Oberhelman et al. 1998), in addition to the important direct negative effect of parasites: especially various kinds of worms derogate nutritional status, harming health and (thus or even directly) growth. For example round worms inhibit diet utilisation, whipworms produce diarrhea, and the dangerous types of tapeworm erode the host's body (Mehlhorn and Pierkarski 2002).

[15] In this paper it is, of course, impossible to study actual determinants on household level; but it is possible on a macro level.

[16] Sherman (2006), p.10: "the word "plague" comes from the Latin plaga meaning "to strike a blow that wounds".

Natural factors are area-specific effects, such as extreme altitude and local climates;[17] but since the populations examined in this paper come from similar environments these factors can be seen to have little or equal effects on the populations.[18] By using dummy variables for the three major European regions these general differences in natural and cultural environmental aspects are taken into account.

A natural factor that could however influence the temporal changes in nutritional status is the change in climatic condition. The annual variation in precipitation and temperature (including the related spread of vermin additionally affecting the food quantity) could have had an impact on the harvest, and therefore food security. Also, the effects of climate change can be different for various regions in Europe.[19] For the time after 800 A.D, different authors have recently analysed the overall climate change for the Northern Hemisphere. The summation of the results has been published by IPCC (2007). The temperature development resulting from twelve investigations is shown in figure 1. Here, the variability and consequently the uncertainty of the temperature curves are the dominant impression. An agreement has not been reached. However, both the climate optimum in the Middle Ages and the Little Ice Age can be seen. In contrast to older climate reconstructions it can be stated that the climate optimum comprises only a small temperature increase in the 11th century A.D. More pronounced is the Little Ice Age from the 15th to 17th century A.D., with a temperature nadir in the 17th century that is three times larger than the increase during the Medieval optimum. For the time before 700 A.D, only very little climate information is available (for details see Koepke and Baten 2005b).[20] It is a widely supported hypothesis that climate in terms of warming has a positive impact, respectively substantial cooling has a negative impact

[17] Basic height in populations living in polar or tropical climates is adjusted in terms of adjusted body surface to uphold the thermal-balance: being shorter to minimise, or longer to maximise heat loss population in Polar Regions (Jurmain 2000, 423 ff.).
[18] A natural variable, which could cause regional differences, is the extent of navigable water ways in a region, providing a special situation in terms of trading connections and thus food supply. But it cannot be tested for the effect of this variable in this study, because it is not possible to reconstruct, which of the smaller rivers were usable for transport of goods. E.g. it is proven for Roman times that 'Plattboote' (flat bottom ships) were used in the Rhine region, opening also shallow waterways for transport (Höckmann 1985), but for other regions and periods the knowledge is not available.
[19] General temperature change will have different effects for different regions: In a colder region temperature increase will be positive (Greenland during the medieval climate optimum), while it may be rather negative in an already warm region. The opposite holds for a temperature reduction, which could even improve regional climate conditions with respect to food production in the Mediterranean case.
[20] The only slightly longer series are Mann and Jones (2003), and Moberg et al. (2005), with reconstructed temperature from 133 A.D. onwards. But these data also show no significant statistical effect on overall mean height. Climate data going much further back in time are available (IPCC 2007), but have a resolution that is useless for this study.

on net nutrition (and thus morbidity and mortality) (see Baten 2002; Grove 2002; Pfister 1988). Koepke and Baten (2005b) showed that the negative impact of colder climate becomes perceptible from the ninth century onwards concomitant with the increase in population numbers.[21] Because climatic data are not yet available for the centuries B.C., climate was not tested for separately as a determinant in the current paper. Any possible temporal changes in the natural factors (including Northern Hemisphere climate changes) are subsumed into dummies standing for the periods under study.

3.2. Agriculture and Animal Husbandry

Essential for nutritional status are the type of agriculture products and the yields, which depend not only on the natural factors mentioned above, but also on the methods and technology used. For many pre-industrial people grain, whether as 'porridge' or bread, was the dominant part of their diet, especially in periods of comparably high population numbers (Hirschfelder 2005, 81 ff.; Walter and Schofield 1989; Drummond and Wilbraham 1991; Stone 2006; Miedaner 2006).[22] Since "meat and meat products were scarcely present in the diet … any element of protein … derived from cheese, milk, and butter must have been a particular significant addition to diet largely based on cereals" (Woolgar 2006, 100). Consequently, we assume that what makes the difference in net nutrition in the long-run is the additional supply and therefore consumption of dairy products. Moreover, the effect of milk depends largely on geographic proximity and local supply. This was the case due to transport limitations prior to the innovation of refrigeration.[23] The availability of dairy products was closely related to the scale of husbandry livestock (Woolgar 2006). The question remains whether (or not) its effect is visible in the very long run pre- and early historic data.[24]

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[21] Additionally, short time weather conditions may affect diet supply: Even a single frost night in late spring (when plants are in full bloom) can destroy completely the harvest of a year. Even today under comparably favourable conditions for agriculture – where compensating technologies are available (e.g. by fertilisers), a series of harsh, frosty springs has a negative effect on food production. Correspondingly, such a series could also affect the output for a century. Similarly, the inter-annual variation of precipitation can have an impact. However, weather data do not exist for the period before the 18th century A.D.

[22] The dependency upon grains in particular resulted in starvation due to harvest failure caused by the mentioned weather extremes (see Schofield in Woolgar et al. 2006, 247).

[23] Cheeses were tradable, but the archaeological findings do not indicate a widespread trade of this type of good as far as across the borders of the three major European regions.

[24] Koepke and Baten (2008) discussed the 'milk-question', and linked questions (such as lactose intolerance, production and consumption possibilities) in detail.

For recent centuries, several studies found that animal protein is an important factor for human height, and that milk in particular, can make an essential difference to nutritional status (e.g. Baten 1999; Komlos 1998; Baten and Murray 2000; Prince and Steckel 2001; Hoppe, Mølgaard, and Michaelsen 2006). This is, because the proteins, vitamins and microfibers of milk, whey and some cheese types are of especially high biological value, because they contain the amino acids, which are indispensable for growth as well as maintenance (Scott and Duncan 2002, 11). Did the development in milk and beef availability support an explanation for differences between major regions in the very long-run? Interestingly, several ancient authors (e.g. *Tacitus*) mentioned that the Germanic tribes (in contrast to the 'civilised' Mediterranean contemporaries) regularly consumed large amounts of meat and milk. This documentation started with *Poseidonius* (approx. 80 B.C.), who reported that the Germanic people enjoy "per extremity" grilled meat together with milk in their daily diet (*Poseidonius*, book 30). Similarly, *Tacitus* (*Germania* 5,1) and *Caesar* (*de bello Gallico* 6,35,6) emphasised that *Germania Magna* is rich in cattle and that the German tribes' pride is their cattle herd sizes (Thüry 2007). Notably dairy cattle are registered in the *leges Barbarorum* (e.g. in the L Bai IX,2, see Weber 1985) of the Germanic tribes dating from the end of the fifth to the end of the eighth century A.D. In contrast, traction power seems to have been the main motivation for cattle husbandry in the heartland of the *imperium Romanum* – and subsequent to Romanisation, perhaps also in some of the Northern provinces. Likewise, several authors emphasise the special value of large animals, particularly for traction power (e.g. *Cassiodorus, variae* 3,50).[25] However, several different sources indicate that cattle have always been used for their milk yield in addition to traction power, at least to some extent (Crabtree 1996; Seetah 2005).

To test this potential determinant, zoo-archaeological data on regional and temporal supply differences in animal husbandry were utilised. As is commonly performed in faunal remains quantification, we use the relative proportions of the different species in archaeological assemblages in order to extrapolate the relative importance of each species.

In contrast to absolute numbers, which would give a distorted picture, cattle share can be used as an indicator because, firstly, taphonomic biases tend to affect the total

[25] We can presume that even in the Roman case milk (other than cattle meat) was somehow seen as a product of interest in cattle husbandry – consulting esp. Pliny the Elder (*naturalis historia* 8,179), who stresses that the milk efficiency (and working capacity) even of the autochthonous cows was remarkable (actually highest) despite their smaller size.

number of surviving bones, but not the shares of large animal types. Secondly, changes in the relative composition of cattle bones in general reflect milk consumption, because cattle have always also at least partially been kept to produce milk. Furthermore, in general, the use of cattle for meat production was less important than its use for milk production due to its much lower efficiency in terms of protein gain, and the stronger influence of milk availability in human nutrition.[26] The third important fact is that the animal products were actually consumed in the region where their bone remains were excavated; correspondingly, we can test the impact of milk. Thus we can use the share of cattle bones in respect to the total share of large animals (the means of cattle, pigs, and sheep/goats) as proxy 'cattle share' for milk supply and consumption (see Koepke and Baten 2008).[27] The levels of cattle share are different for the major regions (Figure 2). The lowest cattle share is found in Mediterranean Europe, including an extreme decline that occurred during the centuries before the start of the Common Era. After the first century A.D. the cattle bone share stagnated on a low level until the sixth century A.D. The highest cattle share is found in North-Eastern Europe, with only a slight decrease over the course of the centuries. The Central-Western Europe series lies in between, with a substantial increase from the third century B.C. onwards, followed by stagnation in the cattle share from the second until the sixth century A.D., and a decline afterwards. Overall, the Mediterranean cattle share was constantly lower than the Central-Western one, with the share in North-Eastern Europe ranking highest.[28]

[26] Only some temporal and regional differences in the aim of cattle husbandry arose in the course of the long run, means especially the utilisation of cattle as draft animals for grain production in Roman times.

