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Agricultural Specialization and Health in Ancient and Medieval Europe

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ABSTRACT

It has been argued that protein-rich milk and beef are major determinants of the biological standard of living for societies of the late 18th and 19th centuries: a high local supply of milk lead to better nutrition and taller stature (which is correlated with health and longevity), even if purchasing power is not necessarily high: The shadow price of milk was extremely low, because this food item could not be shipped, but was used for subsistence (and the butter was sold). In this paper we consider this proximity-to-protein production effect in ancient and medieval Europe. The decisive protein production can be traced quantitatively for the first time using a sample of 2,059,689 animal bones. The share of cattle bones is *ceteris paribus* an indicator of milk (and beef) supply, especially if controlling for population density. We compare information on cattle bone share with estimates of heights in three European regions (Mediterranean, Northeast, Centralwest) for the 1st to 17th century A.D. In an experiment, we suggest height estimates for today's Turkey, Greece, the Near East and Egypt during antiquity, based on the regression formulas we find.

Between 600 and 300 B.C. an astonishingly extreme decline in cattle share took place in Mediterranean Europe. During the time of the Roman empire cattle share stagnated on a very low level in the Mediterranean regions, whereas a high share of cattle bones was typical for North-Eastern, Central and Western Europe. In contrast, a high pig bone share became typical for the Mediterranean regions when the cities grew enormously during the Empire formation, because near those large cities like Rome or Pompeii cattle grazing became inefficient or impossible. Thus the poor and middle income groups substituted beef and milk with grain and vegetables, whereas the richer strata of society could afford pork. Pigs were easier to feed with the remains of human nutrition and imported fodder.

The central finding of this study is that the share of cattle bones, interacted with land per capita, was an important determinant of human stature. Thus, also for ancient times we can state that proximity to animal protein production was decisive for the level and development of nutritional status.

Introduction

Most pre-industrial societies were characterized by a strong scarcity of high quality protein (especially animal protein). Moreover, especially after the neolithic agricultural revolution, the distribution of protein consumption became increasingly unequal. The availability of milk appears to have been a bottleneck of health and longevity, given that it is rich in high-value protein, calcium and vitamins.[1] For the 18th and 19th centuries, it could be shown that a good local supply of milk leads to better nutrition and taller stature, and – *ceteris paribus* – better health and longevity values, even in regions that were not "rich".[2] As the main scope of this study we want to test whether the relationship between the first two variables also exists for ancient and medieval history:[3] For example, can we explain the larger stature of the Germanic tribesmen with their milk consumption, as it is e.g. mentioned in the ancient literature?[4] In the

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[1] Especially vitamin D, and additionally milk is also a good source of important trace elements, fat, and sugar: see Davis (1987) 155; thus it is of special importance for a good quality of nutrition.
[2] See e.g. Baten (1999); Komlos (1998).
[3] See e.g. Garnsey (1999).
[4] Lactose intolerance was probably not a decisive limiting factor in Europe. Crotty (2001) emphasized the importance of lactose intolerance in his bold attempt to explain the evolution of capitalism based on cattle farming patterns. Crotty argued that lactose-intolerant people could not make sufficient use of cattle. Lactose intolerance means that many people in the world have digestive problems, if they do drink large quantities of milk after age 5–7, because at that age genetically lactose intolerant people loose their ability to digest fresh milk without diarrhoea and similar problems. Especially East Asians (east of Tibet and Rajasthan), American Indians and some African people have problems with lactose intolerance. For Southern Europe, the results are mixed – one study on Spain categorized the country into the highest group of lactose tolerance (70 % and more lactose intolerance) and a Greek study found a middle position (30 – 70 % lactose intolerance); whereas in Italy and Turkey less than 30 % were classified as lactose tolerant (see Mace et al., 2003). But even lactose intolerant people can digest modified milk as Kefir, Lassi and similar products. Moreover, all people can drink about a cup of milk per day if they train their intestinal bacteria to live in a milk environment. Even many South Koreans today consume some milk, using this method of permanent training. We thank Barry Bogin, Anthropology Department U. Michigan/ Dearborn, and S. Pak, Seoul National U., for hints.

written sources one can find that the autochtonic people in the *Germania Magna* beyond the borders of the *imperium Romanum* used milk as basic food – other than the Roman-Italian population.[5]

The share of cattle bones among the animal bones of the four main domestic animal species pigs, goat, sheep and cattle can serve as an index that proxies two aspects. Firstly, population density tends to be negatively related to the cattle bone share, as Jongman (1988a) also argued: Extensive cattle husbandry is not possible, where population was dense.[6] Secondly, the share of cattle bones is sensitive to climatic and landscape conditions.[7] Goats and sheep can be more easily kept both in dry and warm climates, and in cold ones.[8] Cattle is quite demanding and thus cannot cope well with meager vegetation (and in general they need stables during winter).[9]

What are the effects of a high cattle share? For pre-industrial times, a high value typically implies a substantial local supply of milk, because milk could not be transported unspoiled over more than five or ten kilometers.[10] Apart from this direct effect of proximity, there was an indirect advantage via equality: the transport problem lead to a very low shadow price of milk in remote milk producing areas. This induced a relatively egalitarian distribution of high-value proteins. Thus, even low income groups could consume a healthy diet. In contrast, in large cities, only high-income groups could afford a protein-rich diet which was based on meat there (especially pork). As nutritional inequality tends to reduce average height because of declining

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[5] see for example Tac. Germ. 23; Plin. nat. VIII 179.

[6] For example, Benecke (1986) states for the Southern Baltic Sea– region that it is striking how the increasing importance of pig keeping correlates with an increasing rise in population at the beginning of the early medieval period. It takes a large area for cattle to graze, whereas pigs can be kept on smaller slices of land.

[7] See e.g. Bökönyi (1974).

[8] Thinking of fodder they are of special unpretentiousness on the one hand; on the other hand, furthermore, sheep are more common than cattle in very cold areas of Northern Europe as they do not need any stable during winter (because of their fur skin).

[9] Benecke (1986); Reichstein (1972b); Nobis (1955).

[10] Baten (1999); Craig (2004); Komlos (1989).

marginal effects of food on height, this second effect reinforces the proximity-to-nutrients effect on average height (Steckel 1995, Boix and Rosenbluth 2004). Taking those two relationships together, we formulate the hypothesis that a higher cattle share should lead to higher average height (and perhaps lower inequality). It is not clear whether the cattle bone share alone already captures the population density effects, or whether it should be interacted with the inverse of population density, namely, land per capita.

