GLOBAL TRENDS IN NUMERACY 1820-1949 AND ITS IMPLICATIONS FOR LONG-TERM GROWTH

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Abstract

This study is the first to explore long-run trends of numeracy for the period from 1820-1949 in 165 countries, and its contribution to growth. Estimates of the long-run numeracy development of most countries in Asia, the Middle East, Africa, America, and Europe are presented, using age-heaping techniques. Assessing the determinants of numeracy, we find school enrollment as well as Chinese instruments of number learning to have been particularly important. We also study the contribution of numeracy as measured by the age-heaping strategy for long-run economic growth using a pooled cross-section analysis. In a variety of ways, numeracy proved to be crucial for growth patterns around the globe.

Keywords: Human Capital, Age-heaping, Growth, Industrial Revolution, Numeracy

JEL codes: I21, N01, N30, 015

1 Introduction

Human capital is at the heart of modern economic growth studies (Lucas 1988, Romer 1989, Mankiw, Romer and Weil 1992 and Jones 1996 among others). Growth economics has strongly emphasized the role of human capital formation and its persistence in nations over time. Also Unified Growth Theory has underlined the role of human capital in the transition from the Malthusian stagnation to the contemporary era of modern economic growth (Galor and Weil 2000, Galor and Moav 2002, Galor 2005). Becker, Murphy and Tamura (1990) placed investments in human capital at the center of their study, assuming that the return on growth-enhancing investments in human capital rises rather than declines as the stock of human capital increases. Their framework is characterized by multiple steady states that differ in regard to schooling decisions and opportunity costs of child care. Initial human capital stock and other major exogenous shocks play an important role in the determination of fertility, growth rates and the wealth of countries. However, their model was found to be inconsistent with the historical evidence which Mitch (1991) and Mokyr (1983) presented. They suggested that some countries' growth paths did not fit into this demographic-educational pattern. For example, Britain experienced stagnating literacy between the mid-18th and mid-19th century, while France had an early fertility decline as early as 1800 without becoming a driving force of growth in 19th-century Europe. While education and a slowing population growth do not seem to explain the first Industrial Revolution satisfactorily, many economists who study long-term growth believe that these factors played a key role in the later transition to a regime of sustained economic growth (Boucekkine, de la Croix and Licandro 2003, Glaeser et al. 2004, Cervellati and Sunde 2003 among others). Economic factors eventually altered the parental quality-quantity decision and stimulated human capital investments, reinforcing technological progress and economic growth.

Given that human capital accumulation is a crucial factor in long-run economic growth theory, efforts have been made to strengthen the available empirical evidence. O'Rourke and

Williamson (1997), for example, were able to include schooling in European convergence regressions for 16 countries for the period between 1870 and 1913, concluding that globalization forces had, in fact, a greatly important influence on comparative development.[1] When going further back in time to the early 19th century and beyond, schooling data, even for Europe, disappears, and literacy must generally be inferred from a proxy - the ability to sign one's name on marriage certificates and legal documents (Reis 2005). Leaving Europe, it becomes increasingly difficult to find systematic, comparable data. Crafts (1997) reports enrollment and literacy rates for 17 advanced economies since 1870 while Lindert (2004) provides school enrollment rates and teacher-student ratios on some fifty countries, substantially improving the Mitchell (2003a-c) data set. Benavot and Riddle (1988) have compiled additional schooling data for LDCs for the period between 1870 and 1940. Morrisson and Murtin (2007) have revised and extended Mitchell's (2003a-c) data set, using national census data to obtain an educational attainment data set for 1870 to 2000. Since census information was scarce for the developing world prior to the end of the 19th century, the authors had to assume enrollment rates of 1 or 0.1% for the LDC world in 1820.

Although these studies represent a clear improvement in our knowledge, about half of the existing 165 countries with populations above 500,000 are not yet documented for the late 19th century. As a result, existing samples of human capital data are biased towards today's richer spectrum of countries, as those were the first to introduce schooling statistics. Studies on human capital development in the poorer half of the world would provide important insights into overall human development.

This study is a first step towards achieving almost global coverage of human capital estimates since the late 19th century. Moreover, quite a number of additional countries can be included in the period between 1820 to 1890. Another aim of this article is to broaden the literature on human capital by constructing a numeracy index. We would argue that numeracy

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[1] Tortella (1994), using literacy data, offers a different interpretation, at least for southwestern Europe.

should be considered as a historical measure of human capital since knowledge about numbers and numeric discipline are even more crucial for economic growth than the ability to sign one's name on a marriage certificate. Numeracy goes hand-in-hand with technological abilities, and it is a necessity for modern commercial economies. For Weber, Sombart, and Schumpeter, numeracy was at the very heart of modern rational capitalism. They traced the latter's roots back to the invention of double-entry bookkeeping in late-medieval Italy. Carruthers and Espeland (1991) have described in some detail the process of abstraction and organization inherent in compiling a ledger, which made possible the development of concepts like capital, depreciation, and the rate of profit. It is no accident that the introduction of Arabic numerals to Europe and the earliest accounts of mathematical education stem from the same time and place. Hence, in this paper, we go beyond traditional literacy and enrollment indicators by presenting proxies for numeracy based on age-heaping.

What is age-heaping? Demographers normally use age data to describe a population's age structure and to forecast population growth. In contrast, the idea behind this study is to use irregularities in the reporting of ages to estimate the level of education in an economy. Such irregularities appear in the form of heaped data, i.e. the age distribution does not run smoothly but rather exhibits sharp jumps and clustering at certain ages. This phenomenon is attributed to age-heaping, a term which describes the ignorance of one's own age or the tendency to round ages. Age-heaping is a well-known phenomenon among demographers and applied statisticians. However, while both groups of scholars perceive age-heaping mainly as a data problem because it leads to biased vital rates on the one hand, and only the degree of heaping as a measure of data quality on the other hand, we use it as a proxy for non-numeracy.

A half-century ago, an influential study by Bachi (1951) and Myers (1954) investigated age-heaping and its correlation with education levels within and across countries. Thereby, Bachi (1951) was able to analyze the degree of age-heaping among Jewish immigrants to Israel in 1950 and among Muslims in Mandated Palestine in 1946, finding, amongst other things, that the increasing spread of education resulted in a better knowledge basis according to lower age heaping. Myers (1976) found a negative correlation at the individual level between age heaping and income. Another innovative example is the study by Herlihy and Klapisch-Zuber (1978) who used successive Florentine tax enumerations and found distinct heaping on multiples of five for adults, which declined substantially in the period from 1371 to 1470. Furthermore, they showed that age-heaping was more prevalent among both women in rural areas and small towns, and among the poor. Duncan-Jones (1990) employed this technique to study age data from Roman tombstones. Mokyr (1983) was the pioneer who established the age-heaping measure as an explicit numeracy indicator in economic history. He employed the degree of age-heaping to assess the labor-quality effect of emigration on the Irish home economy during the first half of the 19th century, as emigrants from pre-famine Ireland were less sophisticated than those who stayed behind. Thomas (1987) considered the slight but discernible improvement in the accuracy of age reporting as evidence that numerical skills in England had improved between the 16th and 18th century. Budd and Guinnane (1991) studied Irish age-misreporting in linked samples from the 1901 and 1911 censuses. They found considerable heaping on multiples of five in the 1901 census, which was also more frequent among the illiterate, poor, and aged. More recent research was conducted by Long (2005, 2006) who analysed age data from the 1851 and 1881 British population censuses, identifying urban migrants in Victorian Britain as being educated beyond average. By exploiting repeated observations, he was able to show that individual age discrepancies (another measure of missing age awareness) had a significant negative impact on socio-economic status and wages. De Moor and van Zanden (2006) studied the relative numeracy of women during the Middle Ages, and Clark (2007) has recently reviewed the evidence.

From the literature cited above, we can conclude that demographic evidence exhibited significant age-heaping at least until the turn of the 20th century, and that the degree of heaping varied across individuals or groups in a way that makes age-heaping a plausible measure of human capital. The correlation of age-heaping and the prevalence of illiteracy among the population was explored in more detail by A'Hearn, Baten and Crayen (2006) who found in their analysis of 52 countries or 415 separate regions that the level of age-heaping is indeed correlated with illiteracy. The authors also concluded that the probability to report a rounded age increases significantly with regional and personal illiteracy.

In sum, we would argue that age heaping is a proxy for basic numerical skills. As such, it is an important component of human capital and a precondition for more advanced skills. A perfect human capital measure in our view would be a composite index of basic and advanced text-related skills, of basic and advanced numerical skills, of technological, social and organizational creativity, and perhaps other components. However, given that such perfect composite indexes are impossible to construct in most real world situations, scholars often use proxy indicators for more broad concepts. We would suggest that our basic numeracy indicator can also be a proxy for general human capital, especially if other indicators are not available (or point actually to similar values of human capital).

In the following section, we will first discuss important methodological aspects of age heaping as a numeracy proxy. The third section examines the (non-interpolated) country level data especially for the Islamic world and the industrialized countries. The next section will attempt to make a first estimate of the global development of numeracy for eight world regions from 1820 to 1949. This section will use interpolation. Section 5 will discuss the potential determinants of numeracy. Finally, section 6 tests the implications for economic growth, and the seventh part provides a conclusion.

2 Methodological aspects

2.1 The age-heaping technique

The age-heaping technique can be applied to many sources of age data such as census returns, military enrollment lists, legal or hospital records, and tax data. However, care must be taken as to by and to whom the age question was posed, how it was formulated, and whether self-reported ages were compared to birth registers. Double-checked age information does not normally reflect any age-heaping besides minor, random fluctuations and therefore cannot be used. If the enumerator asked for both age and birth year, the resulting evidence sometimes became unusable for our purposes due to mixed age and birth-year heaping. As a result, we used only census information, which was not influenced by such problems in order to maximize the validity of our numeracy proxies.

As a measure of age-heaping, the Whipple Index was designed to capture heaping on ages ending in 0 or 5. Applied to an age range divisible by 10 (i.e. in which every digit occurs with the same frequency), it adds the frequencies of all ages ending in a multiple of five and expresses the result relative to one fifth of the sample size. The resulting ratio is multiplied by 100, yielding an index, which ranges from 0 to 500. Accordingly, a Whipple Index of 0 (500) implies no (only) ages ending in multiples of 5. Generally it is assumed that a Whipple Index of 100 reflects the “true” age distribution with exactly 20% of all ages ending in a five-digit multiple. The Whipple Index is linear, and a 50% increase in the share of ages ending in multiples of five translates into a 50% increase of the Whipple Index.[2]

We assessed the possibility that wars, famines, civil wars, and epidemic disease invalidated the assumption of a smooth age distribution in an appendix to this study (see appendix C). The large numbers of deaths and reduced fertility might have “dented” the age pyramide in some extreme cases. We found that most of those events did not systematically

[2] An even more intuitive linear transformation of the Whipple Index (WI) is the ABCC Index which reports a society’s share of individuals who probably know their true age (named after A’Hearn, Baten and Crayen as well as Greg Clark, who first gave us this comment for our 2006 paper). The formula is ABCC=1-(WI/100-1)/4. In this version of the paper, we still report the Whipple Index, as it is the UN standard measure (UN 2000).

affect the Whipple Indexes, although in country studies the disturbing effects of those events clearly has to be taken into consideration.