[27] The basic bone material we utilised for this approach was compiled and published by King (1999), Benecke (1986) and others.

[28] When comparing the development of the domestic animals species by regions (not shown), it can be found that in all three parts of Europe, the pig and cattle share developed more or less antipodally, whereas the sheep/goat share developed 'independently' and was overall relatively stable. Although the Romans substituted beef with pork the overall meat consumption was still relatively high in the Roman Empire (e.g. Jongman 2007) – albeit not necessarily *per capita*. Cattle husbandry provided particularly important advantages in terms of proximity to milk production, and meant that our results were not directly based on meat per capita values. By levels of absolute bone numbers, it can be conducted that the diet of the Mediterranean region with its high population density was probably marked by much lower overall meat consumption. The Mediterranean population was larger; and in the Mediterranean, only one seventh of the Central-Western Europe bone number was found, for the first century A.D. For the second century and thereafter, the gap is even wider. A part of this gap can certainly be explained by taphonomic distortions. It is unlikely that the Mediterranean population consumed more meat per capita than the Central-Western Europeans. The differential of pig bone levels is much smaller (only 1:3 in favour of Central-Western Europe in the first century A.D., and about 1:4 in *per capita* terms), whereas the differential of cattle bones is almost 1:20.

Another aspect with respect to milk availability is cattle plague (Spinage 2003; Barret and Rossiter 1999). Even today cattle plague causes devastation to livestock, resulting in heavy economic losses. Even more so one can presume that periods of livestock disease had a negative effect on the supply of animal protein and milk, as well draft power (and fertiliser[29]) when no effective vaccine was available.[30] The first descriptions of cattle plague and its effects come from Roman times (Barret and Rossiter 1999). Since the effect of cattle plague could be independent from cattle share we tested its possible impact for each major European region by a determinant 'cattle plague', which however, due to the archaeological background of the study, we only can approximate as a dummy variable. This is created based on the data collected by Spinage (2003, esp. 81 ff.) with '1' for centuries of known 'regional large-scale disease prevalence' and '0' for disease-free centuries.

Improvements in cultivation methods could also have had an impact on nutritional status. For the centuries under study the only improvement is the three-field crop rotation system.[31] This method meant the introduction of summer and winter crops, and also the introduction of the 'fallow fields'-method (Küster 2006) that led to soil regeneration as well as effective weed killing. This could have resulted in an increased harvest output.[32] There is a debate as to whether the crop rotation resulted in an increase in the quality and quantity of the output, having a positive effect on the population, or whether this was immediately counterbalanced by increase in population numbers (Grupe 2003 contrary Comet 2000), respectively whether the innovations are only initiated due to a previously occurring increase in population density (Boserup 1983; Cohen 1989; in contrast to Floud 1983). However, due to the 'dispersion' of risk factors over more seasons and due to a new diversity of crop types, the introduction of the three-field rotation technique certainly brought important improvements. In particular, it enabled the provision of fodder grain (oats) for livestock and grazing possibilities on the fallow land, whereas previously pastures were lost due to the complete shift to grain

[29] In addition, marling, lime, and conflagrative fertiliser were utilised; from the 13th century onwards ash was scattered about the fields (Comet 2000, 161). But none of these methods came near to the effect of modern fertiliser.
[30] According Barret and Rossiter (1999, 102) e.g. in the 19th century the loss of a very large part of cattle stock resulted in the incapacity to till the land which "led directly to the great Ethiopian famine of 1880-1892".
[31] The 'invention' of the metal plough had already happened earlier.
[32] E.g. Schultz-Klinken (1981) presumes that this advanced agricultural exploitation, esp. in combination with the introduction of the so-called 'Flurzwang' yielded larger surpluses.

cultivation. In addition, regular higher quality food increases the milk production of cows. Therefore one would expect that the three-field rotation technology improved yields and nutritional status (e.g. Wiese and Zils 1987). To test these different aspects a 'three-field rotation'-dummy was created: with '0' standing for 'untouched' centuries, and '1' standing for the 11th century A.D. onwards, when three-field rotation was certainly in common, widespread use.

3.3. Other Determinants

The essential factors for quantity and quality of diet/nutrition, both, production and provision, depend (besides the factors already mentioned) on population density and on concentration in settlements, which can be described as 'urbanisation'.

In modern pre-industrial societies there is a negative correlation between mean and population density (Dalgaard and Strulik 2009, 10). However, this is not necessarily the case for the long-run. In the early centuries of the our study period free land was available, with the consequence that an increasing population allowed for an increasing amount of land use for food production: land was abundant. With population growth, land became scarce in later pre-industrial societies. However, the question is when this limit actually was reached and whether there were differences for different regions. With population growth land became scarce in later pre-industrial societies. However, the question is, when this limit was actually reached and whether there were differences for different regions. Higher population density resulted in changes to land to labour ratios, which in turn resulted in declining marginal labour productivity. In Malthusian terms this means less food *per capita*. It also caused changes in agricultural production, which again reduced food availability (see Koepke and Baten 2008). Similarly, Woolgar et al. (2006) and Dyer (1998, 70 f.) found in the case of Medieval England: "As the population increased, quantities of livestock *per capita* diminished … This decreased productivity of agricultural land and animal husbandry, restricting for many both the variety of diet and amounts of food – and at some points, leading to starvation. … After the late fourteenth century (after the Great Famine and the Black Death) famine was a far less significant element … and the pattern of diet was considerably improved, with a greater availability of meat and dairy products". In addition, the dilemma of overpopulation (relative to the existing potential capacity for food production), which was reached towards the end of the 13th century A.D. in Central Europe, resulted in permanent settlements in regions which were unsuitable for agricultural production. This, in turn resulted in considerable impacts on “the local ecosystems … and … accompanying alterations of the landscape with its fauna and flora” (Grupe 2003, 281). Thus, overall different outcomes for changes in population density might be possible. We used ‘land *per capita*’ in order to depict population density.[33] For the periods under consideration, the data on population numbers are generally rough estimates, as is also the case with approximation of the urban rate (Zimmermann 1996; Zorn 1994). In order to control for population density we used data collected by McEvedy and Jones (1988). Their work is the only one which gives detailed population estimates on all European regions for the centuries B.C. in Europe.[34] We reconstructed population density for each of the three large European regions (see Figure 3).

How did population density develop in the three major European regions from the eighth century B.C. until the 18th century A.D.? Looking at figure 3 it can be seen that population was by far the most dense in the Mediterranean region until the 15th century A.D., when the North-Eastern and Central-Western Europe finally caught up. Overall, population density increased gradually in all the three European regions until the ninth century A.D, when a strong increase set in. Prior to this population decrease, it was only during the *imperium Romanum* that a dramatic increase took place (especially strong in Mediterranean Europe); but this development was ‘neutralised’ with the decline of the empire. Population density moved on at a reduced level until the boost that occurred from the ninth century A.D. onwards, mentioned previously. The total European population increased by about 140% between 950 A.D and 1300 A.D. (approximately 22 to 55 millions) (Comet 2000, 156). The only exception was the stagnation in the centuries that were negatively affected by the great plague, the Hundred Years War et cetera. Interestingly, the Thirty Years War is not discernible in the data in terms of an obvious decline in population numbers (see also Livi-Bacci 1991).

An even stronger negative effect can be assumed for urbanisation. This can result in a number of aggravating factors: the concentration of people living together

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33 In the regression analysis population density was included in logarithmic form to account for decreasing marginal product effects.

34 The numbers given in Zimmermann (1996) are primarily local estimates. Other estimates in the literature on prehistoric centuries are only discussing the whole world as one research unit. For the centuries AD different studies exist on single periods and regions. Looking at the ‘world level’ in all cases the estimates of McEvedy and Jones (1988) are comparably low values, but these fit together with UN-estimates: see webpage of the U.S. census Bureau, Population Division. Newer estimates would have been available for the later centuries; but those data were not used here, because the combination with the data for the earlier centuries could result in some discontinuity.

closely results in a more difficult equable provision of food in general – and urban dwellers had no access to non-tradable goods such as milk. Additionally, diseases could break out more easily (due to densely built dwellings, cramped circumstances with-in housing, bad air condition and water quality), and infections could spread faster. High population density also results in high rates of refuse disposal, which in turn has an impact on the parasite exposure and the disease environment. Moreover, the prices for goods were probably higher in towns than in rural areas due to transport costs and intermediate trade. Although, wages could also have been higher, Komlos (1998) states that, in general, commodities which result in a higher nutritional status, were less available and affordable for the average urban dweller. A further possible negative aspect is that "high levels of violence are commonly associated with high density living" (Scobie 1986, 433). Interestingly, the observation that cities are unhealthy places for living can already be found in several ancient texts (listed in Nutton 2000); however, no serious recommendations on the topic of practical improvements are given in the early written sources. Consequently, and far from implementation at a municipal level, no concept of 'public health' concerning the whole community existed (Thüry 2001).[35] In later centuries, other than exaggerated reactions to lepers, communal action to protect public health generally was more or less crisis-oriented, and not instigated as a precautionary measure. This only began to change from 1500 onwards (Carmichael 1995). In comparison to modern standards (Townsend 1979), early historic townspeople lived in poor housing conditions (with structural defects, inadequate facilities, and overcrowding). Scobie (1986, 402) describes the common situation as "similar to the shacks in slums today".