We will therefore address the following questions: does the development of the cattle bone rate, as estimated by archaeozoologists, support a nutrition-based explanation for the trend in mean human height in ancient and medieval Europe? Is the explanatory power even stronger, if we interact the cattle bone share with land availability per capita? In order to answer those questions, we will proceed as follows. Firstly, we document the data set of animal bones that was collected by King (1984, 1999a, 1999b); Benecke (1986) and others.[11] We will trace the development of the cattle share. Next we compare the cattle bone share with estimates of human heights conducted for three European regions (Mediterranean, Northeast, Central West) for the first to 17th century. Those anthropometric estimates are documented elsewhere in greater detail (Koepke and Baten 2005), but here we summarize our strategies to control for migration and social and regional composition, and we describe how we compared several regions to look for mutually corroborating evidence. In a third step we estimate a regression of human height on the cattle bone share, urbanization, population densities, inequality (gender and social), a set of period and region dummies and other variables.

[11] Becker (1980); Bökönyi (1955) Boessneck/Wiedemann (1972); Enderle (1975); Heinrich (1985); Hüster (1990); Johansson/Reichstein (1979); Luff (1982); Paul (1978); Reichstein (1990); Reichstein (1991); Reichstein/Pyrozok (1991).

Data section I: animal bone data

In earlier decades, archaeozoologists mainly assessed the qualitative composition of diets, but recently they also started to analyze the quantitative proportions of food items (incl. meat items) in human nutrition.[12] This is the basis for our dataset on animal bones.[13] It consists of observations from various sites compiled by King, Benecke and others. King (1978, 1984, 1999a, 1999b[14]) collected a large body of evidence on animal bones from published reports and unpublished archival data[15]: his data subsumes analyses on the four major domestic animal species: cattle, pigs and sheep/goat.[16] To assure that the animals were for regular daily food consumption, no burial sites, but only civilian and military settlement sites were taken into account. We also excluded assemblades which obviously represented remnants of merely industrial or craft production.

Following our earlier anthropometric study we divide Europe into three categories: The regions along the river Rhine – Benelux, Northern France, Western Germany, and South-

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[12] See e.g. Uerpmann (1972): All bones which result from human activities of one settlement should be collected; accordingly good preservation conditions for organic substances are important for correct interpretation. One has to take care not to combine data based on different counting methods.
Additionally to the important information on the quantitative proportion of animals in human nutrition one can get more precise insights on the composition of food by the help of the determination of the animals' age at butchering: e.g. zoologists found a large number of cattle butchered at older age as an indicator for different kinds of production/consumption but meat: milk; e.g. in the Northern German dwelling mound Feddersen Wierde the main percentage of cattle was used for milk production: s. Jahnkuhn (1973); furthermore the high percentage of only a few days old, esp. bull claves (in the small group of young cattle) can be explained by aiming at dairy-farming: see Reichstein (1991) 246.
Furthermore the longer slaughtering can be delayed, the larger the animal and the greater the quantity of meat: see Reynolds (1995) 309.
Also Kokabi (1988) comes to the conclusion that (corresponding to its utility) cattle is the most widely represented (husbandry) animal in the existing bone material from the Roman provinces – but his description implies that cattle was mainly employed for as 'working animals' for field processing: this is indicated by the gender distribution (remnants of ox and bull nearly double the remnants of cows); pig and than sheep follow concerning the percentage of bone remains.

[13] We are thankful to Willem Jongman for pioneering the use of this kind of data in quantitative economic history (albeit for different questions and with other methods).

[14] King (1999b) included the great collection Luff (1982), Lepetz (1996), Peters (1998) etc. to create and overview for the whole Roman Empire.

[15] This evidence was recently used by Jongmann (forthcoming), who based his argumentation on approximate completeness of the palaeo-zoological record, for Roman antiquity.

[16] Furthermore domestic fowl was kept, and additionally to the farm livestock in some cases a wild animal were consumed, but this accounts only for a small amount of food supply, and therefore was not included in the study. Fish can probably not be estimated accurately with this method.

Western Germany, Switzerland, Eastern France –, as well as Bavaria/Austria, and the UK are summed up as "Central/Western Europe".[17] "Northern and Eastern Europe" denotes those regions that had only little or modest contact with the Roman Empire and its provincial economy: Scandinavia, Northern-Eastern Germany, Russia, Romania and Hungary. "Mediterranean Europe" of our sample includes Italy, Spain, and Provence.

We use only the European sites King recorded and omit Africa, and the Near East.[18] Because North-Eastern Europe is extremely underrepresented in King's data (due to his concentration on the compilation of regions that were at some point in time Roman provinces), we enlarged our data set. We added bone data (collected by Luff, Benecke and others) on Sweden, Denmark, Hungary, Russia, and Northern Germany.[19] Thus currently our animal data set consists of 415 sites.[20] The sample covers the centuries between 400 B.C. and 600 A.D. quite well for all regions (see Table #1). Before 400 B.C., only Italy is well-documented; after 600 A.D., only North-Eastern Europe.

Trends in cattle share

The development of the cattle share by "large" regions from the 10th century B.C. to the 17th century A.D. was dramatic (Figure #1). Especially in Mediterranean Europe an extreme decline occured during the centuries before the turn of the eras (eighth to third century B.C.: from almost 40% to approximately 17%). After the first century A.D., the cattle bone share

[17] Compared with the population estimates of the Roman Empire, the number of sites documents a somewhat larger amount of bones for the UK. But as we are only using the shares of cattle and not the number, this means only a slightly higher precision for those regions for which more data is given.
[18] King recorded animal bone data from 533 excavation sites all over the Roman Empire, including some post-Roman sites. At the average site 1867 animal bones were excavated, ranging from a minimum of four to a maximum of 366,507 animal bones. Overall cattle bones are more frequent than sheep/goat bones, and pig bones are least common.
[19] In concordance with the height estimates, those data points were aggregated with the observations given in King on Eastern Europe, as those regions were only integrated into the imperial economy to a limited extent. For example, Northern Romania (on which we have good data) was *de jure* part of the Empire for only some 150 years).
[20] This is a preliminary stage of research, as we want to add more data especially on animal share for the *Germania Magna*, but also on the other regions.

stagnated on a low level (approx. 20% of total mammal bone share) until the sixth century A.D.[21] Except for the small parallel decrease in cattle share during the fourth to third centuries B.C., the development of cattle bone share in the Central Western European region followed a different pattern: After a substantial increase starting in the third century B.C., the share of cattle remained relatively constant from the second to sixth century A.D. Afterwards a (dramatic) decline took place. The cattle bone share that is given in the North-Eastern European region had a less volatile development. There was some decrease over the centuries, but this took place 'stepwise', with long periods of quite constant levels. Overall, the North-Eastern cattle share was on a higher level than the Central-Western one, and the share in Mediterranean Europe was the lowest.[22]

Comparing the development of cattle bones to the share of the other domestic animals by regions (not shown) we find that in all the three parts of Europe the pig and cattle share moved more or less anticyclically, whereas the sheep/goat share moved 'independently', and was relatively stable. Because Romans substituted beef with pork, Jongman (2005b) finds that there was still a indication of substantial meat consumption, even in periods and places of the highest population densities of antiquity (see also Jongman 1988b, 2005a). However, in this study we argue that cattle husbandry provided important advantages of proximity to milk production.