2.2 Age-group boundaries

As mentioned above, one technical requirement for the calculation of the Whipple Index is an age range of 10 successive single years. Since generally fewer people are alive at age 69 than at age 60, the total share of people whose age ends in 0 should be naturally larger than the total share of people reporting an age ending in 9. Thus, age-heaping is likely to be overestimated if we calculate the Whipple Index over an age range such as 20-29, 30-39, etc. In order to mitigate this effect and to spread the final digits of 0 and 5 more evenly across the age ranges, we calculated the Whipple Index for fixed age ranges starting with the final digit 3 and ending with the final digit 2, such as 43-52. The age-group-specific Whipple Index values were used as proxies for the numeracy levels of the decades in which most birth years of the cohort were placed. For example, individuals belonging to the age-group 23-32, enumerated in the 1881 British census, were born between 1849 and 1858. The corresponding Whipple Index was used to proxy the numeracy level for the birth decades of the 1850s.[3] We also considered the question of one birth cohort having different Whipple indices due to age-specific effects, as described in the appendix A.

3 A first glance at country level data

For the industrialized countries, the coverage of our data set is very good (Figure 1 and appendix B: Data sources appendix). Most of these countries conducted several censuses during the 19th and 20th centuries, and our cohort analysis covers the majority of the Western world (incl. Japan). However, given that many of these countries had already experienced the peak of their decline before 1820, the observations mainly cluster together between 100 and 120 for the early-to-mid 19th century, and between 100 and 110 for later years. There are two extremes and a few notable exceptions. The extreme cases are Greece and Cyprus that started

[3] In case the birth cohort stretched symmetrically over two birth decades (five birth years each), we assigned the birth cohort to the earlier birth decade.

out from a very high age-heaping level in the late 19th century and then improved rapidly. The numeracy retardation of those countries might have been caused by the backward educational institutions of the Ottoman Empire which might still have impacted numeracy some time after Greece became independent in 1829, and Cyprus was ceded to Britain in 1878; or possibly the Greeks did not improve their institutions considerably.

Initially quite strong age-heaping characterized the time series for Italy, the U.S., Spain, Portugal, and Ireland. While Italy experienced a steady improvement of numeracy levels, the other four countries show signs of adverse development during the early (U.S. and Spain) and late 19th century (Ireland and Portugal).[4] For the U.S., age-heaping was mainly a Southern phenomenon (Crayen and Baten 2009). Even the UK had substantial age-heaping during the early 19th century, whereas Scandinavia and central Europe had relatively good numeracy values during this period.

A strong contrast to the industrialized countries existed in the Middle East and North Africa, but even here, interesting differences are observable which might be even more informative than the absolute level of age-heaping (Figure 2). For the latter two world regions, documentation was much more sparse than for the industrialized countries, especially before the 1880s. In addition, we must note here that our sources vary in regional coverage. We have a number of censuses from the 1930s-1950s period; from these, we obtain age-heaping estimates for the birth decade 1880-89 and later periods. Two other sources date from earlier periods. One of them is the Egyptian census of 1907 that lists individuals born as early as the 1830s. Another source is a census of the Turkish province of Kars, which was under temporary government by the Russian Czar in 1878-1918 so that we were able to obtain information about Kars from the Russian census of 1897. In this period, mainly Turks, Armenians, Kurds, Azerbaijanis, Greeks, and a minority of Russians (7%) inhabited the Kars region. Yet how representative might Kars have been for the territory, which is now Turkey?

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[4] On the age-heaping increase in Spain during the 19th century famine period, see Manzel 2007

Of course, literacy and numeracy were presumably much lower in the countryside than in the metropolis of Istanbul. Otherwise, when judging from height data, for example, this region seems fairly representative of Turkey's rural and small-town landscape. If we compare the final years of the two early series with the Egyptian and Turkish series starting with the 1880s, the levels are very similar. Those two early series indicate very high age-heaping levels, Egypt having even worse values than the Turkish Kars region.

In general, the countries in this world region had high age-heaping values that showed steady improvement during the early 20th century. However there are also exceptions. For example, Algeria and Tunisia had much better (i.e. lower) values than the other countries. It remains to be tested if the French educational policy had a positive impact on these two countries, even if it was probably insufficient in general. Moreover, the French settlements in both countries might have caused spill-over effects to the native-born majorities in those countries. Iran performed third-best in the region. Iraq did also quite well initially, but was overtaken by countries such as Turkey and Morocco later on. Afghanistan and Egypt performed worst in the early 20th century.

To sum up our evidence from the Middle East and North Africa, age-heaping was quite high, and there was slow improvement during the 19th century. During the early 20th century, numeracy improved considerably but was still far from the European (or East Asian) level in the mid-20th century. This is astonishing, given that Arabic numerals were a huge innovation in Europe in the later Middle Ages and early modern period. In this era, Islamic countries were presumably advanced in terms of numeracy compared with the Europeans, because many important innovations originated in the Middle East. Unfortunately, we do not yet have age-heaping information on the early modern or late medieval period in the Islamic world. Yet any attempt to associate the lagging development of the Middle Eastern region in the 19th and early 20th century with an "Islamic" mentality must be clearly dismissed, since neither the Christian populations of the nearby Caucasus and Balkan regions (Georgians, Armenians, Serbs, Greeks) nor most Hindu regions were doing much better in terms of numeracy. Rather, it was probably the adverse institutional and educational infrastructure of this world region that led to low numeracy levels, just as there were positive exceptions such as the Algerian and Tunisian cases.

4 World region estimates

We will also present a very preliminary estimate of numeracy trends for the different world regions (Figure 3). For the industrialized countries and East Asia, we obtained many of the necessary country-birth decade observations, whereas for the Middle East and North Africa, documentation was much scarcer, in particular for the pre-1880 period. For East and Southeast Asia, we were able to produce estimates for the period from the 1840s onwards, while values for sub-Saharan Africa and Latin America could only be traced back to the 1880s and 1890s. The remaining gaps were interpolated, mostly using a benchmark for a given country and then applying the growth rates of the most similar neighboring country (or countries) for which information was available. The assumption here is that trends in neighboring countries were often quite similar, although they might have differed in levels.[5] The final step was to calculate population-weighted averages for the eight world regions.

East Asia (clearly dominated by China; Japan was put in the group of the industrialized countries) is the only region for which we partly relied on sample information. Census information did not become available for the birth cohorts before the 1890s. For earlier periods, we worked with the estimates of Baten, Ma, Morgan and Wang (2007) who used data on Chinese migrants to the U.S., Australia, and Indonesia, as well as on soldiers in Beijing and legal records to estimate a Chinese age-heaping trend. Especially the close correspondence between all those series led Baten et al. (2007) to the conclusion that age-heaping levels were substantial during the early and mid-19th century, culminating during the civil war and famine period of the 1840s and 1850s. During the 1870s and 1880s, in contrast,

[5] The interpolation decisions are documented in an internet appendix.

Chinese age-heaping vanished. The authors took great care in assessing cultural explanations of Chinese age reporting preferences, such as assessing tiger year preferences, 4 avoidance, 8 preferences etc. As a result, Chinese age-heaping was not found to have been fundamentally different from rounding patterns in other parts of the world, although the Chinese cultural interest in the calendar and astrology had a positive effect on numeric abilities and numeric discipline.

For Southeast Asia, the estimates are halfway representative from the 1890s onwards. For earlier times, we relied mostly on Myanmar (the British province of Burma). For Latin America and the Caribbean (LAC) as well as sub-Saharan Africa, we restricted our preliminary estimates to the last four to six decades, since we did not have representative data for the preceding period.

What we can infer from these trends is that South Asia and the Middle East/North Africa had the highest age-heaping (lowest numeracy) during most of the 19th century, whereas the statistics substantially improved during the 20th century. In contrast, the industrialized countries displayed only moderate age-heaping that disappeared around 1880. The age-heaping levels in Eastern Europe/Central Asia[6] were similar to those in the industrialized countries after 1900, and had only slightly higher values during the two birth decades before. Between those five world regions of high and low numeracy in the late 19th century, we can identify three world regions of medium numeracy: South East Asia did considerably better than South Asia (but not as good as East Asia), and Latin America's numeracy developed even more favorably. Sub-Saharan Africa performed fifth best (or third worst) around 1900.

The global distribution of numeracy is shown in Figure 4. We do not have estimates for the territories of present day Libya, Israel, West Sahara, Uzbekistan, Turkmenistan,

[6] The aim was to estimate numeracy for the formerly socialist countries (reference year: 1980). We were able to include Siberia and Kazakhstan but could not yet create estimates for the other Central Asian and Caucasian countries. Omitting Kazakhstan changed the estimates only marginally.

Tajikistan and Laos (and countries with a population less than 500,000), but the remainder of the world is roughly covered. In only 23 cases were we forced to interpolate by using the values of similar neighbouring countries, whereas we had direct data for 73 countries in 1890. For another 49 countries, we had direct benchmark values for the decades following 1890 and approximated growth rates by using the growth rates of similar countries. In conclusion, we found that the least numerate populations of this period lived on the stretch between Egypt, Sudan, southern Arabia, India and what is today Bangladesh. The remaining northern Islamic region between Persia and Turkey was doing better, with the same applying to Islamic northwestern Africa (except Morocco).

Within other world regions, there were also substantial differences. Africa had much better values for its southern part, which reached as far northward as Angola. The Sahel zone was characterized by slightly lower age-heaping than the highly populated Gold and Ivory Coast in this period, and the least numerate Africans were located between Nigeria and the Congo. Similarly, Latin America had a strong North-South gradient. Moreover, Brazil and Venezuela performed better than the countries located between Bolivia and Mexico.

Finally, within Europe, the expected West-East differential holds, but this does not apply to the far West and Southwest (Ireland, Spain, Portugal). The relatively poor Scandinavians were the “Impoverished Sophisticates” frequently described in the literature. Similar descriptions could apply to the Chinese and Southeast Asians (except for Indonesia and the Philippines).

Summing up, we were able to describe global trends in numeracy for eight world regions, two of which started out with very low numeracy levels (the Middle East/North Africa and South Asia), while three world regions had quite good values from the beginning of our sample period (the industrialized countries since the early 19th century, Eastern Europe and East Asia from the second half of the 19th century on). Among the three regions of medium-level age-heaping, the case of Africa is particularly remarkable, as it performed better than South Asia and the Middle East. Given its educational standing today, it was unexpected that Africa would have started out from a relatively promising level. Another noteworthy case is the deterioration of numeracy in East Asia during the mid-19th century civil war catastrophes (albeit still on a relatively modest scale).