Food quality could also be affected by parasites, which presumably were particularly rampant in the urban environment. There might have been, however, regional differences in parasite exposure. In general, it is possible to measure vermin or worm infestation by the analysis of coprolite remains (mineralised or desiccated excrements) for the period under study. But so far, these kind of studies have been conducted only rarely (although started comparably early, see for example Aspöck et al.1973; Herrmann 1985), and therefore data are not adequate for the long run study. Therefore we cannot create a direct variable on parasite exposure. However, conditions were

[35] Exception seems to be the rule to bury the dead *extra muros* (Patterson 2000; Lindsay 2000); but in the absence of any other sense of settlement hygiene, this fact can rather be explained by the Romans being frightened of wraiths.

certainly worse in an urban environment (see for example Jackson 1988; Weeber 1990; Herrmann 1987) and correspondingly the parasite effects are incorporated in the 'urban rate' variable, which we created as a proxy-variable in order to test for the various urban effects.

We used data from Bairoch (1976) as well as Federico and Malanima (2004) in order to test whether urban rate might explain mean height.

How did the urban rate develop in the three major European regions? As one would expect (see Figure 4), in both Central-Western Europe and particularly in the Mediterranean region, the urban rate increases during the period of the Roman Empire, while this was not the case in North-Eastern Europe. In the centuries afterwards, population density experienced a decline, and then grew again all over Europe from the tenth century onwards.

Another determinant of possible relevance for nutritional status could be 'periods of supra-regional wars and persecution', if they affected large parts of the population. Correspondingly, we created a dummy-variable named 'war/prosecution'.[36] We only included those wars that would most likely have had an impact on the nutritional status due to their duration or intensity (e.g. civil wars in Mediterranean Europe at the end of the Roman Republic or the Thirty Years War for Central Europe). A possible effect resulting from war could be worsened nutritional status due to reduced working power, food damage, and long time fallow fields and scorched-earth tactics. However, improved circumstances could be possible for the survivors due to a reduction in population density, even leading to an overall positive effect for the remaining population. Therefore, temporal resolution better then hundred years would be an advantage, but is unattainable. As detailed information of the 'correlates of war' is only available for later centuries, for the long-run those centuries, during which conditions presumably affected a European region on the whole major level a dummy 'war/prosecution' was coded as '1', for the remaining centuries the dummy was coded as '0'.

Diseases affecting large parts of the population could have an impact on the nutritional status due to reduced working capacity and direct health effects. Various diseases existed in early historic times, and are described in contemporary written

[36] The available information stems from www.ancientworlds.net, and http://en.wikipedia.org/wiki/List_of_wars.

sources, but a clear taxonomy did not exist back then. For example, 'plague' stands for any severe disease of epidemic proportions. Ancient sources mention many different occurrences ranging from widespread ergotism (especially in medieval periods: Willerding 1986, 248) to the Antoninian plague. Moreover, major epidemics are commonly mentioned in Roman annals, but the cited epidemic diseases are actually only rarely detectable other than in non-literary sources. In order to capture a possible effect of major epidemics, we created a dummy for those centuries in which plague epidemics dominated the environment.

Another important human-made determinant is the socially contrived differentiation of roles for different genders. Gender specific effects can have an effect on overall well-being because the living conditions of the mother-to-be during her own growth period, as well as during the child's early life, can affect the next generation's height outcome. Under-nutrition of a child can start with malnutrition of the mother, because environmental conditions during growth of the future mother determine the body proportions of the gravida, and also the placenta, whose size is related to foetal, and infant growth (Leiarraga 2002; Hindmarsh et al. 2008). Poorly nourished gravidae tend to give birth to small babies, "which tend to show poor growth in … height over time. The cycle of poor nutrition, poor health, and unsanitary living conditions repeats itself" (Gopaldas and Gujral 1995, 226). Moreover, preterm birth (with additional negative effects on the child) is related to low maternal pre-pregnancy body-mass index (Merlino et al. 2006). In addition, foetal growth (and in turn postnatal height and health outcome) depends on the nutritional status of the mother during pregnancy (De Onis et al. 1998; Wu et al. 2004; Langley-Evans and Carrington 2006; Mericq 2006; Martin-Gronert and Ozanne 2006; Roseboom et al. 2006). A breastfeeding mother needs extra calories to meet complete diet requirements for healthy infants, and "mothers in communities suffering from malnutrition… may be unable to produce sufficient quantities of good quality milk to satisfy the requirements of the growing infant" (Scott and Duncan 2002, 151). Furthermore, during the lactation period, nutrition and nutritional status of the contemporary population is of special importance, because maternal nutrition influences lactational performance. Not only is mother milk per se of special importance for 'backing up' adequate nutritional supply and protection against infections in (pre-modern) underdeveloped societies (see for example Brown et al. 1998). Moreover, adequate nutrition for the mothers enables prolonged breastfeeding, which has both an important impact on the infants' health and stature, and results in extended birth intervals, which in turn means support for ameliorated maternal health during the next pregnancy (Scott and Duncan 2000). All these aspects indicate the importance of female living conditions for the next generation (Motarjemi et al. 1993; Marino 2007). Consequently, gender discrimination might be of special importance for mean height in general, and in particular, for explaining differences in average stature between males and females, if societies of different patriarchal structure are studied (Koepke 2009). We constructed the variable 'gender inequality' relative height difference.

3.4. Roman Impact

A further potential determinant influencing mean height is the expansion of the Roman Empire. In fact, the overall effect could be twofold – negative or positive – due to a vast conglomeration of factors subsumed in the Romanisation impact: these could range from changes in sheer population number to the process of 'Romanisation' in terms of establishing related changes in customs and techniques, as well as economic restructuring. For example, food customs in general were different in the *imperium Romanum* compared to the other European regions. The Roman expansion caused differences in the living conditions and welfare, and therefore presumably affected the nutritional status of the population, both in the core country as well as the area newly under Roman government in comparison to populations in the non-affected Europe. It would be possible that in the Italic heartland this involved utilising new arable land, a cheap supply of natural resources, a labour force (soldiers and workers) and the founding of new trading bases to enhance contact with regions further afield. In the case of the new provinces, as an result of the Roman impact positive effects could be induced by cultivation of new crops, such as the introduction of leguminosa improving the diet quality, Roman law (which might have brought some stability), and anything from a trading network to organised water supply.[37] Moreover, taking various aspects of infrastructure (such as public bathing or road net expansion) into consideration, a

[37] To some extent a positive impact also might be possible due to regularly consumed *garum* (fermented fish-sauce), although it is unclear whether the fermentation process reduced the protein quality significantly in comparison to fresh fish. Furthermore, for example, improved housing quality could have had a positive impact (stone houses with heating systems became common in Central-Western Europe during Roman times, which might resulted in lower energy intake requirements to sustain body temperature).

positive as well as a negative effect is possible. Negative changes probably took place due to wars conquering the territories;[38] this was followed by changes in the population density due to an influx of the army, civil servants, traders and their families, who fostered new customs of a wide spectrum, which presumably further affected net nutrition of a birth cohort negatively, such as comparably high exposure to lead at that time. The ancient Romans not only used lead water pipes, but also utilised lead in cooking pots, beverage storage vessels, toys, cosmetics et cetera.[39] This could be an important factor because lead is a toxin that affects growth – and thus height – negatively (see Stinson 2000, 434). In a similar vein, an attitude towards restricted breastfeeding and early weaning might have contributed negatively to the mean height development (see Barbiera and Dalla-Zuanna 2009). Furthermore, for the first time in European history, a 'non-subsistence-only'-economy occurred with the result that only a part of the civilian population was working in food production, whereas the other part had to be fed, what created a class of people (workers) dependent on wage income (Haines 2004).[40] Moreover, on the one hand, the fact that people had to make contributions to the army might have been disadvantageous for the mean nutritional status of the population.[41] On the other hand, the introduction of organised food supply

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[38] It depends on the region, whether the Roman occupation was more an integrative process, or performed as "extinctional" act: e.g. friendly trade contacts with the kingdom of *Noricum*, the Gallic War, or the annihilation of Alpine tribes. For an overview on the Roman provinces see Bechert (1999), with detailed bibliography on various aspects of military and settlement history, etc. It is unclear, how densely the indigenous people lived directly prior to the occupation, and therefore, what the effect of the Roman expansion actually was. At the time of Roman land-grab of the formerly (around 100 B.C.) frequently existing so-called Celtic *oppida* (and farms) only a small number of settlements were remaining in the Roman North-Western provinces (which are equal to our Central-Western Europe) (Reuter 2006; Zanier 2000). For example, for Northern Gallia Metzler (1995) found settlement continuity, but in the case of *Raetia*, on the contrary, the research discussion is whether even a population hiatus can be detected in the pre-occupation phase, which would have made the effect of the inclusion in the Roman Empire and resulting population dynamics even more extreme. The recent research opinion (Steidl 2007) is that there were certainly autochthonous people living, although the archaeological remains in the pre-occupation period are small. But nevertheless archaeology and archaeo-botanic pollen analyses provide evidence of continuity. Moreover, in particular the (early) post-occupational remains clearly speak for a presence and survival of the autochthonous population (see e.g. *Tropaeum Alpium* in La Turbie – a victory monument mentioning many defeated autochthonous tribes –, so-called military diplomas mentioning Celtic origin of the soldiers etc.). Of special interest are phenomenons such as the emergence of the so-called 'Heimstettener Gruppe' – female graves in Celtic tradition, with lavish folkloric costumes – in the second 'pre-occupational' generation, which is interpreted as revivalistic behaviour (as reaction on the cultural shock based on the newly introduced *ritu Romanorum*), which also indicates that no real hiatus took place.