[21] There is only very small variation in between: from the third to the first century B.C. the percentage increases slightly. In the eightth century the Mediterranean average reaches the higest share (23%) in the eighth century A.D.

[22] There were also some interesting special developments that related to individual cities. For example, during the Roman imperial period large cities like Rome or Pompeii had a very small share of beef and milk consumption, because grazing was too costly, and therefore instead it was substituted with grain and vegetables – and pork was left to the richer strata of society to consume. In fact the impressive cattle share of 28 % in Rome (*Aqua Marcia* excavation) in the first century B.C. to the first century A.D. fell to 7.9 % in the first to second century, 0 % in the second and third century A.D. During the forth century the share was still negligible (0.6 % on the Palatine). Only in an excavation on the fifth century (*Schola Praeconum*) again a substantial cattle share was found, after the population density had significantly decreased and Germanic invaders brought their agricultural system (and perhaps taste). Similarly in Naples, the share was low during the first to third century A.D. (2- 6 %), and somewhat higher during the fifth to seventh centuries (6 – 9 %). Ostia and other excavation sites display a similar, but more mixed result. In general, the second to fourth centuries A.D. have low urban cattle rates in Italy.

Data section II: human height data

We estimated height trends for the Mediterranean, Northeast and Centre-West for the first to the 18th century A.D. in a related study (Koepke and Baten 2005).[23] There we devoted considerable space to describe our strategies to minimize measurement error, here we will only summarize them. We could rely on a sample of 9477 height estimations, which we standardized so that the same longbone-to-height formula applied. In some cases heights of two to 360 individuals were aggregated by previous investigators; thus we had 2974 separate height numbers. We used both weighted regressions (weighted with square roots of N) and regressions with individuals only, in order to estimate height trends by gender and by the three European regions. The regression approach allowed us to control for migration[24] and social status[25], as far as we (and earlier scholars) were able to determine this using grave goods and

[23] Because of dating limitations for a regular archaeological site the unit of analysis is restricted to the century.

[24] Migration required additional assessments, as environmental circumstances during the first three years of body growth have the most important impact on adult height. Two points are important in this respect. Firstly, most migrants experienced a different environment during their first years of life, compared with the autochthonous population. For example, if they were born in a Northern or Eastern European agricultural environment and than migrated to the Mediterranean in their later life, we would expect them to be significantly taller. Secondly, if immigration is large enough, agricultural production techniques might be transferred to the target region, if they turn out to be sufficiently efficient in the new environment. We know that the most important migrationstreams moved from the Mediterranean region into Central and Western Europe in the first to third century, and there was an important Germanic (and other) migration from Northern Europe to Eastern, Central and Southern Europe and later to the British Isles from the forth to sixth centuries.

Migrants from the Mediterranean to Central Europe (especially Roman soldiers and officers, as well as administrative staff) turned out to be 4 cm shorter than the rest of the population. But skeletons that could be identified as "Germanic migrants" were not significantly different from Eastern Europeans. Also not statistically significant, but economically meaningful was their coefficient in the "Mediterranean" regression: Germanic migrants, which died in the Mediterranean region, were 1.63 cm taller.

Moreover, it is important to control for migration, because a number of anthropologists are still convinced that genetic height potentials play a large role, whereas other anthropologists have doubts whether genetic height potentials explain any variation in average height of a population (in contrast to individual height which is clearly influenced by genetic factors, see Bogin, 1988, Mascie-Taylor and Bogin, 1995).

[25] Social status is an important variable, as many studieson the 18th to 20th centuries found height differences of typically 2-4 cm among adults of lower versus middle and upper class (see e.g. Baten, 2000). In our data set, we relied mostly on the classification schemes of the original studies. If skeletons were not of higher social rank, the excavation reports often did not find this fact worth mentioning. We therefore assigned dummy variables only to the cases of middle and upper class social origin (leaving a "lower or unknown" group for the constant). This also means that we should not over-interpret the coefficient of this social status variable. However, this variable is not only important by itself, but is also necessary to control for the social composition and potential social selectivity when we analyze height trends. Although the bulk of our measurements stems from burial sites that represented all social strata, we wanted to exclude the possibility of social selectivity causing height trends as far as possible. But it was at best marginally significant.

similar information. We arrived at height time series as given in Figure #2. Overall, heights stagnated and indicated no real progress in European nutritional status until around 1800. However, there is considerable variation between centuries: for example, the increase of the fifth and sixth centuries and during the medieval warm period ($11^{th}/12^{th}$ century).

How could we make sure that this was a reliable estimate of height development? Naturally, this kind of estimation has many limitations – even if our sample is larger than earlier studies, the number of cases is still small in comparison to data sets on more recent periods, but we found it reassuring that height trends for separate European regions and for genders moved in similar directions, except where we expected them to diverge (Figure #3a and 4c). For example, we expected a worsening development for Northern and Eastern Europe during the Little Ice Age (14-17^{th} centuries) because of the more extreme impact of the climatic change. In contrast the conditions were more favourable in more maritime Central-Western Europe during this period. And Western and Central Europe developed much better than Northern and Eastern Europe, especially the Netherlands and the UK who took over economic world leadership during this period (on NE-Europe, see also Steckel 2004). Female mean height is naturally always lower than male height. But female growth is also determined by discrimination of females (Figure #3b). Female heights were even more depressed relatively to males during the Middle Ages than in the other epochs, whereas gender dimorphism decreased in the Renaissance period, as we would have expected based on the literature. In the following, we pooled heights of both genders[26], and controlled the deviation with a dummy variable in order to make use of all available data points for height estimation possible (see Koepke/Baten, 2005). We adjusted to male height levels.

[26] Based on the assumption that the secular trend of female and male heights move (more or less) together.

Apart from those expected deviations, height trends moved relatively similar. Hence we conclude that the estimates of height development are very likely to be reliable. Moreover, we applied an additional strategy to ascertain reliability: we checked burial sites that were used for more than a century. If those shared the same trend with the large region, we could be sure that it was not a random regional composition effect that caused our trends. Among those cases with large sample numbers the majority pointed in this direction. Nevertheless, we also need to stress the limitations of our height estimates: there is certainly some remaining measurement error in the three series.[27]

Results: determinants of mean height

In order to check whether, and to which exent, the cattle bone share – as a proxy for protein intake - and various other determinants influenced average height, we applied panel data analyses on the level of the three European regions (for as many centuries as we could cover with the animal bone data. All the time information refers to A.D. values from here). An earlier model proposed in Koepke/Baten (2005) was characterised by an absence of statistical significance (except for some dummy variables), and modest economic significance. By including the cattle share in the regression model, we now obtain higher explanatory power.[28] Here we discuss WLS estimates with regional dummies (equivalent to fixed effects) and with period dummies (for antiquity etc.) to control for unobserved inter-temporal heterogeneity. Moreover we will report fixed effect estimates below.