5 Determinants of age-heaping

Age-heaping mainly originates either from a respondent's ignorance of his or her exact age, or missing numeric discipline. Nowadays, we can assume that most people living in industrialized countries know their exact age or their year of birth, and otherwise they can check this information in registries, passports etc. if necessary. By contrast, people living in developing countries will more often have only a vague idea about their age or the year when they were born (this even applies to societies where birth registration has become well established). In such countries, numeracy can still be quite low (Kaiser and Engel 1993). One likely determinant of age-heaping is the degree of schooling a person received. In school, children are taught numbers, and the formal schooling system is likely to improve their structural thinking skills in general, which in turn might enhance their numeric knowledge and discipline. A second potential determinant of age-heaping is the degree to which an individual interacts with the state or religious and other administrative authorities, and the degree to which that authority is involved with market transactions. Another numeracy-enhancing factor besides the state bureaucracy, market demand or schooling success is the frequent use of calendars or astrological elements as in the Chinese culture, for example. Finally, in many historical societies and the poorest economies today, the infant protein malnutrition syndrome (IPMS) plays a role. After their experiments to assess the influence of protein malnutrition in childhood and the intellectual ability later in life, biologists and psychologists suggest that IPMS limits an adult's cognitive abilities.[7] While the ethical backgrounds of those experiments are debatable, the results cannot be ignored. For example,

[7] Particular thanks to Joachim Voth for hints on the following review of IPMS.

Lucas (1998) finds that children who had received less nutrient-rich diets showed markedly lower neurodevelopment during the first two years of life, compared to a control group. Even as late as age 7.5 the IQ scores were significantly lower. Studies on Guatemala suggest that protein supplements can produce marked improvements in cognitive ability (Brown and Politt 1996). Especially numerical abilities could be affected (Paxson and Schady 2005). Most relevant for the justification of this variable is the study by Grantham-McGregor (2002) which points to a link between heights and cognitive ability even on the individual level. Her study on stunted children showed that nutritional supplements can produce important gains in intellectual development.[8] This factor might be especially important in our context when we observe increases of age-heaping although there is no deterioration in the political, economic or educational sphere that would sufficiently explain this development, as was the case in China or Ireland in the mid-nineteenth century, or in England around 1800 (see Baten, Crayen and Voth 2007 on English regions; Manzel 2007 on Spanish regions; Baten, Ma, Morgan and Wang 2007 on China). In principle, an IPMS reduction could also explain the decline of age-heaping during the 19th and 20th centuries, when protein access improved. However, the IPMS phenomenon is easier to identify in times of rising or stagnating age-heaping. Thus, numeracy yields valuable information both about individuals and the society they inhabit.

To explore the correlation of age-heaping with schooling, state development and protein malnutrition, we included primary school enrollment information from the famous Lindert data set[9], supplemented by Benavot and Riddle (1988) in our model specification. As our age-heaping evidence was organised by birth decades whereas primary school enrollment takes place at approximately age 10, we lagged the Whipple Index by one decade. To

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[8] Several other studies indicate that the persistent exposure to undernourishment and poverty produce a cumulative effect on cognitive ability. e.g., Gorman (1995), Strupp and Levitsky (1995). The longer a child's nutritional and educational needs go unmet, the greater the overall cognitive deficits. This applies not only to severe but also to mild undernourishment. Magnusson, Rasmussen, and Gyllensten (2006) reason that genetic influences cannot fully explain the correlation between heights and cognitive ability from observing stature and intelligence of Swedish siblings.

[9] Primary-school students per 1000 children of ages 5-14, Lindert (2004).

approximate state development, we used the data on state antiquity by Bockstette, Chanda and Putterman (2002) who constructed a variable that measures that share of years in which the territory of a modern state was ruled by a government of the same size. For example, China was ruled roughly in her present borders during most of her history, whereas Malawi was not. Bockstette, Chanda and Putterman argued that the Chinese government was able to gain experience to govern a state of this size, and therefore state antiquity might proxy the strength of the state and the quality of its institutions. Although time-invariant, this variable also provides valuable information on the history and importance of state-level institutions that might have generated a demand for the knowledge of one's age even if the prevailing human capital level was not too high. As an alternative (time-variant) measure for state development and for the demand for the knowledge of one's age in society, we computed the number of censuses taken in each country since 1600 up to and including the birth decade.[10] Following Domschke and Goyer's *Handbook of National Population Censuses,* Greece received the highest score for 1880, from a total of 16 censuses that had been conducted by 1889. In our model, we used three dummy variables denoting '1 or 2', '3 to 5' and '6 or more' past censuses. Fourthly, we included a (time-invariant) dummy variable for those nations, which were influenced by the Chinese calendar/astrology/culture.[11] Finally, we used the recent global height estimates by Baten (2008) to control for infant protein malnutrition (also lagged by one decade). [12] In order to measure non-constant marginal effects, we included square and square root terms but found the log specification to perform best. The inclusion of all explanatory variables led to a decline in the number of cases. Moreover, here we included

[10] Censuses were counted only if they covered the vast majority of the population (i.e., colonial censuses enumerating the white population only were not included) and if the censustakers asked for the age.

[11] The dummy variable takes the value 1 for China, Hong Kong, Taiwan, North and South Korea, Japan, Singapore, and Vietnam.

[12] This unpublished data set is described in Baten http://www.wiwi.uni-tuebingen.de/cms/fileadmin/Uploads/Schulung/Schulung5/Paper/baten_global.pdf (lastly accessed on March 16th, 2009. There is also an online appendix on its data sources referenced in the notes to Figure 1.

only age-heaping data points, for which we had direct data, producing a sample size of 22 to 70 observations per birth decade.

As the results displayed in Table 1 show, all specifications yield that schooling is by far the strongest determinant of age-heaping patterns. In the birth decade-specific OLS regression, primary school enrollment has a very robust coefficient and very large t-values. It is important to note that the coefficients remain similar if the underlying samples are large enough. In contrast, height has a variable influence, which is evident only for the decades for which we have the largest number of observations (1920s-1940s, plus the 1900s). The state antiquity variable by Bockstette, Chanda and Putterman (2002) which proxies the authority of the state is never significant in this series of cross-sections, and the East Asia dummy variable has the expected reducing effect: in China and its neighbouring countries, we observe less schooling but more numeracy. We also tested several panel regression models, using both random and fixed effects estimation techniques.[13] The fixed effects represent the cross-sectional dimension here (the countries). We found our previous results confirmed (Table 2). Notably, primary school enrollment is closely correlated with age-heaping in the fixed effects regression, which controls for unobserved heterogeneity between countries as well. The schooling variable is statistically and economically significant: a change of one standard deviation of the primary student enrollment variable (1.19) in the random-effects specification, multiplied with the coefficient, accounts for 44% of the standard deviation of the dependent variable (0.47). In contrast, the same procedure for the height and state antiquity variables leads to the conclusion that a rise of those variables by one standard deviation leads to a less than 10% increase of the standard deviation of the dependent

[13] The country-specific unobserved effects were taken as fixed effects in order to control for unobserved heterogeneity. For example, there could cultural differences between countries, which cannot be controlled for otherwise. On the other hand, we also use random effects models, as they allow to include time-invariant variables such as East Asia and State Antiquity. Moreover, it has been argued in the empirical growth literature that using the fixed effects model alone puts too much weight on the variation over time, which is often fraught with more measurement error, and reduces the weight for the cross-sectional variation, which is sometimes more accurately measured.

variable.[14] Particularly in the case of the height variable, we also have to admit the possibility of endogeneity (numeracy might improve the welfare level). If present, this should raise the significance levels. Moreover, height is also closely correlated with GDP, so that its effect might proxy a general developmental effect rather than an infant protein malnutrition effect. Once the dummy variables indicating the number of past censuses are integrated, the height variable loses significance. From those considerations, we conclude that the importance of the height variable might not be given in global cross-sections and panels, whereas the importance of malnutrition in time series of age-heaping was shown in related studies (Manzel 2007; Baten, Crayen, and Voth 2007; Baten, Ma, Morgan and Wang 2007).

Could there be potential endogeneity effects of numeracy impacting schooling decisions via welfare levels? It is important here to consider the timing of the variables. We organized the age-heaping evidence by birth cohorts, and the primary student enrollment variable by the decade when most children reached age 10. An increase in numeracy had an effect on welfare levels, but it should only occur two, three, or even four decades after birth (hence in our growth regressions we work with growth during the period 40 and 50 years after the numeracy variable was recorded). Hence the impact on schooling decisions via a welfare increase can only occur with a considerable time lag. Moreover, Lindert (2004) actually argued -- and tested empirically in a variety of ways -- that schooling decisions were not strongly influenced by the GDP per capita level of a country. He regards the degrees of democratization, decentralization, and demand for national strength as crucial (for example, the situation when France lost the 1870/71 war against Germany and improved the school system to regain national competitiveness).

[14] We also accounted for interaction effects between schooling and the state antiquity variable by Bockstette, Chanda and Putterman (2002), as well as for interaction effects between schooling and the lagged height variable. In both cases, the coefficient of the schooling variable proved robust, while the other variables did not have any statistically significant impact on the Whipple Index (in logs).

At the same time, countries where census taking has become standard, i.e. countries with 6 or more past censuses, have significantly lower age-heaping levels. The effect is not very large though, as the coefficient of this dummy variable is only –0.05, relative to the reference category (the constant represents the case of no previous census taken).

In order to provide a schooling estimate based on age-heaping, we also performed the regression with primary student enrollment as the dependent variable (see Table 3). The results apply to all world regions except East Asia. Again, the coefficients are robust over time, suggesting that one additional percentage point in age-heaping approximates 1.8-2.0 percent less schooling. Given that this is time-invariant for the period between the late 19th century and the mid-20th century, we would suggest using a value of 1.9 to estimate schooling throughout the 19th century.

6 Implications for empirical growth economics

What are the implications of our new estimates for empirical growth economics? Can age-heaping based on numeracy explain growth capabilities in a large number of countries? To test this subject matter, we employed all available GDP growth figures between 1820 and 1870, as well as between 1870 and 1913 (Maddison 2001), and combined them with our numeracy estimates of the respective periods. In total, we could identify a set of 62 GDP growth figures for those two crucial periods in the 19th century that could also be documented with initial numeracy. The sample not only includes today's rich countries, but also Less Developed and Middle Income Countries such as Myanmar, Egypt, Malaysia, and Armenia (see the notes to Table 4). In a set of regressions, we followed the standard procedure developed by Barro (1991, 1999), who regressed growth rates on a set of "growth capabilities" measured in levels. The amount of human capital available in an economy is such a "growth capability", since theory suggests that after controlling for the initial welfare level (which also proxies a country's capital stock, as Barro (1991) has argued), only countries with high human capital can achieve welfare growth in the following period. Initial GDP per capita is thus included into the growth regression setup to control for (a) growth capabilities arising from a high initial physical capital stock and also for (b) conditional convergence. For both effects we would expect a negative sign. The regression coefficient of initial GDP per capita would only turn positive in periods of substantial divergence, i.e. in the case of high initial welfare levels correlating with high growth rates. Statistical insignificance can be the result of counter-acting forces.