[39] see Stuart-Macadam (1991) 103: From the written sources we know that lead was even "incorporated into wine in as many as fourteen [known] different ways as a preservative and to improve flavour", this maybe was also the case for some foods.

[40] Furthermore, this presumably resulted in an increasing inequality in income and wealth, and correspondingly aggravated the influence of food price fluctuations.

[41] Furthermore, the question arises in how far in the second century A.D. the introduction of the *annona militaris* (payment of the soldiers in non-monetary form, but food rations, equipment etc.) had a negative

for civilians might have reduced the impact of increased population density.[42]

In addition, the expansion of the Roman empire resulted in market integration of remote regions (a widespread road network was constructed), which could have had a negative impact on the nutritional status, presumably because it meant a subtraction of diet goods formerly available in the autochthonous periphery (Komlos 1994).[43] It also could be that market integration had a negative effect on social equality as heights became increasingly determined by wages.

The 'traditional' idea of Roman sanitation and hygienic facilities is that they were of a comparatively high standard.[44] Thus one would assume a possible positive effect. However, a closer look reveals rather inadequate conditions as the common feature: baths were often unclean and unhealthy places as according to the written sources the ancient doctors advised their patients to visit the *thermae* as a cure for illness and water seems not to be exchanged on a regular basis (Scobie 1986; Thüry 2001). Furthermore, *cloacae* were constructed inadequately, and were insufficient in number.[45] Water for consumption was commonly drawn from public wells (Filgis 2005), and the danger of contamination is mentioned even in ancient sources (Thüry 2001). Additionally, in Roman times people seem to have had a poor awareness of hygiene (as emphasised by Jackson 1988). Sewage and latrines were often located near to wells and to kitchens. Even rivers, which were used to supply drinking water, were also used as garbage dumps. This resulted in a wide spreading of parasites, which became even intensified due to the common use of public latrines, resulting in the spread of bowel diseases into vast parts of the population. The circulation of pathogens and diseases was augmented with the expansion of the *imperium Romanum.* The impact of Rome's conquest and 'unification' of formerly isolated regions in terms of infection conditions is a notable risk (Duncan-Jones 1996; Stannard 1993). Moreover, the army's movements and trade

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impact. This was presumably the case in those regions, where the military was based, and where the local people were in charge of the supply of the soldiers. Kloft (2006, 116) presumes that these compulsory levies (esp. in combination with further rigid tax policies) caused distress and misery in the civilian population.

[42] Furthermore, this resulted presumably even in an increasing inequality in income and wealth, and, correspondingly aggravated the influence of food price fluctuations.

[43] Due to the integration transaction and transport costs decreased, and a high percentage of the locally produced high-quality food was withdrawn from the rural autochthonous population and sold to townsfolk and armed services.

[44] As many scholars presumed, having in mind *aquaeductūs*, and esp. *balnea* and *thermae* of complex technology.

[45] In the cities of Rome or Pompeii, households were by no means endowed with a comprehensive channel system, or other sanitation equipment; in most of the smaller cities sewage and all other rubbish was apparently 'led away' directly onto the streets. E.g., even from the famous *Cloaca Maxima* sewage was funnelled into intra-urban sections of the river Tiber.

contacts resulted in long-distance disease propagation, affecting more people, and thus increased the severity of diseases with the resultant impact on the economy. For example, the Roman army spread the so-called Antoninian plague (around 170 A.D.) over the whole empire after the Parthian War with a decisive impact on the economy. Moreover, no proper discourse took place considering public health or urban pollution (Nutton 2000). Average health conditions were thus rather bad.

To test whether an overall effect of being part of the Roman Empire we generated a dummy-variable coded as 'Roman bath/technology', being '1' for centuries and regions belonging to the *imperium Romanum* and '0' for unaffected parts.

4. Results

4.1. Development of European Mean Height from the eighth century B.C. to the 18th century A.D.

The overall height development in the long run, over 25 centuries from the early Iron Age onwards, separated by the European major regions Mediterranean, Central-Western, and North-Eastern Europe, of males and females pooled is shown in figure 5.[46] This estimation of the development over time is based on Weighted Least Square (WLS) regression on the individual level with variables for each century (birth century "cohorts").[47]

[46] Because the topic of gender specific height development is a complex additional aspect this issue is studied in more detail in a further working paper (Koepke 2009).

[47] This method has further been used to check the mean height difference between females and males, and to control for social status and migration. For details see Koepke and Baten (2005a). The explanation is that the socio-economic status tends to determine childhood diet and other living conditions (Gunnell et al. 1998). It is a coercive determinant in societies with inequality. Because socio-economic status has an important influence on mean height, particularly in early-modern times, it even has been used to reveal status differences in past societies (Floud et al. 1990). In fact, mean height can differ even more between different social classes of one historic population than between the elite of different populations (Eveleth 1979; Wolański and Siniarska 2001). E.g. in the case of ancient Mycenae the difference in stature of high class and lower strata comprised a notable 6 cm, which Angel (1984) explains with royal nutrition including "more meat protein than the average citizen got" (66).
Migration might determine mean height, because environmental living conditions in the first years of life have the largest influence on adult height, and in comparison to autochthonous people, the migrants probably experienced a different environment during that phase of life. Thus, one would expect a difference in mean height.

The new, enlarged data set confirms the previous results of the earlier one (Koepke and Baten 2005a; 2008). In both data sets the up- and downward movements in mean height are more or less the same, however with reduced extremes in the enlarged data set.
The main finding concerning the long run development is that over the course of the centuries under study there was a slight upward tendency in all of the sub-regions. This was strongest for Central-Western Europe and lowest for North-Eastern Europe. Overall, it is only a modest increase in mean height of about 0.5 cm per 1000 years, and there is no constant upward trend: the data indicate strong temporal variations.[48] If we look at the temporal development more closely we find periods when people were taller were continually succeeded by periods when they were smaller indicating that more beneficial and detrimental centuries alternate; the Mediterranean region shows the largest variability. Nevertheless, overall conditions seem to have improved even prior to industrialisation.

Overall, we can state that the North-Eastern Europeans did comparably well: on average they are the tallest. This is what one would expect based on low population density and a protein-rich diet. The height series indicates that North-Eastern Europe lost the leading position in the 17th century A.D.; this might be due to the Little Ice Age having a particularly strong effect in the North-East (compared to Central-Western or Mediterranean Europe) (contrary Kelly and Ó Gráda 2010). The Mediterranean population shows on average the smallest mean height, indicating people there lived under less favourable conditions. In between moves the height series for Central-Western Europe – the region that temporarily was under Roman occupation.

When we consider the temporal development in more detail, it seems that the Roman times were particularly harmful.[49] Mediterranean mean height decreases in the first century B.C.[50] One reason for the deterioration could be contemporaneous changes in

[48] But we cannot go that far as to speak of cycles. Our temporal solution does not allow us to test for an association with business cycles (Komlos 1998; Sunder and Woitek 2005).
[49] Beforehand, during the eighth to third century B.C. mean height moved quite consistently around 168 cm in the Mediterranean region, while for the other two regions mean height is going up and down alternately for each century. However, one has to keep in mind that the data are comparably scarce, which might explain the variability making an interpretation for these centuries difficult. Thus, one only can conclude that conditions were more or less stagnating.
[50] The finding is in accordance with the preliminary result by Jongman (2006) who found a similar development of an extreme increase in ancient Roman mean height from the first century B.C. to the first century A.D. Moreover, the underlying observations can be directly compared to the observations dating in the first century A.D., because all of them stem from the Italic heartland. The low mean height in the Mediterranean region in the first century B.C. is also not caused by a particularly small number of observations.

the availability to animal protein as we know that with the expansion of the Roman Empire came a shift towards an extremely grain-intensive agriculture, which became the basis for the food supply system in Roman times.[51]

The first century A.D. shows increased height in Mediterranean and Central-Western Europe, probably due to stabilisation during the early Principate under Emperor Augustus (the famous *pax Augustae* coming after a long period of distress during the Roman revolution and civil war). The subsequent centuries of the main Roman period did not bring a positive development in mean height. Particularly remarkable is the mean height decline in both regions affected by the Roman impact – albeit to a lesser extent in the Mediterranean case – in the second century A.D.[52] As this period is regarded as the ancient Roman 'heyday' century with a pronounced economic upswing (see e.g. Wilson 2009) this finding is rather unexpected at first glance, because it is in stark contrast to the common idea of Roman suzerainty being advantageous. However, taking into account economic historic studies on more recent centuries in combination with ancient sources this finding is not so astonishing, though still remarkable. Actually, this finding seems to reflect another economic 'growth puzzle' as it was found for the early Industrial period (Komlos 1998). Nutritional status is often linked positively to overall national economic development (for example, Arcaleni 2006; Fogel 2004; Komlos 2007; María-Dolores and Martínez Carrión 2011); nevertheless, this does not mean that economic growth always can be associated with overall beneficial biological well-being, as the 'Industrial Growth Puzzle' shows. In addition to 'urban height penalty', factors such as increased inequality and inadequate or unequal food distribution and availability can result in stagnating or decreasing mean height despite a national economic increase (Steckel and Floud 1997; Baten 2000; López-Alsonso and

[51] Another assumption is that climatic conditions worsened during late centuries B.C.: see Schönwiese's hypothesis (1995) of the general Northern hemisphere climatic development during these centuries. Additionally, the remarkably low mean height in Mediterranean Europe in the first century B.C. might partly be explained by the first expansion waves resulting in the neglect of agricultural production, in favour of a focus in supplying troops with armament, and the dispatch of men to the frontiers (and therefore a withdrawal from the local economy). Similarly, also the decline in mean height in first century B.C.- Central-Western Europe can be explained by the negative impact of military 'infringement' due to both, immediate killing of people during the primary occupation phase and subsequent relocating esp. of autochthonous men to prevent rebellion (compare Steckel 2004b). This occurs in combination with the arrival of additional people due to the mobility of the Roman administration, traders etc. These aspects reduced the available food resources per person, introduced new diseases, et cetera. But unfortunately, this hypothesis has to remain rather speculative as one only can get an idea from the literature, but no exact numbers to work with quantitatively.