[27] As we already admitted earlier it is apparent of course that studies that are based on archaeological data on the one hand naturally cannot be based on a similar amount of cases compared to studies on written sources, and on the other hand they involve some uncertainty (concerning dating etc.). Anyhow it is important to compile and collate all information and learn as much as possible from it – on limitations see Koepke/Baten, 2005.

[28] Even if we do not focus on statistical significance only, but also on economic significance, following McCloskey and Ziliak (1996).

Other potential determinants of height (discussed in Koepke/Baten 2005, and here in the footnotes) are factors like land *per capita* and urbanization[29], climate[30], social inequality[31], Roman public health and technology[32], gender inequality[33], and the disease environment, which is very difficult to measure in a comprehensive way (for alternative strategies, see Steckel/Rose 2002).[34] We assign a plague dummy for those centuries in which this disease was most prevalent. The expectations can go in both directions: shorter heights of those who were infected during childhood, but survived it, and taller heights of those who were born after the pandemics and benefitted from better land and capital per capita endowments.

Which variables have actually explanatory power for the long-run development of mean height? In the base-line model without the cattle bone variable, only the regional dummy for North-Eastern Europe and the period dummy for antiquity are statistically significant (on the

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[29] The data on population density is based on Allen's (2004) study on Europe for the time from the 13th century onwards. According to Malthus land is the limiting factor of human development; he would expect a decline in the nutritional status of population under risk before a mortality crises occurs. Did population growth tend to outpace food production? Furthermore, an increase in urbanization rate might have a negative impact on the BSL due increased exposedness to infectious diseases or/and separation of urban residents from *de facto* untradeable goods such as milk.

[30] Colder winters and correlated weather extremes tended to make food production (especially protein production) more difficult in Central-Western and North-Eastern Europe (see e.g. Baten, 2002); resulting worsened supply situation probably influences the BLS negatively. Thus the impact on human history was immense (see e.g. Grove 2002; Pfister 1988). We report in Koepke and Baten (2005) how we created the climatic index from tree rings, glacier movements etc.

[31] Previous research found inequality to be an important determinant of mean height (Steckel, 1995). Growing income inequality of purchasing power without changes in aggregate real GDP *per capita* might make the poor poorer and the rich richer to the same extent. But as the rich will spend less on additional food, and the poor will lose decisive nutrients at their low level, average height will decline even if average purchasing power does not. We can only measure this by period (antiquity…), using the centimeter difference between middle/upper and lower/unknown class.

[32] The question is if the common idea of an impressive Roman (water supply) technology, and especially the Roman institution of bathing facilities is correct, and/or if most of the population really benefit from this? We assigned a dummy variable that was 1 for those centuries, when a region was part of the Roman Empire.

[33] One would expect that higher gender inequality *ceteris paribus* has a reducing effect on mean height, as Osmani and Sen (2003) have convincingly argued that female discrimination hurts both, girl's and boy's height if their mother lives under unfavourable nutritional conditions. We measure this by century, calculating the height difference between genders. We measure this by calculating the gender differential of height (by centuries).

[34] For example, heights in the fourth century in North/Eastern Europe were 3 cm shorter than one would have expected them to be. Although not much is known about it yet, the arrival of the Huns in the fourth century A.D. might have spread new diseases that were brought from Central, North and East Asia – in addition to the population pressure and worsening conditions due to the very beginning of the 'main' Migration of peoples. The decline of the Roman Empire and the wars of this century could have had an influence on Central and Western Europe, but it is unclear why it should have had an influence on Northern and Eastern Europe. To be on the save side, we excluded North/Eastern Europe of the 4th century.

10%-level, see Model 1 in Table #2).[35] The only difference to the Koepke/Baten (2005) model is that we experimented here with an combined index of population density and urbanisation, because both variables were highly collinear. However, this combined index, and most of the other variables as well, are insignificant. We have to admit that especially the rough proxies e.g. for gender inequality or climate contain probably a large measurement error; thus it is not astonishing that the coefficients are statistically insignificant.

But if cattle share is added to the model, the adjusted R^2 increases from 0.31 to 0.56 (Model 2). It is particularly interesting on the background of the older anthropological literature which assumed "racial" differences of height between different European populations, that the significance of the North/Eastern-Europe dummy disappears, as soon as we control for specialisation on cattle farming. Mediterraneans would have even been estimated as being taller, once their very low cattle share is taken into account (but the coefficient is statistically insignificant). At the same level of protein supply, Mediterranean populations were at least not shorter. It is also striking that once we control for the cattle share, our population/urbanization index becomes economically significant (not statistically): One additional standard deviation of this index results in 1.53 cm lower height, indicatinga substantial urban penalty, or a "density penalty".

What we really want to measure with our main explanatory variable is the amount of high-quality protein available to the average inhabitant of a region and century. Above we entered population density (or an index of population density and urbanization) together with the cattle bone share into the regression. A more direct way of modelling the interaction between the two variables is simply to multiply them. We transform population density into its inverse (1 / popdens), which gives land per capita. We multiply this with the cattle share, in

[35] As one would expect the population of North-Eastern Europe is taller, people living during antiquity were shorter (compared to Central-Western Europeans living during early Medieval Ages).

order to obtain a variable that approximates an agricultural structure characterised by high milk and beef production per capita.

The movement of this variable over time is interesting (Figure #4). Similar to the height series, it is characterized by a notable increase in the fifth century. This is especially true in North-Eastern Europe, but to a certain extent in the other regions as well. North-Eastern Europe experienced a long-term decline after the sixth century. In contrast, central-western Europe started a similar decline after the sixth century, but we lack data beyond the eighth century. The Mediterranean values approached the other two regions somewhat.

If we consider all three regions together in a scattergram, the relationship is not perfect, but quite obvious (Figure #5). Although the obervations on Mediterranean populations cluster somewhat in the lower left corner, they do not own this area exclusively: Also North-Eastern Europe of the 17th century had very low levels of milk and beef supply ("denscat"), and also low heights. Central and Western Europe experienced only modest changes in the first five centuries, but in the sixth century both variables had higher values. During the seventh and the eighth centuries Central/Western European heights declined with the diminishing protein supply per capita of this region (caused by the strong population growth). Most dynamic was the development in North-Eastern Europe, hence we will focus on this region in the following in greater detail. Note however, that the values for the Mediterranean and Central/Western region are not very far from an imagined regression line that would be formed on the basis of North-Eastern Europe alone.

North-Eastern Europe is our best documented case (Figure #6, upper panel). It is interesting to see that even for this cold and continental region of Europe separately, the scattergram indicates a high degree of correlation between the interaction of land per capita and cattle orientation ("denscat") and height. Slight deviations to the bottom-right of an imagined regression line are the values for the first and seventh centuries, during which the relatively high milk and beef level per capita did not yield the expected height level. The opposite is true for the 11th, 12th and 14th centuries. The favourable climate of the 11th, and 12th centuries might have played a role here, because apart from protein supply, the grain harvest was also more successful. The 14th century in contrast could be a distorted observation, because it makes an important difference whether the measurements refer to the pre-plague or post-plague period, and we do not have this temporal resolution. The time path of changes is also very interesting (Figure #6, lower panel). There was no unidirectional trend, but a movement to the upper right between the 1st and the 6th centuries, and a gradual movement with three major swings after that, until in the 17th century the lowest milk and cattle availablity (and lowest height) was reached in North/Eastern Europe.