The numeracy estimates given in the Whipple Index have considerable explanatory power: the coefficient of the Whipple Index is consistently negative, as expected, and highly significant. In a general regression (column 3 in Table 4), we controlled for the initial level of GDP, an East Asia dummy (due to the Chinese calendar usage, numeracy in East Asia might be lower than would be expected from the low age-heaping levels) and the state antiquity index by Bockstette, Chanda and Putterman (2002). A standard deviation of the logarithm of the Whipple index of those 62 cases which we could include in column (1), and (3)/(5) amounts to 0.53. Hence, the difference in annual growth rates is 0.37 percentage points between average cases and those that feature age-heaping levels one standard deviation higher (we multiplied the schooling coefficient of 0.70 reported in column 3 with the standard deviation of 0.59), which can be regarded as economically meaningful, given that this is more than half the standard deviation of the dependent variable (the standard deviation of the annual growth rate is 0.71 percentage points). We also regressed GDP growth on Whipple indices alone, and found a significant impact, albeit a smaller coefficient (column 1). The East Asia dummy is in fact negatively significant, which might be caused either by the measurement effect described above, or by the disappointing growth in East Asia for political and other reasons during this period. Initial GDP is not significant in the first specification, but it turns significant once we included a dummy variable for the period 1870-1913, as this pooled cross-section might be characterised by heterogeneous intercepts (but its insignificance suggests it is not, column 5). Hence there is apparently some conditional convergence observable, once we controlled for initial human capital and other variables. State antiquity has a negative effect here (quite the opposite to its effect between 1960 and 1990). This indicates that strong government institutions are not inevitably favorable. In times of massive industrial change, a strong state dominated by vested interest groups and conservative feudalists might have been a hindrance.

In column 6, we ran a regression with a combination of GDP per capita, state antiquity and a dummy variable for East Asia only, in order to assess whether the improvement in the R^2 between model (1), and (3)/(5) is due to the Whipple Index or to the other explanatory variables. In fact, the R^2 is 0.35 for those three other variables, so the largest part of the improvement in explanatory power from 0.05 and 0.47 (or 0.49) between model (1), (3) and (5) can be assigned to the information provided by GDP per capita, state antiquity and the dummy variable for East Asia. The remaining component (the difference between 0.35 and 0.47/0.49), however, conveys the explanatory power which is gained by the inclusion of the Whipple Index, either directly or indirectly by its interaction with the other explanatory variables.

Unfortunately, we were not able to conduct a similar test to measure schooling effects on growth, since the factor of schooling is only available in 25 cases from 1870 to 1913. Because of the constrained availability of the other explanatory variables, the sample size falls to 22. For this period, schooling is consistently insignificant at the 5% level. In addition, we cannot interpret this as evidence that numeracy explains more than schooling. For a direct comparison, the sample (for which we have both numeracy and schooling values) is comprised of only 16 cases. The reduced sample size leads to insignificance of all potential explanatory factors. We can conclude that the age-heaping strategy allows researchers to capture the human capital impact on growth successes and failures from 1820 to 1913, whereas our knowledge about schooling is insufficient to do so. Measuring numeracy can thus provide new and useful insights for researchers and add to long-term economic growth analysis.

7 Conclusion

In this paper, we presented age-heaping as an indicator of human capital, which of course has its limitations. However, this is the nature of all human capital indicators. The limitations of signature ability as a measure of functional literacy are obvious, but can also be raised with respect to the self-reported "ability to read." School enrollment as an input measure is conceptually problematic, since we do not know about the quality of schooling and the concept and educational methods of the teacher. We think that the comparison of different human capital indicators is the most promising way of establishing a reliable database that can inform growth economics, economic policy recommendations, and many other fields of research.

South Asia and the Middle East had relatively low numeracy levels in the 19th century (as opposed to the western world and East Asia). In addition, South East Asia as exemplified by Burma, for instance, had better values than South Asia. China stands out as a country with very low age-heaping levels in the late nineteenth century - comparable to western industrialized countries. This suggests there were good prospects for the future economic development of China, which could not materialize because of civil war and other political obstacles to economic and social development.

It is remarkable that both the northern Islamic countries, stretched between Iran and Turkey, as well as the northwestern part (Algeria, Tunisia etc.) of the Islamic world performed much better than the Southeast. Within Europe, the Greeks, Cypriotes, Irish, Portuguese and Spanish stood out as having had relatively low numeracy during the 19th century. Especially for the birth cohorts after the Great Famine, there was even a temporary deterioration before Ireland and Spain converged back to Western European levels. Other parts of Europe experienced their numeracy revolution as early as the 17th and 18th centuries. The United States (or rather its southern part) lagged in numeracy in the first decades of the 19th century, but developed rapidly in the second half of the century. For sub-Saharan Africa and Latin America, the data sources do not allow estimates for the time before the 1880s and 1890s. Preliminary outcomes suggest that Africa belonged to a middle group between Southeast Asia and the Middle East.

We ran explorative regressions on the determinants of age-heaping. We found schooling to be the most important correlate. Protein malnutrition might have played a role, but the results were not consistent, and endogeneity could not be ruled out. While the age and authority of the state bureaucracy did not seem to play a significant role, our results indicated that more generally, state demand for frequent age reporting improved people's numeracy or numeric discipline, as we can see from the fact that countries with a long tradition of census taking had slightly lower age-heaping levels.

Finally, we assessed the contribution of numeracy as measured by the age-heaping strategy for long-term economic growth. In a variety of ways, numeracy was highly significant. We can conclude that age-heaping allows capturing the human capital impact on growth successes and failures between 1820 and 1913, whereas our knowledge about schooling is insufficient to do so. Measuring numeracy is clearly an important activity in order to understand long-term economic growth worldwide. Overall, the age-heaping technique allows a more nuanced view on human capital formation in most of the world's regions during the 19th and 20th centuries.

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TABLES

Table 1: Determinants of age-heaping, measured by the logarithm of the Whipple Index, by birth decade

Coefficient	1880	1890	1900	1910	1920	1930	1940
Schooling	-0.37	-0.26	-0.26	-0.27	-0.24	-0.20	-0.22
	(0.05)	(0.06)	(0.05)	(0.05)	(0.04)	(0.03)	(0.03)
Height	0.52	-1.68	-2.73	-1.38	-2.09	-1.70	-1.44
	(1.17)	(1.38)	(1.19)	(1.09)	(0.83)	(0.63)	(0.59)
State Antiquity	-0.35	-0.20	-0.13	-0.06	-0.10	-0.17	-0.13
	(0.13)	(0.28)	(0.15)	(0.13)	(0.10)	(0.10)	(0.08)
East Asia				-0.91	-0.63	-0.39	-0.33
				(0.3)	(0.17)	(0.11)	(0.07)
Cons.	6.44	9.34	11.03	8.86	9.82	9.00	8.63
	(1.95)	(2.18)	(1.85)	(1.68)	(1.27)	(0.98)	(0.92)
Obs	22	31	45	60	69	70	64
Adj. R-sq	0.73	0.52	0.61	0.52	0.57	0.51	0.59

Notes: Robust standard errors in parentheses, calculated with the Huber/White/sandwich estimator of variance which avoids biased standard errors caused by heteroskedasticity. The dark and light, grey-shaded areas denote significance at the 1% and 5% level, respectively. Dependent variable: Whipple Index of age-heaping (logarithm), lagged by 10 years. Independent variables: schooling: Primary school students per 1000 children of ages 5-14 by Lindert (2004), supplemented by Benavot and Riddle (1988) in logs. height: Average body height in cm by Baten (2008) lagged by 10 years. State Antiquity: State antiquity by Bockstette, Chanda and Putterman (2002). East Asia: The dummy variable takes the value 1 for China, Hong Kong, Taiwan, North and South Korea, Japan, Singapore, and Vietnam. The birth decade ‘1880’ refers to the years 1880-89 etc. Sources for the Whipple Index: see appendix B: data source appendix.

Table 2: Panel regression results: determinants of age-heaping, measured by the logarithm of the Whipple Index

Coefficient	Random Effects (general)	Random Effects (specific)	Fixed Effects (general)	Fixed Effects (specific)
Schooling	-0.17	-0.16	-0.13	-0.15
	(0.02)	(0.02)	(0.01)	(0.01)
Height	-0.64		-0.17	
	(0.24)		(0.40)	
State Antiquity	-0.18			
	(0.09)			
Censuses (1 or 2)			-0.01	
			(0.04)	
Censuses (3 to 5)			-0.04	
			(0.04)	
Censuses (6 or more)			-0.05	
			(0.02)	
East Asia	-0.44			
	(0.20)			
Cons.	7.11	5.85	6.00	5.76
	(0.38)	(0.10)	(0.66)	(0.11)
Obs	402	477	471	477
Number of countries	73	91	90	91
R squared (within)	0.41	0.37	0.39	0.37
R squared (overall)	0.58	0.49	0.49	0.49

Notes and sources: Robust standard errors in parentheses. The dark and light, grey-shaded areas denote significance at the 1% and 5% level, respectively. Dependent variable: Whipple Index of age-heaping (logarithm), lagged by 10 years. Independent variables: Primary school students per 1000 children of ages 5-14 by Lindert (2004), supplemented by Benavot and Riddle (1988) in logs. height: Average body height in cm by Baten (2008) lagged by 10 years. State Antiquity: State antiquity by Bockstette, Chanda and Putterman (2002). Censuses: Dummy variables indicating the number of censuses taken up to and including the specific birth decade (based on Domsche and Goyer 1986a-c). East Asia: The dummy variable takes the value 1 for China, Hong Kong, Taiwan, North and South Korea, Japan, Singapore, and Vietnam. Sources for the Whipple Index: see appendix B: Data source appendix.

Table 3: Age-heaping as a determinant of student enrollment ratios, by birth decade (East Asia omitted)

Coefficient	1880	1890	1900	1910	1920	1930	1940
Whipple	-2.02	-1.78	-2.01	-1.94	-2.07	-2.06	-2.14
	(0.30)	(0.35)	(0.30)	(0.19)	(0.26)	(0.29)	(0.25)
Cons.	15.79	14.37	15.53	15.18	15.74	15.74	16.18
	(1.45)	(1.72)	(1.44)	(0.93)	(1.28)	(1.39)	(1.19)
Obs	23	35	51	71	82	84	77
Adj. R-sq.	0.70	0.49	0.57	0.61	0.53	0.50	0.57

Notes: Robust standard errors in parentheses. The dark shaded areas denote significance at the 1% level. Dependent variable: schooling (Primary school students per 1000 children of ages 5-14 by Lindert (2004), supplemented by Benavot and Riddle (1988) in logs). Independent variable: Whipple Index (logarithm), lagged by 10 years. The birth decade '1880' refers to the years 1880-89 etc. Sources for the Whipple Index: see appendix B: Data sources appendix.