[52] Strictly speaking we would have to utilise Italian data, if we want to control for the impact of Roman expansion on the 'mother country'. But as our Mediterranean data mainly consists of observations from this region anyhow 'Mediterranean Europe' is used here in terms of 'centre of the *imperium Romanum*'. Roman expansion within this part of Europe is taken hold of by the temporal solution.

Condey 2003; Haines 2004; Łaska-Mierzejewska and Olszewska 2007; Chanda et al. 2008). Applying this reasoning to the more recent centuries of the period under study, whilst also considering the information that archaeological findings and ancient sources give us, we suggest the counter-hypothesis that conditions worsened due to the increasing expansion of the Roman Empire.[53] The Roman effect 'subsumed' various related aspects. A large increase in population density was correlated with a low amount of animal protein available in the diet as well as an increased distance to protein production. Taking ancient authors into account, for example, gives us the information that during the Roman Imperial period in particular, milk intake was considered barbaric. This attitude might have played a significant role as milk is an important factor for longitudinal growth (especially in pre-industrial populations). Further possible associated reasons are the increase in urban rate worsening the sanitary and health environment, and/or cultural aspects resulting in changing consumption patterns (see chapter 3). The perceived decrease in Central-Western Europe could also be explained by similar market integration related processes, as for example Komlos (1994) found for Austria-Hungary of the 18th century A.D.: with the expansion of the Empire the established economic structure changed. Additionally, the construction of long-distance roads in this context presumably even changed the settlement structure as the concomitant creation of road service areas resulted in the growth of existing settlements as well as the emergence of new settlements, which in turn augmented an increase in population density, and all the succeeding factors influenced nutritional status negatively. What additionally confirms the impression of a malign Roman impact is that no effect is visible for the unoccupied North-Eastern European regions.

In Central-Western Europe in the third and fourth centuries A.D. mean height stagnates however at a higher level than in the second century. This is interesting because, the third century A.D. is often labeled as the century of crises that lead to the

[53] Roman imperialism started in the Italian home country in the third century B.C., and the region was Roman until the fifth century A.D.; Roman imperialism was expanded to Central-Western Europe from the first century B.C. onwards, and Roman impact remained active until the fourth century A.D. On the contrary, throughout this time North-Eastern Europe remained (mostly) unaffected by the expansionism of the ancient Romans. This means that this region stayed free from Romanisation, and was affected by the Roman imperialism only to a negligible extent in terms of single trade contacts, and a few foundations of *emporia* and military bases east of the Rhine during the first years of the first century A.D. prior to the *clades Lolliana* ("battle in the Teutoburg Forest", now located at Kalkriese, near Osnabrück). That the contact between the empire and regions outside was rather loose can be also seen e.g. in the spreading of agricultural techniques which were not introduced beyond the *limes*.
This is in concurrence with the finding of no decisive change in North-Eastern European mean height during the first to fourth centuries A.D.

decline of the Roman Empire (Nuber 2005).[54] Therefore, we would have expected decreased mean height due to decreased living conditions, resulting from unstable political conditions, such as the turmoil of the *imperium Galliarum* (Gallic Empire) and the related civil war. However, recent excavations indicate a period of reconstruction (such as repair measures), which show that conditions might have not been extremely adverse. Additionally, 'barbaric' attacks might have been less extreme than one would expect, as a mutual acculturation took place (such as Germanic mercenaries in the late Roman army). The current archaeological, numismatic and historic sources have made no clear statement.[55] What seems to be clear, according to the newest archaeological excavations, is that there was no hiatus between remaining late Roman and early Merovingian residents (Fingerlin 2005; Nuber 2005). This is confirmed by our findings: the situation in terms of nutritional status was apparently not as bad. However, the finding could also be caused by a 'counterbalancing' effect due to reduced population numbers as a result of the Antonine plague and turmoil (Figure 3) in combination with a return to an emphasis on 'proximity to protein' in agriculture.[56] Likewise, in the fifth century the nutritional status of the provincial people in Central-Western Europe did not change despite the political turmoil. However, the end of the Roman Empire and the 'setting' in of the main Migration Period resulted in a very pronounced increase in Mediterranean mean height, indicating particularly improving conditions in the nutritional status of the former Roman heartland after the decline of the *imperium*

[54] Although one has to take care not to over-interpret changes in archaeological material distribution (see Wilson 2009). Several archaeological findings indicate worsened conditions. E.g. toward the second half of the third century A.D. increased abandonment of *villae rusticae* seem to have taken place in Central-Western Europe. People moved back out of the open country to densely settled hilltop sites. This is probably due to not only the political changes, but also to the previously extensive utilisation of land due to an eluviation of the soil (Gaitsch 2002); the disappearance of people is also detectable by the re-forestation. Also, Germanic settlers started to colonise the provincial regions. Furthermore, a transformation of the appearance of still existing towns took place from the mid third century A.D. onwards in the Central-West, and in 'Italy' from the fourth and fifth century A.D. onwards (Krause and Witschel 2006): All cities (some sooner, some later) received defence walls – that generally enclosed a smaller area than before – to reduce the danger of invasion. Moreover, on the Iberian Peninsula large late Roman villas were still in use by the Visigoths (Bowden et al. 2004).

[55] E.g. in the case of the Rhine-Danube-provinces the comparably high number of hoards dating to the third and fourth century A.D. speak for the fact that the former owner presumably died in the course of a raid (because otherwise he/she would have recovered his possessions some day); however, these findings do not indicate how bad the attacks actually had been. Similarly, the findings of contaminated wells (at least in cases where carcasses were used for this purpose) can be interpreted differently: destroyed by the enemy, or spoiled by the former owner to leave behind conditions as worse as possible for incoming Germanic settlers (*Alamanni*) when heading south fearing the arrival of the enemy, which actually would not have been so disastrous.

[56] Likewise, for example, data on Northern-Italian sites support this hypothesis indicating that cattle became ample in the early Middle Ages (Giovanni 2001).

Romanum.[57] This might be explained by the renewed proximity-to-animal protein that is noticeable, in particular in this region, where an extreme change in dairy husbandry took place (Hirschfelder 2005, 96 f.), as well as a steep decline in urbanisation (see Figure 4) and cultural aspects.[58] Notably, mean height is on the same level in all three major regions in the fifth century, being the 'climax'-phase of the Migration Period, which resulted in equal economic conditions all over Europe. Same accounts for the sixth century A.D., with the exception of the Mediterranean region, where the disintegration of the Roman world in the west, in combination with the Justinian plague, seem to had a negative impact on living conditions.[59]

During 11th and 12th century A.D, mean height moves on a higher level in Central-Western Europe and in particular in North-Eastern Europe, but not in Mediterranean Europe. This can probably be explained by the medieval climate optimum (see Figure 1)[60] taking into account that a positive effect of increasing temperature could be of larger importance for the Northern regions, and even have an opposite effect for Mediterranean Europe.

A negative effect of the crises of the 14th century (Hundred Years War, Great Famine, and the plague) cannot be seen. Again, a reason could be that a negative influence might have been levelled out by the positive impact of a reduction in density of the contemporary population (see Figure 3), which cannot be distinguished due to the crude temporal resolution of our data. Mean height experienced a decline in the 16th and in the 17th century, especially in North-Eastern Europe. This development might have been caused by the coldest phase of the Little Ice Age (LIA) (Figure 1). The hypothesis that the LIA had a significant negative effect can be found in Jordan (1996), in contrast to Kelly and Ó Gráda (2010), which indicates that temperature alone is not suffient to estimate climate effects on nutritional status. Negative effects for nutritional status could also have resulted from the Thirty Years War, which presumably caused a decline

[57] This result is confirmed by Barbiera and Dalla-Zuanna (2009).

[58] Concerning Roman ideals in terms of cultural-environmental factors, of particular importance presumably was the change towards intensified breastfeeding, in particular in combination with an improved adult and thus maternal nutritional status resulting in an improved immune defence and correspondingly advantageous starting conditions for the next generation (see Barbiera and Dalla-Zuanna 2009; *Dittmann and Grupe 2000*). Unfortunately by now not enough data are available in order to test this potential effect.