We tested the relationship between the interaction term cattle bone share * land per capita and height also in fixed effects models and found it consistently statistically and economically significant (Table #3). A very high explanatory power can be reached with only this variable plus a dummy for the antiquity and high middle ages, and social inequality (R-Square 0.65).[36] A standard deviation difference of landpc*cattle means 1.3 cm additional height, which indicates a remarkable economic significance (Table #4).[37] Even alone, this variable explains 41% of the height variation in a fixed effects estimate (not shown). This interaction variable of land per capita and cattle bone share is negatively correlated with social inequality (correlation coefficient -0.38, p-value 0.03) – which is also interesting by itself - hence the social inequality variable does not add as much to the explanatory power of the milk and beef production variable as could have been expected (Model 2 of Table #3).

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[36] The "modern" dummy represents only very few cases of NE-Europe and is dropped in the fixed effects model)
[37] In studies on the 18th and 19th centuries, differences of between 1 and 3 cm are often interpreted as economically significant phenomena (see e.g. Komlos and Baten, 1998).

An experiment: estimating mean height for Asia Minor (today's Turkey), the Near East, and Egypt

How tall might the inhabitants today's Turkey have been in antiquity? What were the expected anthropometric values for the other Eastern and Southeastern regions around the Mediterranean Sea? As height data for those regions was published quite rarely, one possibility to get an idea of mean height is to estimate it by the help of the regression model we presented above. We will perform an experiment with the explanatory variable that turned out as being most important in our model, the land per capita interacted with cattle farming orientation, 'densecat'. We use this variable to create expected values of mean height, and compare tentatively some values for Greece below, for which we have empirical height data.

The estimation equation is as follows:

y = 168.42 + 0.21* 'densecat' + e

The data we have on land per capita and cattle share for the southeastern regions are just as reliable as the data we have for the European regions studied above: we obtained the data on cattle share from King (1984, 1999a, 1999b), the data on population density we took from McEvedy/Jones (19802). We aggregated the data by major regions and centuries: In King's classification, "Asia Minor" stands for today's Turkey. We also have sufficient data on Greece, the "Eastern Provinces" (i.e., the Near East with today's Syria, Israel, Palestine and Jordan); "Egypt" represents Upper and Lower Egypt.

The expected height trend in the different regions develops with quite some variety (see Figure #7). In Asia Minor mean height increases after the third century, and especially around the sixth century AD, which represents the period, when this region represented the core land of the Eastern Roman Empire; from the 12th century onward we estimated lower heights there, compared with the period before. In Egypt heights were nearly stagnating over the centuries. The same is true for our mean height estimates on Greece.

Overall, (1) conditions of cattle share times land per capita was more favourable in Asia Minor and the Eastern Provinces in comparison to the other Eastern Mediterranean regions; (2) the expected mean height estimations for all for regions outside Europe do not vary very much: we estimate the variation in height within a band width of ca. 1.5 cm (around a mean height of approx. 169 cm). In reality this development is probably more pronounced, given that some unexpected variation is caused by other variables that are not included here. We plan to collect human height data on the Near East and other regions in the future, in order to countercheck whether our estimates are reliable. One very small data set of height evidence that has been publsihed on an overlapping period and region is Angel's (1984) estimate of 169.2 cm for Greece around 120 AD-600 AD. This estimate is relatively close to our estimate for Greece during this period.

Conclusion

Important shifts in agricultural specialization shaped the economic history of Europe over the period BC 1000 to 1800 AD. As population density and urbanisation grew on the Appenin-Peninsula, agriculture switched from an initial specialization in cattle and goat breeding – that meant a relatively high and egalitarian protein supply – to a completely different system: during the Roman imperial period, mainly pork was produced for the urban high-income strata, whereas the poorer Roman population consumed mainly vegetarian food.[38]

[38] Resulting of lower protein consumption: see Souci/Fachmann/Kraut (1994).

In this interdisciplinary study between archaeology and economic history we tested hypotheses like the one above and considered the effects on health using anthropometric techniques. Agricultural specialization, and the decisive protein production bottleneck in particular, [39] could be traced quantitatively for the first time using a sample of more than 2,000,000 animal bones. We constructed indices of specialization for seven regions of Europe for the period BC 700 to 1500 AD (with some gaps). The share of cattle bones turned out to be a very important determinant of human stature (that correlates with health and longevity), because it is *ceteris paribus* an indicator of milk (and beef) supply (especially holding population density constant). Without taking this milk/beef indicator into consideration it seemed to early scholars that Germanic, Celtic and Slavic populations of Northern and Eastern Europe were genetically taller than Mediterranean populations. Controlling for this indicator, however, we obtain dummy variable coefficients for North/Eastern Europe that are not statistically significant. Hence, autochtonic Germanic people in the *Germania Magna* beyond the borders of the *imperium Romanum* were taller than in the core-land of the empire, because they produced and consumed more milk and beef.

Our newly created milk/beef indicator, the share of cattle bones, and a set of nine other variables (such as populations density, climate etc.) can explain 55% of height differences for the period 0 A.D. to 1500 A.D., and the relationship also holds with region fixed effects. Interacting both factors, the importance of land availability *per capita* and cattle share for mean height is demonstrated (the adjusted R-Square increases to 0.65). In an experiment, we suggested height estimates for today's Turkey, Greece, the Near East and Egypt during antiquity, based on this relationship.

[39] Especially the availability of milk appears to have been a bottleneck of health and longevity, given that it is rich in high-value protein, calcium and a number of vitamins.

We certainly have to emphasize the limitations of those estimates, but are confident that this approach will continue to generate interesting findings. If we want to study the economic history of the very long run, anthropometric and archaeozoological techniques provide important insights on some of the central aspects of human life.

Figure #1

DEVELOPMENT OF CATTLE SHARES IN THE THREE EUROPEAN 'LARGE' REGIONS

Source: see text.