Table 4: Growth Regressions with Age-heaping (Whipple Index) and other determinants (pooled cross-sections: 1820-1870 and 1870-1913)

	(1)	(2)	(3)	(4)	(5)	(6)
Whipple Index	-0.32		-0.70		-0.75	
	(0.08)		(0.21)		(0.21)	
Schooling		0.10		0.43		
		(0.06)		(0.22)		
Initial GDPpc			-0.34	-0.37	-0.43	-0.08
			(0.20)	(0.19)	(0.20)	(0.16)
East Asia			-1.06		-1.12	-0.82
			(0.28)		(0.27)	(0.23)
Period 1870-1913					0.23	
					(0.13)	
State Antiquity			-1.62	-0.33	-1.67	-1.47
			(0.64)	(0.45)	(0.64)	(0.67)
Constant	2.57	0.68	6.18	-44.90	6.47	2.22
	(0.46)	(0.42)	(1.74)	(1.07)	(1.75)	(0.69)
Observations	62	25	55	22	55	55
Adj. R-sq	0.03	0.01	0.43	0.04	0.44	0.31

Notes: : Robust standard errors in parentheses. The dark and light, grey-shaded areas denote significance at the 1% and 5% level, respectively. Dependent variable is the average GDP per capita growth rate (geometric mean of $GDPC_{1820}$ and $GDPC_{1870}$ or of $GDPC_{1870}$ and $GDPC_{1913}$), based on Maddison (2001). Independent variables: Whipple Index of age-heaping (logarithm), lagged by 10 years. schooling: Primary school students per 1000 children of ages 5-14 by Lindert (2004), supplemented by Benavot and Riddle (1988) in logs. Initial GDP per capita: In $1000 units, based on Maddison (2001). East Asia: The dummy variable takes the value 1 for China, Hong Kong, Taiwan, North and South Korea, Japan, Singapore, and Vietnam. Period 1870-1913: Dummy for the specified period. State Antiquity: State antiquity by Bockstette, Chanda and Putterman (2002). Sources for the Whipple Index: see appendix B: Data sources appendix. All independent variables refer to the initial year of the dependent variable (the Whipple in 1820 for the growth rates 1820-70 etc. Countries included in column (1) are (for both periods, unless otherwise mentioned: Armenia (1820), Austria, Australia, Belgium, Canada (1820), China, Croatia, Democratic People's Republic of Korea, Denmark, Egypt, France, Germany, Greece, India (1870), Iraq, Iran, Italy, Japan, North South Korea, Malaysia (1870), Morocco, Myanmar (1870), New Zealand, Norway, Poland (1870), Palastinian Territory, Portugal, Republic of Korea, Spain, Sweden, Switzerland, Taiwan, The Netherlands, Turkey, United Kingdom, United States of America.

Table A.1: Sample sizes for the age effect analysis

country mean category	sample size
105-124	420
125-149	306
150-174	183
175-224	302
225-299	184
300-245	148
350-500	51

Sources: see appendix B: Data sources appendix.

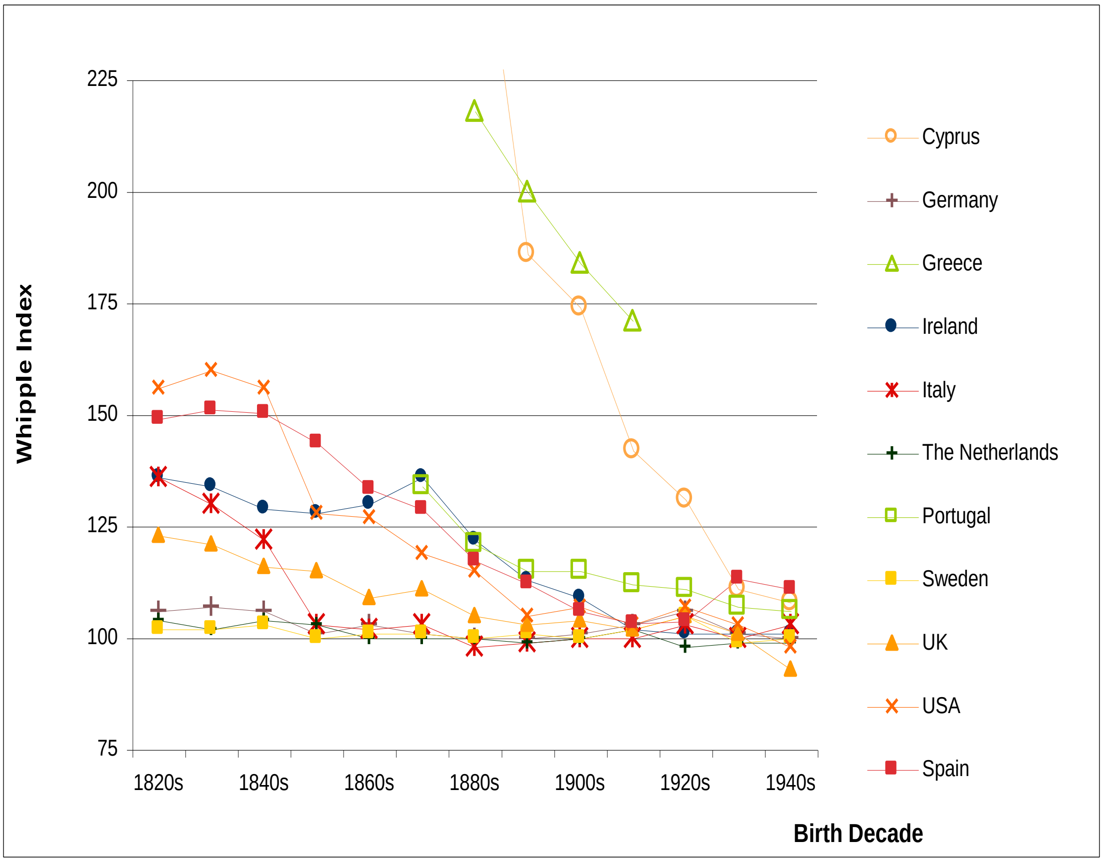
Table A.2: Coefficients of the age-group specific dummy variables (birth decade dummies included)

country mean category	age-group effect 23-32	43-52	53-62	63-72	constant
105-124	-5.19	2.23	-2.38	-5.65	112.37
	(1.39)	(1.88)	(1.96)	(1.65)	(1.73)
125-149	-8.74	2.53	-10.3	-7.65	138.48
	(3.41)	(3.80)	(4.87)	(7.44)	(5.73)
150-174	-25.42	1.6	-3.18	-7.37	166.31
	(12.41)	(10.67)	(9.20)	(9.18)	(10.66)
175-224	-23.03	4.81	-1.16	16.42	194.62
	(8.99)	(8.23)	(8.49)	(13.76)	(8.67)
225-299	-42.39	-3.98	10.39	5.92	271.89
	(15.78)	(17.35)	(19.08)	(14.14)	(27.53)
300-349	-43.22	19.7	31.3	-0.27	318.1
	(15.15)	(16.11)	(18.47)	(27.02)	(17.70)
350-500	-70.91	30.77	34.64	115.98	417
	(19.22)	(16.46)	(18.26)	(16.4)	(19.22)

Note: Robust standard errors in parentheses. The dark and light, grey-shaded areas denote significance at the 1% and 5% level, respectively. Dependent variable: Whipple Index by heaping group (see Appendix A.1). Birth decade dummy variables are not reported. Sources: see appendix B: Data sources appendix.