[59] Counterbalancing positive effects resulting from reduced enforcing powers of elites, such as tax burdens, in the 6th to 8th century (see Wickham 2005).

[60] Although it was not as extreme as previously thought, see very recent climate research (IPCC 2007, Figure 6.10). However, based on the available data Koepke and Baten (2005b) found no important difference between the regions.

in welfare due to aspects such as 'scorched earth' policies and a deteriorated disease environment.[61]

Our findings confirm studies on smaller temporal and regional level, such as Barbiera and Dalla-Zuanna (2009; with overview on further studies), or Cardoso and Gomes (2009), and Steckel (2004), as well as our earlier results (Koepke and Baten 2005a) in that firstly, wellbeing during the Roman period was comparably adverse;[62] secondly, that mean height reached higher values both before and after the Roman period; and thirdly, that in post-Roman times particularly the early medieval period was advantageous for the biological wellbeing of Europeans.

But what actually explains this development?

4.2. Approved Determinants of European Mean Height from the eighth century B.C. to the 18th century A.D.

In addition to the aim of this paper to depict the development of the human mean height, we performed panel data analysis to test for the impact of several different independent variables on mean height, discussed above. The basic regression model bears mean height of a population MH_p as dependent variable, changes in it being explained by independent variables $EC_{i,p}$.

$$MH_p = \beta_0 + \sum_{i=1}^{I} \beta_i \cdot EC_{i,p} + \varepsilon$$

The extents to which the mean heights of different sub-groups vary indicate the degree of varying independent environmental conditions.

We conducted WLS regressions with dummies for the periods[63] on the major regions level (equivalent to fixed effects). All models are weighted by least squares to limit the

[61] Unfortunately for this time we could not compile any data for Mediterranean Europe, where both the effect of climate and war should be less pronounced.

[62] Consequently, our findings also verify that Jongman (2007b) was mislead in interpretating pre-liminary data he cited (as already indicated by Scheidel (2010, 5), and that correspondingly also his critique on the result of Koepke and Baten (2005a) are obsolete.

[63] Prehistory was separated in an early (8^{th} - 5^{th} century B.C.) as well as a late part beginning with the 6^{th} B.C. as around 500 B.C. in Central-Western Europe (and far into France, and also Spain) the change of the Early Iron Age to Latène period took place, and approximately parallel in the North-East the Jastorf culture arose, and on the Apennines Peninsula the Etruscans 'entered' their golden age after centuries of formation. It follows the ancient period which starts differently in the different regions, but continues approximately similarly long in any of the three major European regions until the 5^{th} century A.D. when the Migration period/early medieval ages set in, followed in each region by the high and late medieval periods, from the 10^{th} and from the13^{th} century A.D. onwards, and the modern period starting with the

danger of a wrong assesment in case of also including centuries with a small number of observations.[64] Additionally, to ensure best reliable results, we discarded those centuries for which we were only able to collect less than 35 height observations for each region. As the reference group we used Central-Western Europeans of the Migration Period/early Middle Ages, because this is the best represented group in the data set.

Looking at the base model including all possible testable variables, we find that it has an explanatory power of 49 % (Table 2, col. 2 and 3).[65] However, most of the variables controlled for in the model have no statistically significant impact. Even innovative changes in the cultivation method make no change. The probable explanation for the missing effect of the utilisation of 'three-field rotation' is presumably the parallel exponential increase in population numbers. Controlling for changes in the cultivation methods solely we found this determinant to have a positive impact on the long-run height development: it is statistically significant on the 1% -level (not shown). Exceptions are the period dummies for late prehistory and antiquity: both are statistically significant – at the 5%-, and the 1%-level; in both periods people were on average shorter than during the early medieval ages.[66] In terms of economic significance, higher cattle share results in a 0.59 cm increase in height, whereas the estimated log land *per capita* is also economically insignificant.[67]

Column 4 and 5 in Table 2 show the results if we do not control for cattle share and land *per capita.* The adjusted R_2 is 0.43, and the regional dummy 'Mediterranean Europe' becomes statistically significant at the 5%-level[68]: Overall, Mediterranean Europeans were smaller in height than the people stemming from the other European regions. Both factors 'cattle share' and 'land *per capita*', subsume the beneficial aspects of a pastoral economy (Sandberg and Steckel 1987, Haines 1998, Prince and Steckel 2001, or Moradi

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16th century.

[64] The data are weighted by regional share share and gender share. Females and Males are pooled; female mean height adjusted to male mean height; thus gender dimorphism should be controlled for.

[65] We included all discussed variables except for climate, as data on this variable only cover the centuries A.D., whereas we have (as describe above) a much better temporal composition in height data. In a model where the climate variable was included (not shown here) the former finding could be verified that warmer temperature is of no significant importance for overall mean height in the long run. That even the Medieval climatic optimum had no significant positive impact can probably be explained by the contemporaneous large increase in population.

[66] A possible explanation, which we unfortunately cannot test at this stage of climatological research (see above), is the comparably detrimental climate in comparison to the reference group; at least for the pre-historic period climatologists give a first assumption that climate was presumably comparably bad; this could be also the case for antiquity, as their presumption that climatic conditions were rather good concerns the later Roman period from the second century A.D. onwards.

[67] Economic significance is based on the multiplication with the standard deviation.

[68] If we exclude only cattle share from the model the 'Mediterranean Europe'-dummy also becomes statistically significant, but on the 10%-level. Moreover, the adjusted R_2 decreases a little.

and Baten 2005). The two variables are proxies for proximity-to-protein and a comparably good epidemiological environment, which are not present to a similar extent in the Mediterranean region in comparison to the other parts of Europe. This finding clarifies that it is not genetic differences between different European populations but the different environmental circumstances that explain the height differences between Mediterranean populations and North-Eastern European population. Thus we can confirm for the very long run, what already has been found for early modern Europe (Komlos et al. 2003, Quiroga Valle 1998).

In a third model (Table 2, col. 6 and 7) we concentrate on the two crucial variables: cattle share, and land *per capita*.[69] In this model (adj.R^2 of 0.30) cattle share is positively statistically significant at the 1%-level. But even in this reduced model land *per capita* is insignificant.[70] Hence, the potential contributions of the protein proximity effect seem to be particularly decisive, and much more important than population density. As discussed above, the reason might be that land *per capita* did not yet matter as much for the periods B.C., or because in this case the estimates are less precise.

To test in more detail a possible negative impact of adverse living conditions in terms of epidemiological conditions and actual supply situation, we control for 'urban rate' in combination with the other possible determinants in a further model (see Table 2, col. 8 and 9).[71] This model can explain 61% of the total variation in mean height. Here higher urban rate has a statistically – namely the expected negative – effect on mean height (p-value 0.01). However, none of the other variables are statistically significant except for the time-dummies comprising both pre-historic periods (on the 5%-, and 1%-level).[72] Both regional dummies become insignificant if we do not control for urban share. Mediterraneans seemed to have lower mean height because in this region not only was husbandry was carried out to a lesser extent, but because there was a higher urban rate there, which had the presumed associated detrimental effects such as bad hygienic conditions and the distancing from (the) food production (as discussed above).

In columns 10 and 11 the first model was varied by supplementing the 'Roman bath&technology'-dummy instead of the time dummies in the regression (adj.R^2 is 0.44), revealing that actually the 'gross-effect' of being part of the Roman Empire was

[69] Results are more or less the same, it does not matter whether gender inequality is included or not.

[70] The importance of this determinant, which was discovered in an earlier paper, counts for the centuries A.D. – especially the ninth century onwards, when population pressure obviously became essential.

[71] Except for cattle share (and ln land *per capita*) to prevent multicolliniarity

[72] A possible explanation for the statistical significance of the pre-historic periods affecting mean height in any case could be the supposed, but by now not testable effect of worse climate conditions.

negative: The ‘Roman bath&technology’-dummy has a statistically significant negative impact on mean height of -1.46 cm (on a 1%-level). But again, none of the other variables turn out to be significant. We find that, other than what the temporal development by the major regions (discussed above) would suggest, the ‘Roman impact’ actually had a considerable effect on the provinces outside the Italic heartland. Controlling for the effect of ‘being part of the Roman Empire’ for each concerned region solely (not shown here) we found the impact for Mediterranean Europe was more extreme than for Central-Western Europe – corresponding with the impression one gets, studying the temporal development. However, the Roman influence is negatively significant in both regions.[73] Also in this version, the insignificance of the ‘Mediterranean Europe’-dummy disappears as soon as one excludes cattle share (and land *per capita*) from the model (not shown).

If we control solely for the ‘Roman effect’, cattle share, and land *per capita* (Table 2, col. 12 and 13) the first of these variables remains statistically significant, and additionally cattle share is positively statistically significant (both on the 1%-level). In terms of economic significance overall the positive impact of a higher cattle share predominates the negative Roman impact: +0.6 cm versus -0.5 cm (see Table 3). Although this regression model has a lower adjusted R_2, it can still explain 43% of mean height.