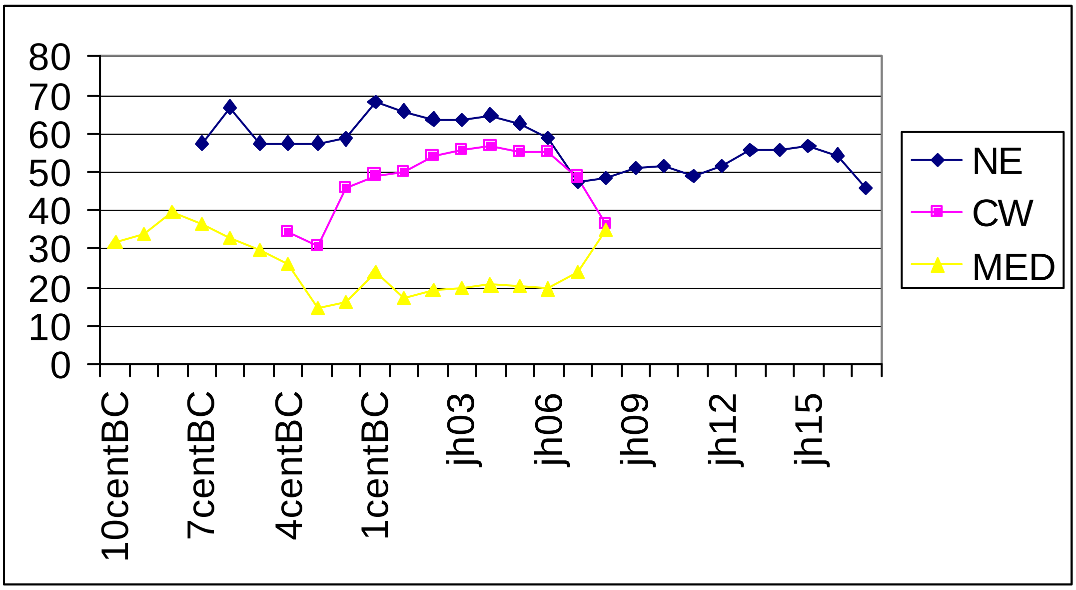

Figure #2

HEIGHT DEVELOPMENT, 1st to 18th century A.D. (IN CM, MALE AND FEMALE)

Source: see www.uni-tuebingen.de/uni/wwl/twomillennia.html. The level of heights was adjusted to male heights of an average European (using the regional coefficients and weighting them with sample weights).

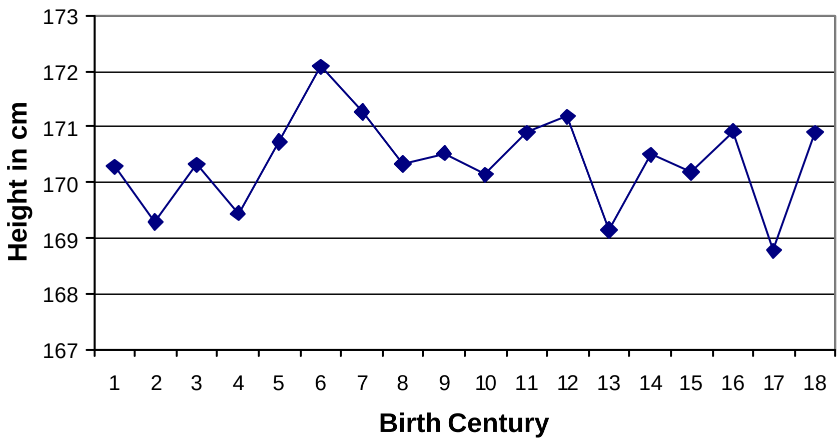

Figure #3a

HEIGHT DEVELOPMENT BY MAJOR REGIONS (IN CM)

Source: see Figure #3a

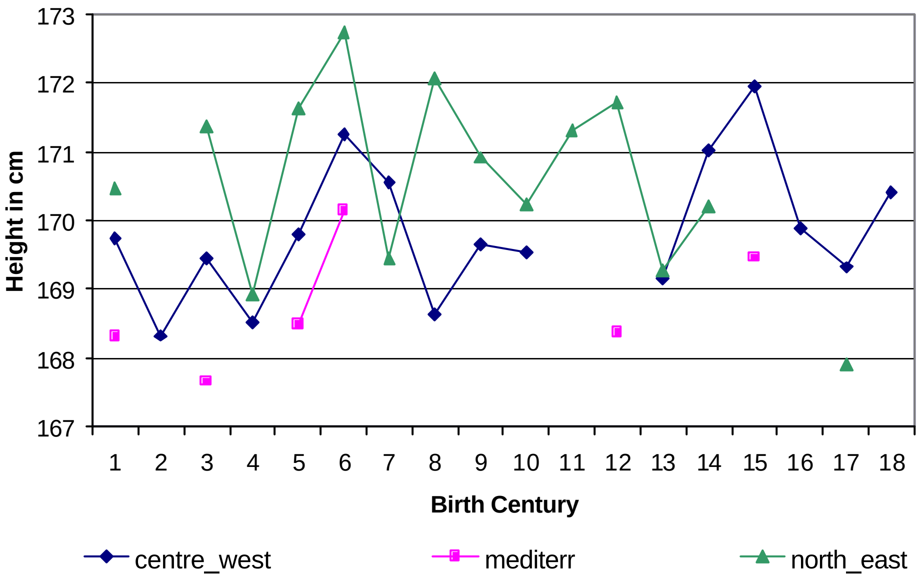

Figure #3b

TWO-AXIS-DIAGRAM

HEIGHT DEVELOPMENT BY GENDER, 1st to 18th century A.D. (IN CM)

Source: see Figure #3a

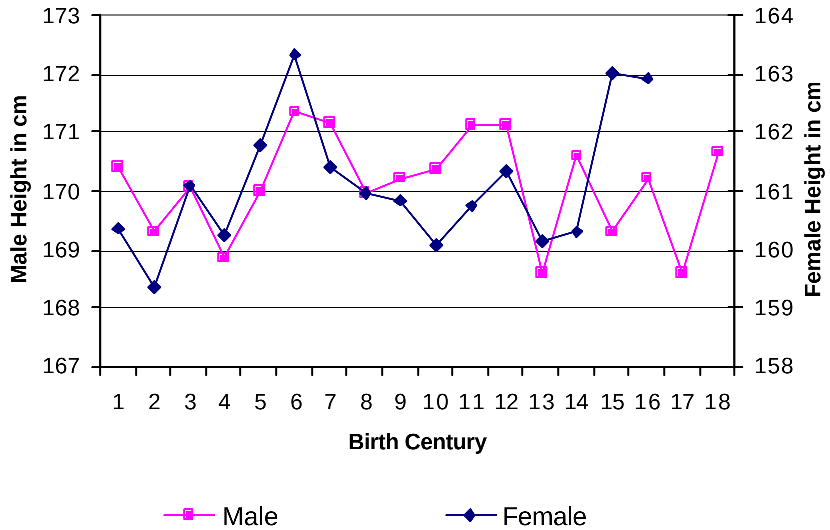

Figure #4

THE INTERACTION OF CATTLE BONE SHARE AND LAND PER CAPITA

Source: see text.