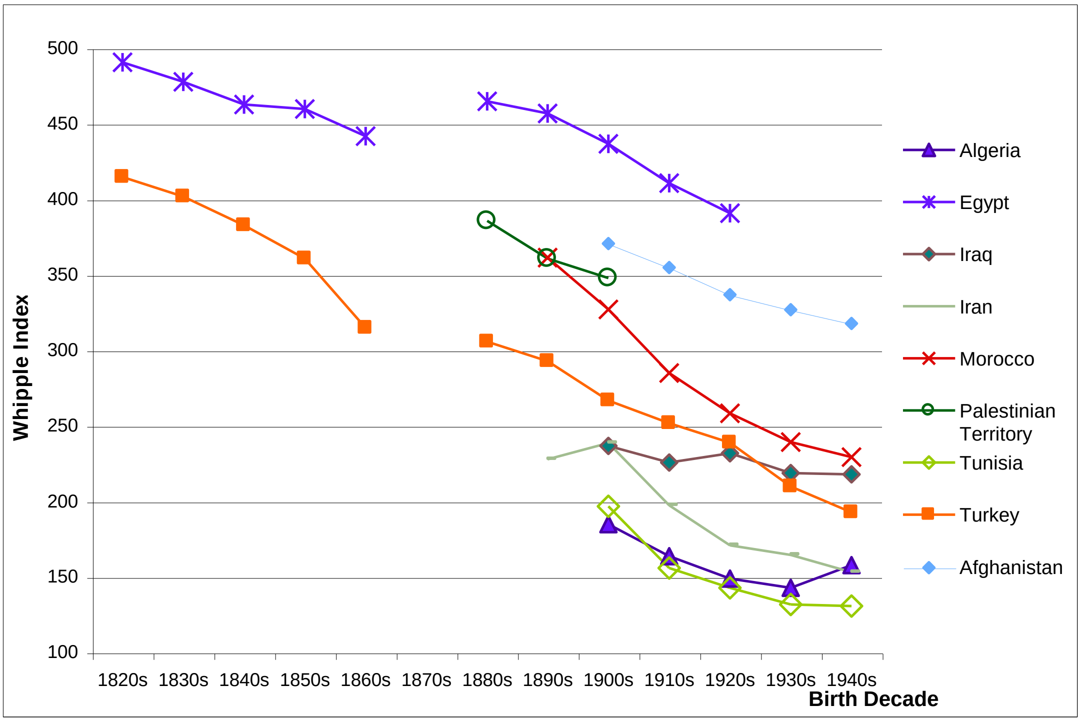
FIGURES

Figure 1: Age-heaping levels in industrialized countries



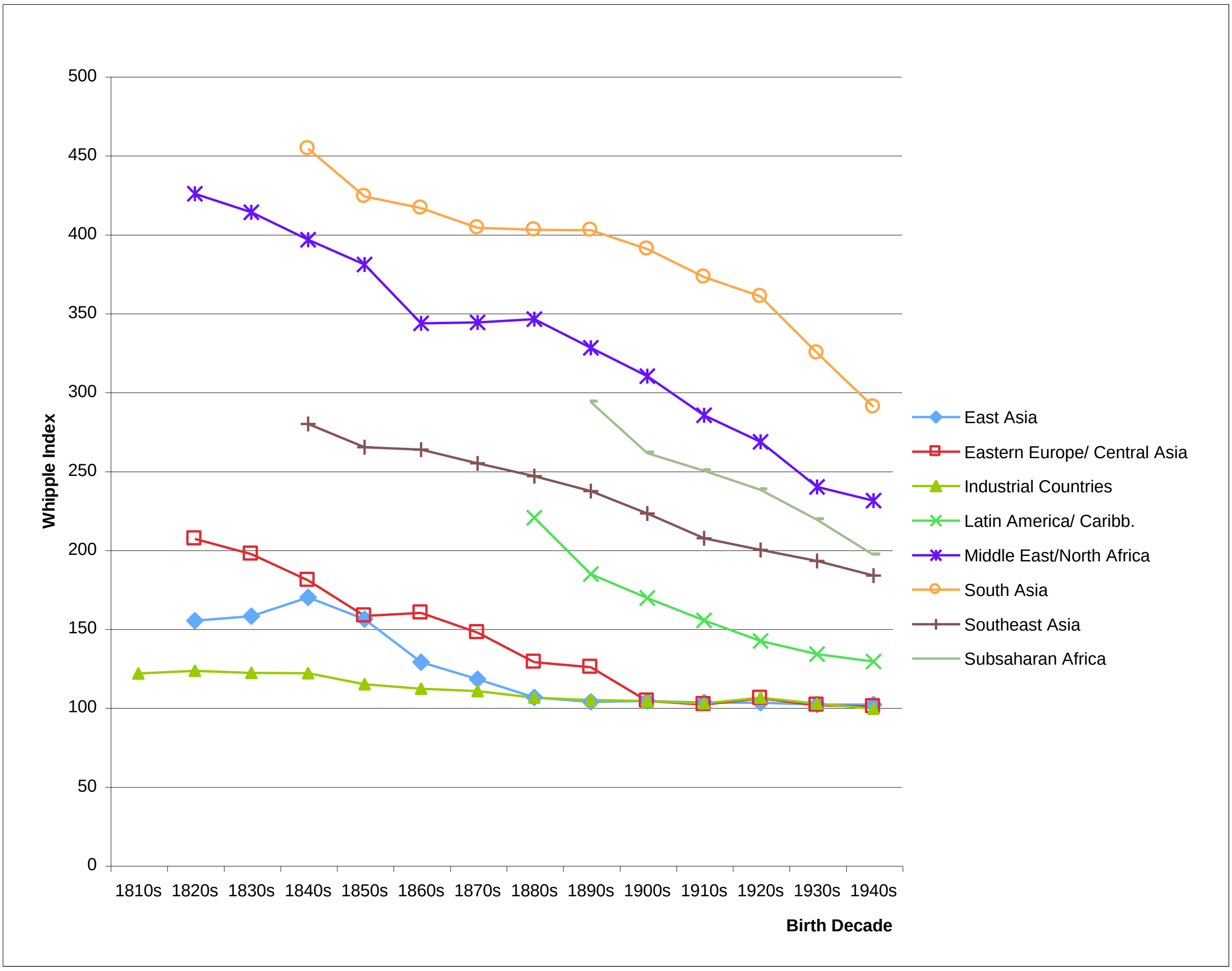
Notes: The Whipple Index ranges from 0 to 500 and calculates the number of self-reported ages that are multiples of 5, relative to the number expected with a uniform distribution of ages. Accordingly, a Whipple Index of 0 (500) implies no (only) ages ending in multiples of 5. At 100, it would imply that exactly 20% of the population report ages ending in multiples of 5, which is considered as 'no heaping'.
The value of Cyprus for the birth decade 1880s is 275.
The birth decade '1820' refers to the years 1820-29 etc.
Sources: see appendix B: Data sources appendix.

Figure 2: Age-heaping levels in the Middle East and North Africa



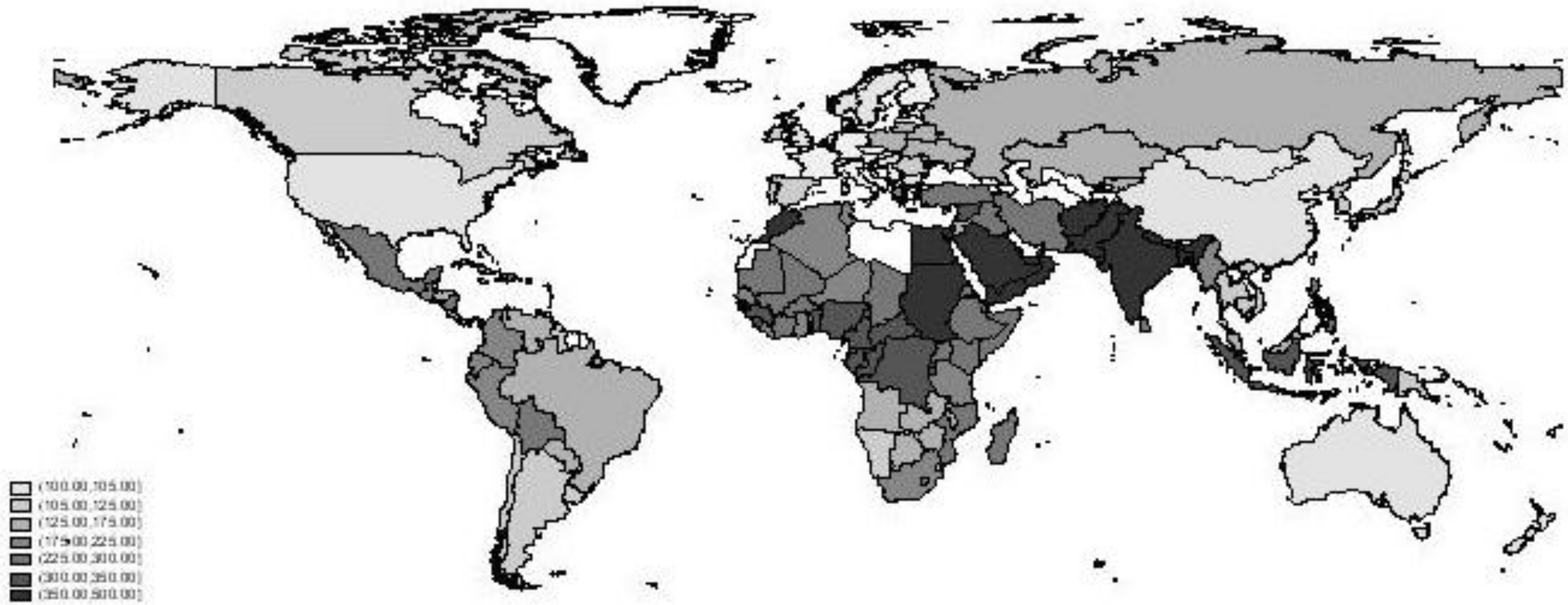
Notes: The birth decade '1820s' refers to the years 1820-29 etc.
Sources: see appendix B: Data sources appendix.

Figure 3: Age-heaping in the different world regions



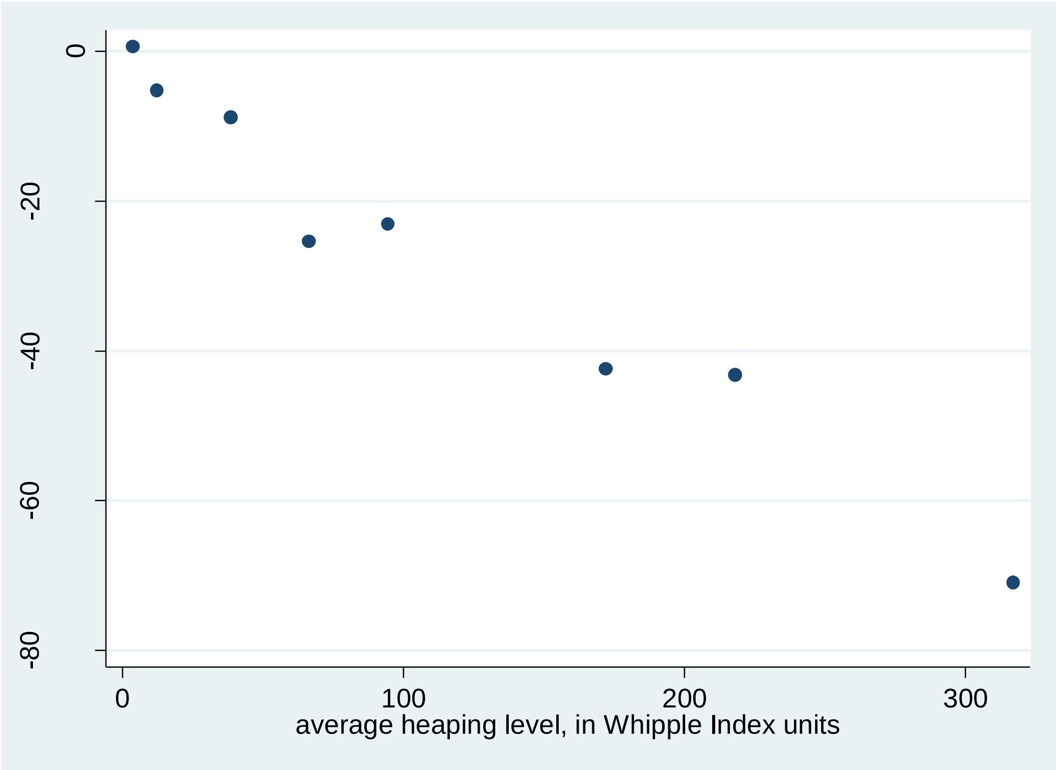
Notes: The birth decade '1820s' refers to the years 1820-29 etc.
Sources: see appendix B: Data sources appendix.

Figure 4: Worldwide overview of age-heaping levels for the birth decade of the 1890s



Notes: The darker the area the higher the Whipple Index. The birth decade ‘1890s’ refers to the years 1890-1899.
Sources: see appendix B: Data sources appendix.

Figure A.1: Heaping level and age effect among 23 to 32-year-olds



Note: the average-heaping level refers to the constants obtained through regression analysis displayed in Table A.2, which refers to age-heaping in the age-group 33-42, minus the 'zero-heaping'-Whipple Index of 100. The age effect on 23-32-year-old is measured by the regression coefficient of the youngest age group, as displayed in Table A.2. See also text of appendix A: Did age-heaping vary by age group and is an age adjustment necessary?
Sources: see appendix B: Data sources appendix.

Appendix A: Did age-heaping vary by age group and is an age adjustment necessary? (to be included in the published version)

The probability of reporting a heaped age can vary with age itself (even when controlling for cohort effects) for several reasons. In the first place, one could imagine that older individuals are more likely to forget their age.[15] Secondly, a society may provide different incentives to different groups for distorting their true age. For example, women who are still single in their thirties or even later in life might feel pressured to report a low age in order to increase their ‘marriageability’, a distortion which could then be associated with heaping, although heaping could also take the form of excess frequencies of numbers like 29 rather than multiples of five.[16] Thirdly, young people may be more aware of their exact age since they are still growing (or they have finished growing recently). They might also be in the process of passing through important stages of their societal life, acquiring increasingly more rights, but also more responsibilities. Minimum age requirements for marriage, military enlistment, and participation in elections are only a few examples of the importance of age in the second and beginning third decade of life. This point is illustrated by Keith Thomas (1987) who states for early modern England that ages were reported with higher precision for people under twenty than at higher ages. Agreeing with this reasoning, Dillon (2007) concluded from Canadian and U.S. census data taken between 1870-1901 that being above 24 increased the propensity to round off one’s age significantly. Using separate logistic regression for each census, she found the age groups 35 to 54 and 35 to 64 (for the 1870/1 and 1900/01 censuses respectively) to have the highest probability to report a rounded age. Moreover, we observe that teenagers and young adults sometimes round on multiples of two rather than multiples of five, if they do not know their exact age.