The regressions confirmed the hypothesis that higher cattle share had a positive impact, whereas increasing urbanity, as well as ‘Roman bath & technology’ have a significantly negative impact.[74] Overall, the negative aspects of belonging to the Roman Empire outweigh the positive aspects. Those aspects were not sufficient to make the Roman period an improving one in terms of nutritional status: Our results display a negative effect for nutritional status in the affected European regions.[75]

[73] Testing the Roman impact by single region we found the Roman impact to be also significantly negative in the Central-Western case (albeit affecting mean height a little less than in the South): -1.14 cm, p-value 0.02 in Central-Western Europe, in comparison to -1.57 cm, p-value 0.01 in Mediterranean Europe (not shown here), and as expected, no impact on North-Eastern Europe. The Roman impact on Mediterranean Europe remains negatively significant also if we exclude the extreme low value of the first century B.C.

[74] Because of a certain dating insecurity (due to the archaeological basis of the data) the impact of the discussed possible determinants for only those observations, for which an exact deposit date could be ascertained, was studied, to discard possible estimation errors. The results are very similar: The only determinant of statistical significance is urban rate (not shown here). This also applies to the results if one excludes heights stemming from cremation burials (which actually provide a statistically significantly lower mean height than data from inhumations).

[75] In terms of food supply, an important factor certainly is that the concentration lay within the feeding of people with calories to enable their surviving, whereas an adequate supply with animal protein could not be provided.

5. Summary

The final adult mean height of a population subsumes the nutritional status during the growth period that is 'composed' chiefly of quantity and quality of diet, disease and workload, and therefore linked to multiple levels of living conditions. This fact provides the possibility of measuring differences in nutritional status by using mean height as indicator, which enables the study of welfare in periods for which no adequate written sources exist, but where physical anthropological data are provided.

This anthropometric approach was employed on skeletal material from Europe, dating from the 8th century B.C. until the 18th century A.D.

Overall, the results of our previous study, restricted to the centuries A.D. (Koepke and Baten 2005; 2008) have been confirmed by the much larger data set in the current paper. Firstly, variation between centuries and regions indicate that there was no large-scale improvement in European biological well-being in the course of the approximately last three millennia. Nevertheless, nutritional status seem to became better even prior to the industrialisation.

Secondly, in contrast to the common idea of a positive Roman effect due to the influence of 'civilisation' (Ward-Perkins 1995) the fact of being part of the Roman Empire and the accompanying changes – including any efforts made by the administration – did not result in improved living conditions for the European population. Instead our new results confirm the finding by Koepke and Baten (2005a; 2008) as well as other scholars concentrating on Italy (e.g. Barbiera and Dalla-Zuana, 2009) that the Roman impact was in fact negative, especially for the Mediterranean region. European nutritional status worsened with the transition from Iron Age to Roman times, and ameliorated from Roman times to Early Medieval times (and declined again afterwards).

Thirdly, for the extended study period from Iron Age onwards we found variation in mean height to be significantly explained by milk availability and the urban rate. Testing for cattle share (as proxy for milk availability) we found that height differences between the regions can be explained by inequalities in net nutrition: if husbandry was present providing the population with dairy products, basic human needs were met comparably well. Consequently, the statement of earlier scholars who supposed that height differences between Mediterranean Europeans and North-Eastern Europeans in pre- and early history were genetic is corrected by our results.

The second important determinant for mean height in pre-modern times is urban rate. The negative effect of increased urbanisation is in line with the idea of problems with the availability of food and detrimental health conditions in pre-modern towns.

In the range of testable potential determinants newly compiled for this study none of the other supposed explanatory variables had a statistical significant impact on mean height in the long run. On the one hand, the insignificance of the variables may result from the vague information on the determinants, which results in rough proxies. In particular, this presumably holds for war/prosecution and cattle plague. On the other hand, the finding of no significant impact can be explained by ‘counterbalancing effects’: for example, in the case of the ‘three-field rotation’-dummy, the missing impact might be explained by a very dense contemporary population. Compensating effects might also operate in the case of war/prosecution and plague; however, this cannot be differentiated due to the low temporal resolution of the data available.

The missing impact of population density in the course of the 25 centuries might be explained due to the (more or less) unrestricted available land in pre-history, but also in this case again counterbalancing effects could be the explanation for the missing impact of land *per capita*. This indicates that in the long run the assumption of the “Malthusian trap” might be correct: as soon as population density decreased, nutritional status improved, which immediately initiated an increase in fertility rate, and thus an increase in population density (or decrease in land *per capita*), which resulted in inadequate nutritional status, and vice versa. Similarly, Scott and Duncan (2002, 15) summarise that “density-dependent constraints (operating via exacerbated malnutrition) reduced fertility and increased child mortality, thereby returning the community to steady-state conditions”. However, this Malthusian ‘up and down’ cannot be analysed in this study due to the low temporal resolution of the data. It could also be possible that the explanation given by Boserup (1966) is correct when she argued that in the course of time there will be technological adaptation and investments in land so that the large population can be fed. Similarly, Garnsey (1990, 144) stated that food crises were frequent, but not disastrous “in large part because of human anticipation and adaptability. Secular responses to … vulnerability of populations led to increase agricultural production, emergency imports and food distribution”, which seem to have compensated for a possible negative impact of higher population density (or lower land *per capita*).

We can conclude that the interdisciplinary approach of combining anthropometry and archaeology is an ideal method to compile knowledge on the long-run economic history. It enables indispensable insights into some of the central aspects of human life during certain periods, which are otherwise not accessible.

TABLE 1
AREAS COVERED BY THE HUMAN HEIGHT DATA SET
(NUMBER OF INDIVIDUALS)

Century	Central-Western Europe	North-Eastern Europe	Mediterranean Europe	Total
-8	79	26	172	277
-7	8	33	140	181
-6	46	96	236	378
-5	3	10	404	417
-4	6	23	158	187
-3	39	117	34	190
-2	82	81		163
-1	41	37	114	192
1	88	217	211	516
2	1146	174	445	1765
3	407	181	124	712
4	1225	318	566	2109
5	222	125	468	815
6	1387	198	150	1735
7	1477	279	56	1812
8	266	787		1053
9	327	533	12	872
10	153	287	20	460
11	136	1423	51	1610
12	216	462	130	808
13	189	358	4	551
14	242	554	7	803
15	55	17	61	133
16	455	18	4	477
17	66	80	5	151
18	103	32		135
	8464	6466	3572	**18502**

TABLE 2

FOUR REGRESSIONS: DETERMINANTS OF HEIGHT for centuries with N>35

1	2	3	4	5	6	7	8	9	10	11	12	13
Constant	**167.51**	***0.00***	**169.63**	***0.00***	**165.95**	***0.00***	**168.57**	***0.00***	**169.02**	***0.00***	**167.41**	***0.00***
Mediterranean Europe	**0.34**	***0.79***	**-1.10**	***0.02***			**0.26**	***0.82***	**-1.36**	***0.16***		
North-Eastern Europe	**-0.12**	***0.86***	**0.44**	***0.25***			**0.02**	***0.96***	**0.03**	***0.96***		
Early Prehistory	**-1.61**	***0.23***	**-0.89**	***0.18***			**-1.85**	***0.06***				
Late Prehistory	**-1.36**	***0.08***	**-1.07**	***0.07***			**-1.56**	***0.01***				
Antiquity	**-1.72**	***0.01***	**-1.39**	***0.01***			**-0.75**	***0.21***				
High Medieval Period	**-0.14**	***0.91***	**-0.81**	***0.37***			**-0.05**	***0.96***				
Late Medieval Period	**-1.00**	***0.60***	**-1.05**	***0.38***			**-1.19**	***0.38***				
Modern	**-3.17**	***0.19***	**-1.70**	***0.19***			**-2.92**	***0.11***				
Cattle share	**0.04**	***0.22***			**0.05**	***0.01***	**0.01**	***0.66***	**-0.01**	***0.80***	**0.04**	***0.01***
Three-field rotation	**0.79**	***0.55***	**0.72**	***0.45***			**0.82**	***0.46***	**0.24**	***0.79***		
Cattle plague	**-0.07**	***0.89***	**-0.24**	***0.54***			**0.25**	***0.58***	**-0.07**	***0.89***		
Land per capita (log)	**0.31**	***0.82***			**0.20**	***0.70***			**0.11**	***0.90***	**-0.22**	***0.65***
Urban rate							**-0.29**	***0.01***				
War-prosecution	**0.05**	***0.90***	**-0.04**	***0.92***			**0.10**	***0.80***	**0.20**	***0.65***		
Plague	**-0.08**	***0.88***	**-0.09**	***0.86***			**0.27**	***0.59***	**-0.03**	***0.95***		
Genderinequality	**1.22**	***0.30***	**0.53**	***0.59***	**1.67**	***0.15***	**1.20**	***0.24***	**1.51**	***0.21***		
Roman impact									**-1.46**	***0.02***	**-1.43**	***0.00***
Adj.R^2	**0.49**		**0.43**		**0.30**		**0.61**		**0.44**		**0.43**	
N	**42**		**52**		**42**		**42**		**42**		**43**	

P-Values in columns 3, 5, 7, 9 in italics. Weighted Least Squares Regression: number of cases adjusted for aggregated observations using square roots. Constant refers to a hypothetical height value for the Early Middle Ages, and Central-Western Europe. Statistically siginifcant coefficients marked red.