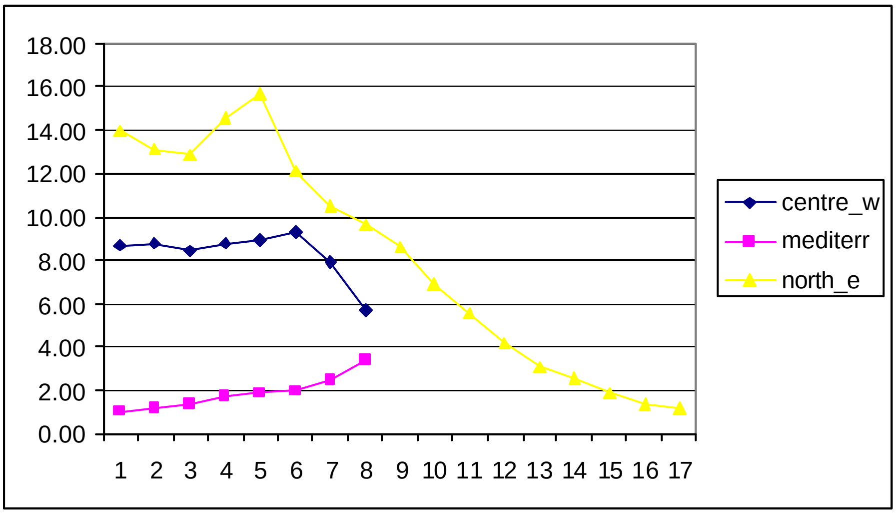

Figure #5

CATTLE SHARE * LAND PER CAPITA AND
HEIGHT IN EUROPE, 1st to 18th century A.D. (IN CM)

Source: see Figure #3a and text

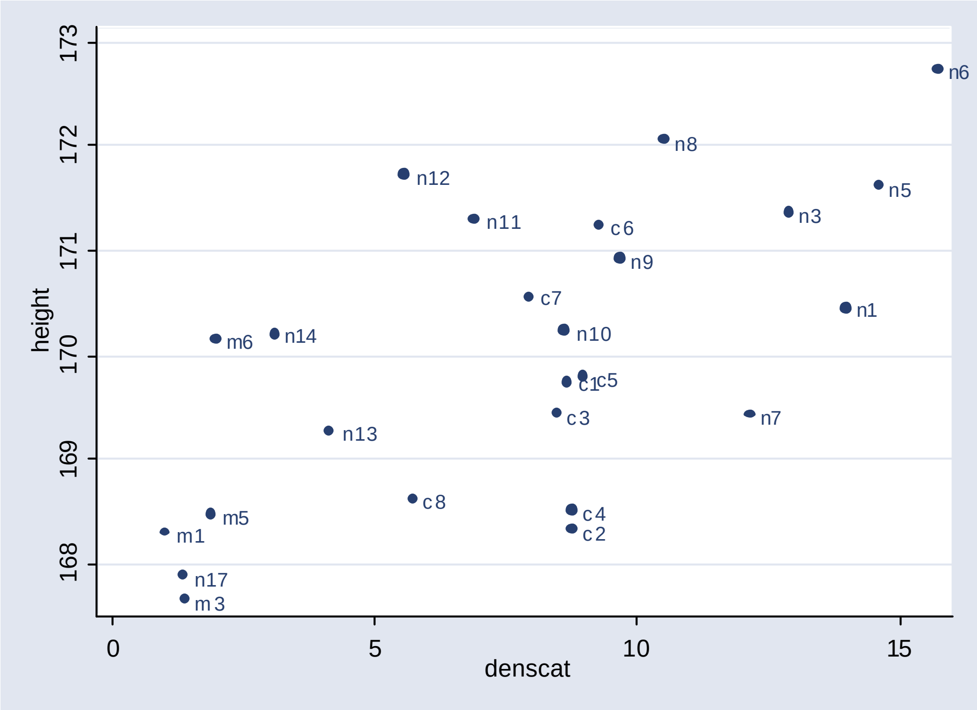

Figure #6

CATTLE SHARE * LAND PER CAPITA AND
HEIGHT IN NORTH/EASTERN EUROPE, 1st to 18th century A.D. (IN CM)

Source: see Figure #3a and text

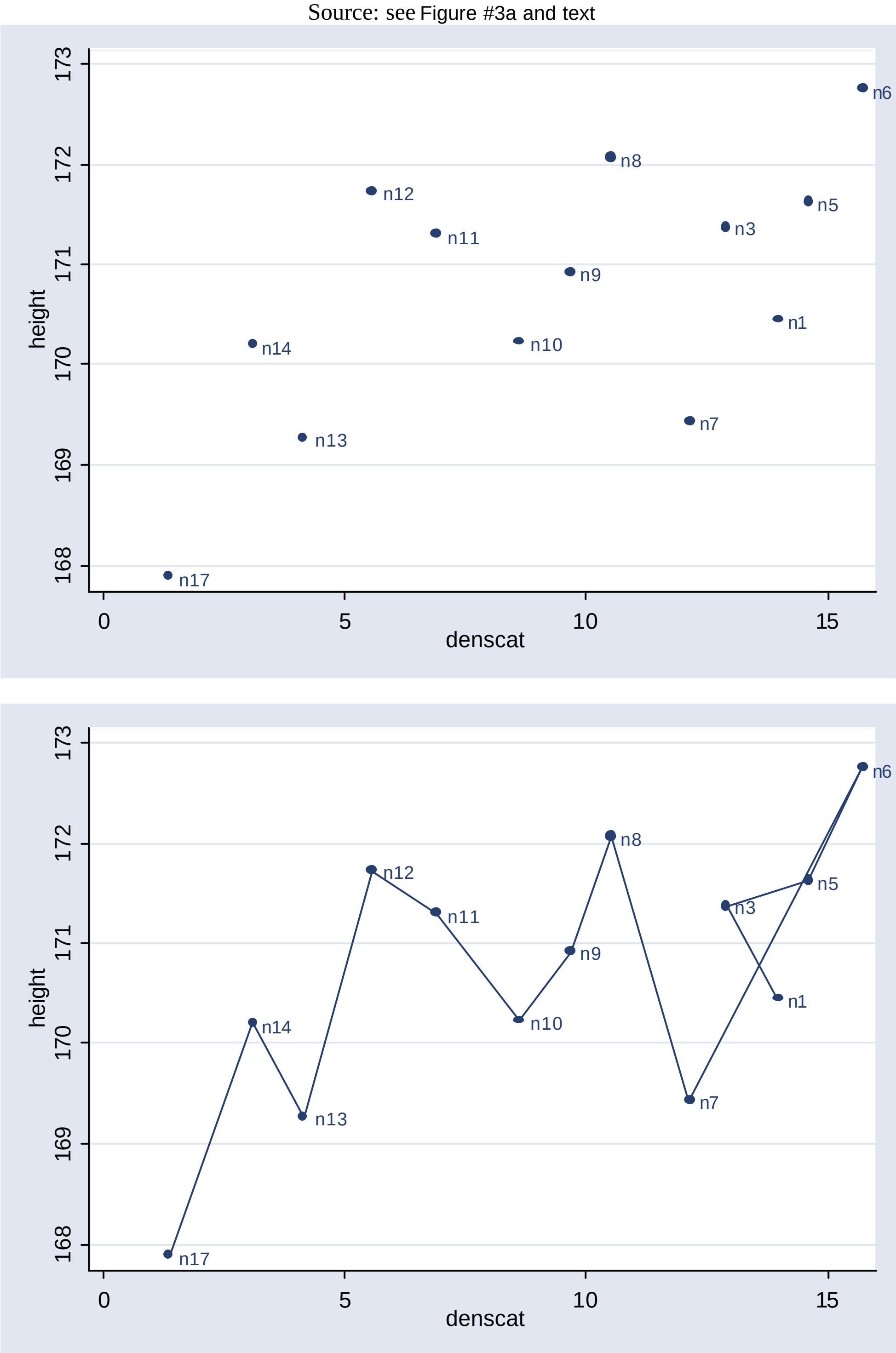

Figure #7

ESTIMATED MEAN HEIGHT FOR THE EASTERN AND SOUTHEASTERN REGIONS, BASED ON LAND PER CAPITA * CATTLE SHARE (without centuries with N < 100)