[15] See the discussions in Kaiser and Engle (1993) and Ewbank (1981).
[16] See Retherford and Mishra (2001) and Narasimhan et al. (1997).

Among the higher age groups, two different effects might play a role. On the one hand, older people tend to pay less attention to their age or forget it, as described above. However there could also be a positive selection effect with regard to older people, given that more educated people have a lower mortality risk. As a second reason for a potential old-age-effect, the literature reports that beyond a certain age, people begin to be extremely proud of their age. This pride might either lead to more mental investment into recalling one's exact age, or to bragging about a very old age ("I'm already 100 years old" was a frequent statement in Soviet Central Asia, which biased life expectancy estimates upwards). It is thus not straightforward whether and how age itself impacts age-heaping levels of older groups.

These factors have inspired our decision to omit the age groups with the highest mortality rates above 72. We also omitted those younger than 23 for the reasons explained above.

Could there still be survivor bias among the older age groups, for example, 63-72? The dimension of the bias will be determined by the degree of selectivity and the inequality of numeracy in the population. However, even under the assumption of extreme selectivity and a mortality rate difference of about 10% between age-groups, the Whipple Index will hardly be underestimated by more than a few percentage points for any reasonable level of numeracy inequality. Due to successive census taking, we were most often able to estimate Whipple Indexes for mixed age groups, a strategy which will reduce the survivor bias further. Egypt and Turkey are examples where for certain birth decades we had single age groups only. Nevertheless, the evidence did not suggest any survivor bias in these cases (Figure 2). The Whipple Index for Turkey stagnates in spite of the shift from the youngest group in the earlier census (born during the 1860s) to the oldest age group in the later census (birth decade 1880-89). On the other hand, the Whipple Index actually increases for the Egyptian period 1870-1879 to 1880-1889, which marks the line between the two succeeding censuses and thus between the oldest and the youngest age group.

After deciding to include only the age groups 23-72, we tested in the following whether there is still an independent age group effect if we hold the birth cohorts constant. In other words, are people rounding more or less on multiples of five in different stages of their life, independent of the "true" numeracy of their birth cohort and country? As mentioned above, we often have several numeracy estimates for the same birth decade because of successive census taking. If heaping behavior changes with age, the "true" numeracy of a given birth cohort in a given country could be under- or overestimated. We regressed age-heaping below on both age group and birth decade dummies to find out whether this is indeed the case.

Before outlining our regression, we should discuss one additional complication. The size of the independent age effect could depend on the general age-heaping level in a country. We might expect that the degree to which individuals change their heaping behavior at different ages depends on the overall numeracy level. Hence, we formed country groups of different heaping levels and then ran regressions separately for each group. Of course, we need to avoid truncating the dependent variable at certain heaping brackets. [17] This could induce the danger of selectivity bias. Therefore we did not group by age heaping of birth decade/country groups. We rather used the average Whipple index of a country over a long period (half centuries). Hence the Whipple Indexes of individual birth decades and age groups is often lower or higher than the brackets of the categories reported below, which relate to country means over long periods. Intensive testing of the residuals of the regressions described below made clear that the residuals were mostly normally distributed. The advantage of the general long-run level classification allows to compare the age effect for relatively homogenous countries. We distinguished seven mean country heaping categories (see Table A.1 for the distribution of heaping categories).

[17] In order to assess the robustness of the results, and to check whether this grouping decision affects them, we also performed a quantile regression, and found that the main results of a strong 23-32 age effect were similar, and the size of the effect increased with increasing level.

In the regressions, birth decade dummies were included to account for cohort effects. We therefore ran level-specific regressions on age-group and birth decade dummies. The 33 to 42-year-olds served as a reference category, as did the birth decade of the 1920s (chosen based on the highest number of observations). We decided to take 33-42 as constant, as we were interested whether the age groups 43-52 also need an age adjustment. The insignificance of most coefficients of those age groups is an important hint that this is not necessary for the period under study. Following the reasoning above, we specifically tested the hypothesis that younger people (aged 23-32) are more aware of their age due to their proximity to birth, marriage, and military service (or rounded more often on multiples of two). We also tested for higher heaping values of the oldest age groups due to lower memory abilities and declining numeric discipline, or lower heaping values due to positive selection and pride of one's old age.

In general, those aged 23-32 did heap systematically less (Table A.2).[18] The result is consistent for all levels of age-heaping. The results for the 53 to 62 and 63 to 72-year-olds living in relatively numerate societies were not consistent. Two level-specific coefficients of these age-groups indicated that 53 to 62-year-olds and 63 to 72-year-olds heaped in fact slightly less than the reference category (represented by the constant).[19] Among the less numerate societies with Whipple Indexes above 300, the negative effect for older age-groups seems to have been stronger (resulting in large coefficients).

In order to create a consistent data set using information on young and old age-groups, we needed to use an age adjustment. In order to do this, we used the coefficients of the 23 to 32-year-olds, which reflected the only systematic age effect, and included them in a second regression framework in which we sought to model the relationship between the heaping level and the magnitude of the age effect in a continuous rather than a discrete and group-specific

[18] Below 105, age-heaping can be regarded as randomly fluctuating around 100. Hence, we omitted this group in our age effect analysis.

[19] Here, we would not suggest a systematic adjustment.

way. We again used the 33 to 42-year-old group as benchmark. There is a clear relationship: the higher the overall level of heaping, the stronger the difference between the age-groups from 23-32 and 33-42 (or older).

We measured the heaping level by the level-specific regression constant minus the 'zero-heaping'-Whipple Index of 100. We found that the larger the heaping level, the stronger the age effect for the age-group of the 23 to 32-year-olds, which suggests the following formula to correct for age-induced heaping biases: add 0.2 Whipple units for every Whipple unit above 100 for the age-group of the 33 to 42 year-olds. For example, if the level of age-heaping in a given country and period can be described by a Whipple Index of 160 for those aged 33-42, and 150 for those aged 23-32, the Whipple Index for 23 to 32-year-olds should be adjusted upward by 60*0.2=12 units, leading to an age-adjusted Whipple Index of 162.[20]

[20] The estimated formula – based on an OLS regression -- is
Adjustment_coefficient = -3.03 –0.21*WI_level_age_33_42
(Adj. R-sq=0.95, p-value of coefficient is 0.00, p-value of constant is 0.19).
Note: The dependent variable consists of the coefficients of the age-group dummy for 23-32-year-olds from the level-specific regressions in Table A.2, column 2. The independent variable consists of the values of the constants minus 100 (from Table A.2, column 6), which refer to age heaping in the age-group 33-42. Alternatively, the formula can be formulated differently in order to calculate the adjustment based on the heaping level of those aged 23-32. A regression of yields:
Adjustment_coefficient = -5.99 – 0.25*WI_level_age_23_32
(Adj. R-sq=0.93, p-value of coefficient is 0.00, p-value of constant is 0.17). The constant is not significantly different from zero. Hence we suggest to increase the Whipple indexes based on age 23-32 by 0.25 for each WI-unit above 100. We applied this adjustment to the data above. If the Whipple level of those above 100 is adjusted accordingly, roughly the same adjustment is achieved (50*1.25=62.5, i.e. an adjusted WI of 150 [age 23-32] becomes 162.5).

Appendix B: Variable sources (to be included in the published version)

Census taking, dummy variables (time-variant): number of censuses taken in each country since 1600 up to and including the birth decade. Own calculation based on:
Domschke, E., Goyer, D.S. 1986a. The handbook of national population censuses: Africa and Asia. Greenwood, New York.
Domschke, E., Goyer, D.S. 1986b. The handbook of national population censuses: Europe. Greenwood, New York.
Domschke, E., Goyer, D.S. 1986c. The handbook of national population censuses: Latin America and the Caribbean, North America and Oceania. Greenwood, New York.

GDP per capita (time-variant):
Maddison, A. 2001. The World Economy A Millennial Perspective. Development Centre Studies. OECD, Paris.

Height (time-variant): Average height in cm.
Baten, J. 2007. Global Height Trends in Industrial and Developing Countries, 1810-1984: An Overview. Working Paper Tuebingen.

Schooling (time-variant): Primary school students per 1000 children of ages 5-14.
Lindert, P. 2004. Growing Public. Cambridge University Press, Cambridge.
Benavot, A., Riddle, P. 1988. The expansion of primary education, 1870-1940: Trends and Issues. Sociology of Education 66 (3), 191-120.

State Antiquity (time-invariant): Antiquity of state scores by country and region ("Statehist5", varying between 0 and 1).
Bockstette, V., Chanda, A., Putterman, L. 2002. States and markets: The advantage of an early start. Journal of Economic Growth 7, 347-369.

Whipple Index *(time variant):* The Whipple Index (WI) is designed to capture heaping on ages ending in 0 or 5. It sums the frequencies of all ages ending in 0 or 5 and expresses the result relative to one-fifth the sample size:

$$WI = \frac{\sum (n_{20} + n_{25})}{\frac{1}{5}\sum_{i=23}^{32} n_i}$$

The summation notation in the denominator is meant to emphasize that WI must be defined over an interval in which each terminal digit occurs an equal number of times, such as 23 to 32. Implicitly, equal terminal digit frequencies in unheaped data are assumed. We calculate the Whipple Index for the age-groups 23-32, 33-42,…63-72 and assigned them to the birth decade. The age-group-specific Whipple Index values were used as proxies for the numeracy levels of the decades in which most birth years of the cohort were placed. In the frequent case of several age-groups per birth decade we used the unweighted mean of the Whipple Index values to proxy the numeracy level For this study, we used the following sources of census data (countries specified below):

Census data collections

Department of International Economic and Social Affairs, Statistical Office (1955/ 5th Issue, 1962/14th Issue, 1963/15th Issue, 1971/23th Issue, 1983/35th Issue, 1993/45th Issue, 1998/50th Issue). Demographic Yearbook. United Nations, New York.

Rothenbacher, F. 2002. The European population 1850 – 1945. Palgrave Macmillan, Basingstoke.

Other census data:

Argentina: National census data of 1869 and 1895, published in Somoza, J., Lattes, A., 1967. Muestras de los dos primeros censos nacionales de población, 1869 y 1895. *Documento de Trabajo No 46, Instituto T. Di Tella*, CIS, Buenos Aires.