TABLE 3
DESCRIPTIVE STATISTICS

1	2 N	3 Minimum	4 Maximum	5 Mean	6 Std. Deviation
Log land per capita	78	-3.78	-0.17	-2.15	0.77
Urban rate	78	0	19.75	4.49	5.33
Plague	78	0	1	0.15	0.36
gender inequality (relative)	56	0.26	1.35	0.95	0.20
Cattle share	53	14.64	14.64	45.04	15.79
Roman bath&technology	78	0	1	0.17	0.38
Cattle plague	78	0	1	0.18	0.39
War&prosecution	78	0	1	0.36	0.48
Three field rotation	78	0	1	0.31	0.47

FIGURE 1
SERIES OF NORTHERN HEMISPHERE TEMPERATURE RECONSTRUCTIONS

Source: ICCP 2007.

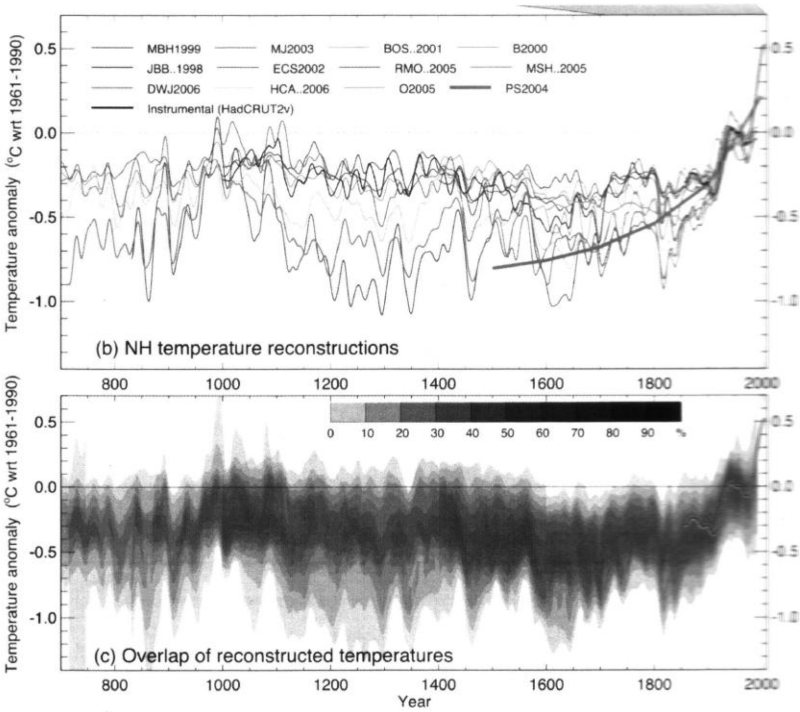


FIGURE 2
DEVELOPMENT OF CATTLE SHARES IN THE THREE MAJOR EUROPEAN REGIONS

Source: see footnote 27

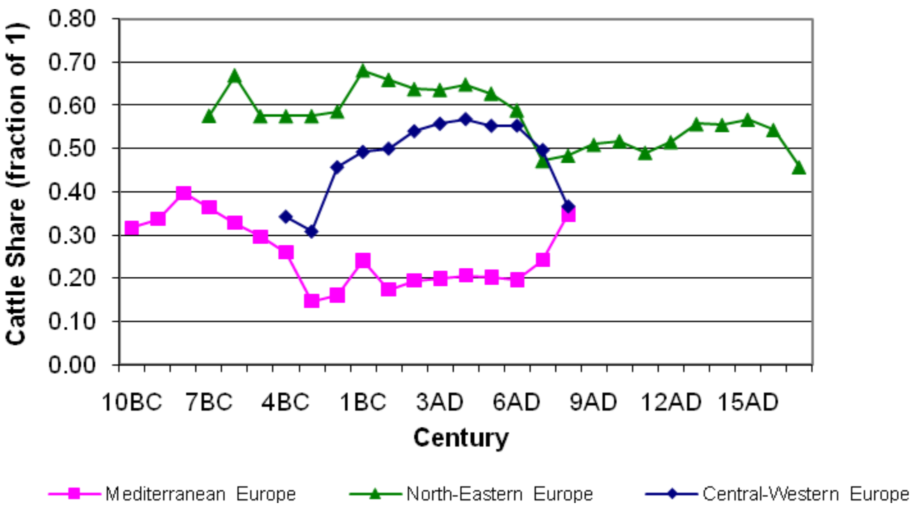


FIGURE 3

DEVELOPMENT OF POPULATION DENSITY
IN THE THREE EUROPEAN MAJOR REGIONS

Source: see text.

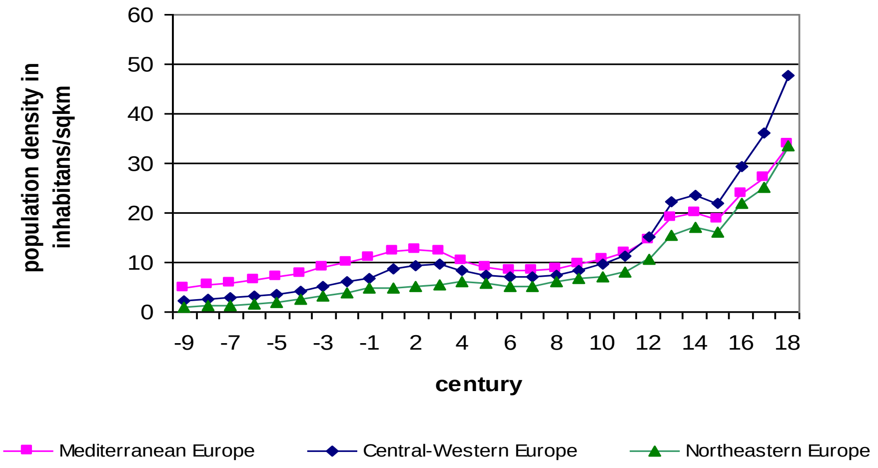


FIGURE 4

DEVELOPMENT OF URBAN RATE IN THE THREE EUROPEAN MAJOR REGIONS

Source: see text.

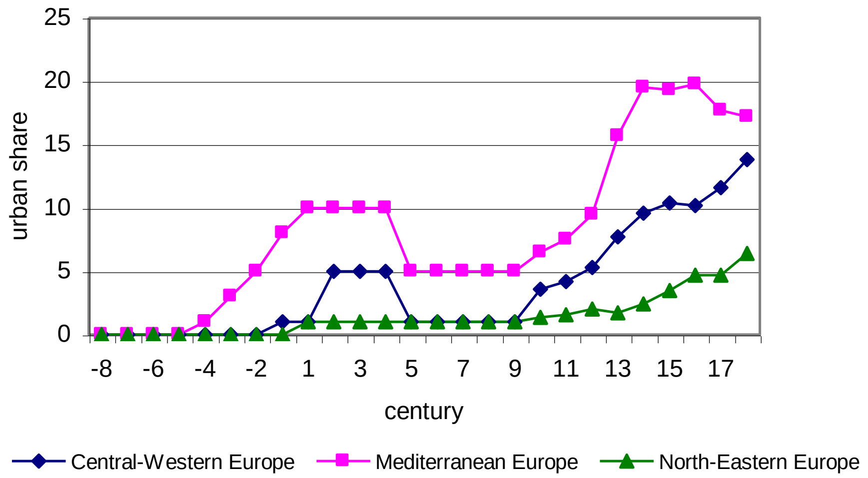
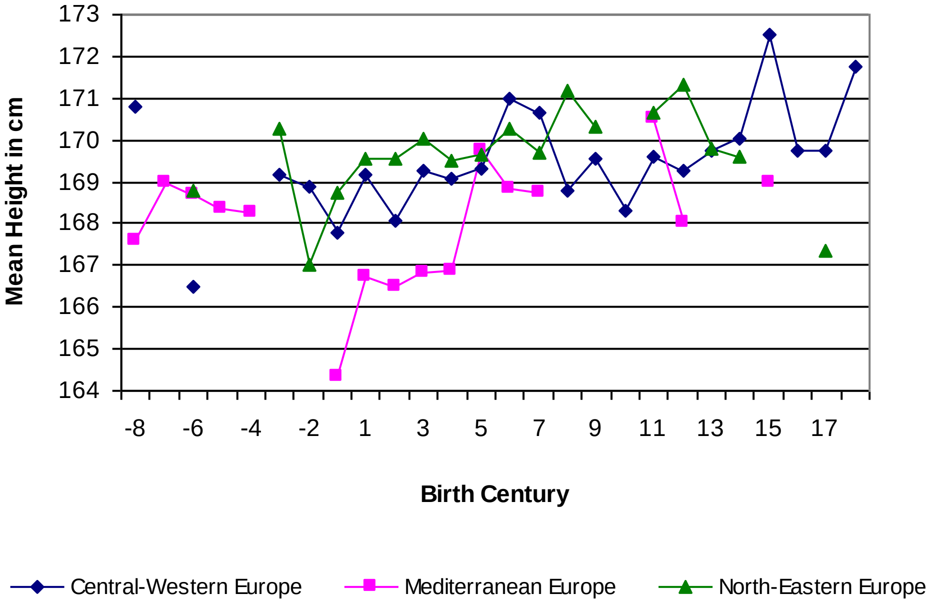


FIGURE 5

HEIGHT DEVELOPMENT BY MAJOR REGIONS
8th CENT. B.C. to 18th CENT. A.D.
(IN CM)

Source: see Figure 5 (N >= 35)



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