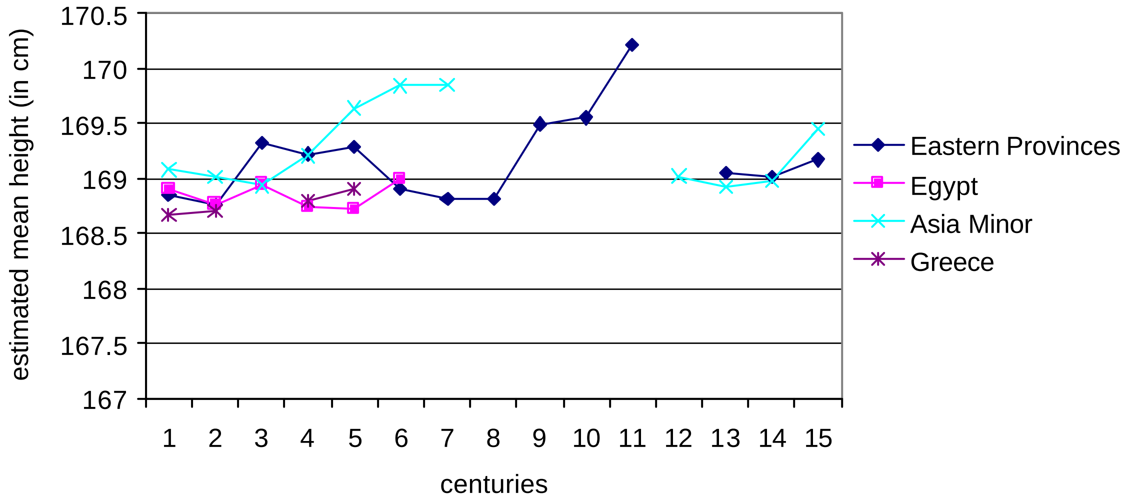

Table #1

REGIONS COVERED BY OUR DATA SET: number of animal bones

Source: see text.

Century	Central /Western Europe			Eastern/ Northern Europe		Mediterranean			Total
	Germany/ Austria	Gaules	Britain	Danube prov.	Barbaricum	Italy	Provence	Spain	
-10	.	.	.	.		81			81
-9	.	.	.	.		516			516
-8	.	.	.	.		457			457
-7	.	.	.	.	94	477			571
-6	.	.	.	.	27836	1471			29307
-5	.	.	.	.	94	468			562
-4		326		.	94	1559			1979
-3		260		.	94	3473			3827
-2	13142	4446	143	256	596	2016	104		20703
-1	289848	10801	3410	.	8235	2989	33		315316
1	64230	16385	35787	10533	18264	5005	10730	508	161442
2	176613	13641	51275	16956	18684	3779	9860	1392	292200
3	111473	9811	55417	11173	18684	2041	895	718	210212
4	32436	15601	61328	932	18352	3431	513	924	133517
5	1623	4060	11434	1198	36910	5567	1368	376	62536
6	33		5694	1077	23280	2654		392	33130
7	33		149	.	33884	1267		156	35489
8			149	.	41882	32			42063
9	.	.	.	1217	102623	.			103840
10	.	.	.	391	106360	.			106751
11	.	.	.	391	175154	.			175545
12	.	.	.	391	102906	.			103297
13	.	.	.	.	96470	.			96470
14	.	.	.	.	93795	.			93795
15	.	.	.	.	18821	.			18821
16					15169				15169
17					2093				2093
	689431	75331	224786	44515	960374	37283	23503	4466	**2059689**

Table #2

THREE REGRESSIONS: DETERMINANTS OF HEIGHT

	Coeff.(1)	*p-val.*	Coeff.(2)	*p-val.*	Coeff.(3)	*p-val.*	Coeff.(4)	*p-val.*
Constant	131.20	*0.01*	148.35	*0.02*	168.42	*0.00*	171.37	*0.00*
Population-Urban-share	-0.01	*0.63*	-0.06	*0.19*				
Plague	0.49	*0.34*						
Gender inequality	-0.29	*0.55*						
Climate warm	4.35	*0.39*	1.95	*0.74*			-0.35	*0.95*
Cattle share			0.08	*0.09*				
Interaction land p.c. *cattle share					0.21	*0.00*	0.23	*0.09*
Mediterranean	-0.93	*0.26*	2.76	*0.13*			0.64	*0.55*
North-Eastern Europe	0.85	*0.10*	0.64	*0.27*			0.47	*0.54*
Antiquity	-1.07	*0.10*	-1.21	*0.13*			-1.0	*0.07*
Late Medieval Period	-0.19	*0.81*	0.13	*0.85*			0.65	*0.55*
Modern	0.35	*0.83*	0.20	*0.94*			-1.1	*0.58*
Adj. Rsq	0.31		0.55		0.38		0.55	
N	35		25		25		25	

P-Values 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.

Table #3

TWO FIXED-EFFECTS REGRESSIONS: DETERMINANTS OF HEIGHT

	Coeff.(1)	*p-val.*	Coeff.(2)	*p-val.*
Interaction land p.c. *cattle share	0.23	*0.08*	0.29	*0.00*
Social inequality	-0.24	*0.55*		
Antiquity	-1.08	*0.03*	-1.02	*0.03*
High middle ages	0.93	*0.21*	1.12	*0.10*
Constant	168.64	*0.00*	167.90	*0.00*
Adj. R-Square	0.65		0.63	
N	25.00		25.00	

P-Values in italics.

Table #4

DESCRIPTIVE STATISTICS

1	2 N	3 Minimum	4 Maximum	5 Mean	6 Std. Deviation
Climate warm	53	9.20	9.40	9.32	0.06
Gender inequality	53	4.14	6.11	5.39	0.54
Population-urbanisation-rate	53	0.00	84.91	27.58	25.51
Cattle share	32	17.38	65.90	45.95	15.37
Plague	53	0.00	1.00	0.17	0.38
Interaction land p.c. *cattle share	32	1.02	15.71	6.82	4.55

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