Austro-Hungarian census of 1880, published as *Österreichische Statistik, Band 1, Heft 1-3, Band 2, Heft 1-2 and Band 5, Heft 3, 1882-1884.* The evidence covers Austria, Bosnia and Herzegovina, Croatia, Czech Republic, Hungary, Slovakia and Slovenia. We merged Austrian, Russian, and German regional statistics to obtain weighted averages for the modern territories of Ukraine and Poland.

Canada: The 1852 and 1881 Historical Censuses of Canada (Canada East, Canada West, New Brunswick and Nova Scotia). Université de Montréal, Montréal.

Egypt: The Statistical Department of the Ministry of Finance Egypt, 1907. Statistical yearbook of Egypt. 3rd census of Egypt 1905. Cairo, The Government Press.

First General Russian Empire Census of 1897, published as Первая всеобщая перепись населения Российской Империи 1897 г. Распределение населения по родному языку и регионам. The evidence covers Armenia, Azerbaijan, Belarus, Estonia, Georgia Kazakhstan, Latvia, Lithuania, Moldova, Poland, Russia, Turkey (Kars province), Turkmenistan, Ukraine and Uzbekistan.

Indian Empire Census of 1891, 1901, 1911 and 1921. The Superintendent of Government Printing India, Calcutta. The evidence covers Bangladesh, India, Myanmar and Pakistan.

Japan: Ministry of Internal Affairs and Communications, 1882. First Statistical Yearbook of the Japan Empire. Population statistics of the Province of Kai 1879 (today's Yamamashu Prefecture). Government Publications, Tokyo.

Latvia: 4th Latvian Census of 1935, published as *Ceturta Tautas skaitišana Latvija 1935. gada. Sastadijis V.Salnitis un M.Skujenieks. IV Tautiba, Riga, 1937*.

Norway: Census of Norway 1865 and 1900. Statistics Norway, Oslo.

Palestinian Territory: Statistical Yearbook of the British Mandate of Palestine, 1935. Second British census of Palestine 1931. His Majesty's Stationary Office, London.

Taiwan: Japan Colonial Government, 1905. Statistical Yearbook of Taiwan. Government Publications, Tokyo.

United Kingdom:
Anderson, M., *et al.*, 1979. National sample from the 1851 census of Great Britain [computer file]. Supplied by History Data Service, UK Data Archive (SN: 1316). Colchester, Essex.

Schuerer, K., Woollard, M., 2002. National sample from the 1881 census of Great Britain [computer file]. Supplied by History Data Service, UK Data Archive (SN: 4375). Colchester, Essex.

Other sources:

China: Baten, Jörg, Debin Ma, Stephen Morgan and Qing Wang (2009). "Evolution of Living Standards and Human Capital in China in 18-20th Century: Evidence from Real Wage and Anthropometrics" Working Paper Tübingen/LSE/Nottingham.

Serbia: friendly communication by Siegfried Gruber, who collected visitation data on a number of Serbian villages. Siegfried Gruber, Karl-Franzens-Universität Graz, Centre for Southeast European History, Project "Kinship and Social Security".

Appendix C: To which degree might the Whipple Index be distorted by birth year-specific mortality or fertility deficit?

This appendix will be made available in the internet. Therefore the table and literature is not listed in the table and "references" sections above, but included in this appendix.

One could imagine that events causing "birth deficit" or significant mortality in a specific cohort or contiguous group of cohorts will lead to a distorted population pyramid. Such pyramides with dents and holes are well-known, for example, from the age distribution after the World Wars in the Soviet Union and Germany. Such events could be:

a) Famines causing significant infant mortality. Moreover, and perhaps even more visible in age pyramides, fertility was reduced by malnutrition, and uncertain future prospects might have postponed or changed family planning decisions.

b) Other such events could be wars with armies consisting mainly of conscripts, if those belonged to only a few cohorts, and if the casualties of human life were enormous among them.

c) Wars and civil wars might have caused a strong birth deficit, if a large part of the male population was far away from home. Moreover, fertility was additionally reduced by malnutrition in many war situations. Uncertain future prospects might have contributed to low birth rates as well.

d) Epidemic outbreaks affecting with particular severity newborn babies or young children of small age, might have also created those dents.

Birth deficits were usually the more important "pyramide-denting" factor, as they related strongly to specific cohorts. For example, the disastrous WWI in Germany led to 29 percent more deaths in Germany and a fertility decline by 35 percent (1914-1918, compared to 1910-1913). But the deaths were spread over a relatively wide age range. Infants and children had high death rates, and elderly people also accounted for a large share of deaths. In addition, a smaller, but still substantial number of middle-aged people died. In contrast, the birth deficit is clearly related to the specific cohorts 1914-1918.

How strong was the effect of those disasters on age-heaping? Can we assume it to be randomly distributed? If we control for the occurrence of those, is age-heaping still related to schooling, or is the correlation between schooling and age heaping perhaps spurious? We ran a set of regressions by adding data on those three major causes for birth deficits, as well as on the variables assessed above.

In order to account for the famine effect, we generated dummy variables for the country and birth decade, in which famines occured. We distinguished between major famines resulting in an estimated 0-5 percent deaths per population and those leading to population losses of more than 5 percent. Given that only one in five years is a potential heaping year (i.e., age ending in the favoured digits 0 or 5), the likelihood of a famine reducing a birth year cohort in another year is four times larger. On average, the number of people who should have reported non-preferred ages would be reduced to a disproportionately high degree by such a catastrophe, hence the denominator in the Whipple formula would be reduced. Therefore, we would expect on average an overestimate of the Whipple index in a famine year. However, we observe a negative famine coefficient. This suggests that famines did not bias the age heaping estimates upward, as would have been expected (see Table C.1, regression 1). We find an insignificant effect, if we do not control for other variables (such as the dummy variable for East Asia, see regression 2). This might have been caused by the fact that some of the most terrible famines occurred in China during the period under observation. Moreover, the correlation with schooling is unaffected in both specifications. The sample is slightly different in the two specifications, as some observations drop out due to missing values for the "State Antiquity" variable. For this reason, the observations on famines with 5% and more mortality was excluded automatically from the regression.

Table C.1 Regressions: Famine, war, and civil war as determinants of Whipple indexes

	(1)	(2)	(3)	(4)	(5)	(6)

Which bias tested ?	Famine	Famine	Civil war	Civil war	War	War
Regression model	FE	RE	RE	RE	RE	RE
Height		-0.0158**	-0.0160**		-0.00909**	
		(0.0028)	(0.0028)		(0.0025)	
Schooling	-0.206**	-0.203**	-0.203**	-0.206**	-0.137**	-0.128**
	(0.011)	(0.015)	(0.015)	(0.015)	(0.015)	(0.013)
East Asia		-0.469**	-0.459**		-0.408**	
		(0.075)	(0.066)		(0.15)	
State Antiquity		-0.187**	-0.186**		-0.190*	
		(0.037)	(0.037)		(0.095)	
Famine, >0, <5%	-0.471**	0.0513				
	(0.15)	(0.087)				
Famine, >5%	-0.252					
	(0.18)					
Civil War			-0.0724*	-0.0607		
			(0.035)	(0.041)		
War					0.0314	0.00608
					(0.016)	(0.014)
Constant	6.025**	8.786**	8.812**	6.027**	7.316**	5.615**
	(0.061)	(0.43)	(0.43)	(0.089)	(0.41)	(0.084)
Observations	516	434	434	516	434	516
R-squared	0.43	0.56	0.54	0.41	0.54	0.41

Notes: **, * significant at the 1 and 5 percent level, respectively. The R-sq is not adjusted, it is the overall R-square in regression 2 to 6. Robust standard errors in parentheses. Regression 2 to 6 are estimated with random effects GLS, Regression 1 with country fixed effects.
Sources: War variables: Correlates of War data set http://www.correlatesofwar.org. accessed on March 3rd, 2009. Famine deaths were were divided by Maddison's population estimates, linearly interpolated where necessary. Data on famine deaths were taken from a variety of sources. We thank our research assistants mentioned in the acknowledgements for compiling those: Bhatia, B.M. (1985) Famines in India: A study in Some Aspects of the Economic History of India with Special Reference to Food Problem, Delhi: Konark Publishers Pvt. Ltd. Davis, Mike, *Late Victorian Holocausts: El Niño Famines and the Making of the Third World*, London, Verso, 2002. Dutt, Romesh C. *Open Letters to Lord Curzon on Famines and Land Assessments in India*, first published 1900, 2005 edition by Adamant Media Corporation, Elibron Classics Series. Genady Golubev and Nikolai Dronin, *Geography of Droughts and Food Problems in Russia (1900-2000)*, Report of the International Project on Global Environmental Change and Its Threat to Food and Water Security in Russia (February, 2004). Greenough, Paul R., *Prosperity and Misery in Modern Bengal. The Famine of 1943-1944*, Oxford University Press 1982. Shipton, Parker. African Famines and Food Security: Anthropological Perspectives. *Annual Review of Anthropology*, 19: 353-394. Srivastava, H.C., The History of Indian Famines from 1858–1918, Sri Ram Mehra and Co., Agra, 1968. http://www.thefreelibrary.com/Famines+through+history-a0114325996 accessed March 11th, 2009.

We did the same exercise also with civil wars and wars. We generated "war" and "civil war" dummies based on the "Correlated of War" data sets which are available on-line. Again, the effect of civil war depended on the inclusion of other variables. The impact of the variable on age heaping was insignificant if other variables were not included, and negative (but small) if they were included.

Finally, we generated a variable of war. The war variable had the expected sign of increasing age-heaping, but turned out to be insignificant. This was true both for a more restricted and an unrestricted model. The coefficient of schooling is of similar size as the one in Table 2 above.

The study of the effect of epidemics is more difficult, due to the complicated data situation. Countries with substantial age-heaping were normally those states which did not have very informative age-specific cause-of-death statistics (if they existed at all, some of the statistics of deaths caused by epidemic disease were only coded as "fever" in early 19th century statistics, for example). Moreover, the typical infectious diseases (cholera, typhus etc.) normally occurred jointly with malnutrition mortality.

Hence we will approach this question by using only one extreme epidemic disease outbreak as case study, the influenza epidemic in India in 1918, the "Spanish Flu" catastrophe. This was probably the most deadly disease event since the Black Death, since some estimates arrive at values as high as 50 million fatalities for India alone. Even for a large country as India, the large number of deaths from influenza in 1918 were unique. How large is the effect of those deaths and the associated missing births on the Indian Whipple Index index of this period? The Whipple Index for the birth decade around the influenza epidemic stood at 218 for the more developed Indian regions for which we have consistent data on this period. 1918 had indeed a lower number of surviving children born in this year. Next we replaced the observed number of surviving children by a moving average including the five years around the influenza epidemic, to simulate the number of surviving children if the influenza epidemic had not occurred. This increased the cohort of 1918 by a substantial 53%, certainly more than the actual number of deaths due to influenza. The Whipple Index of this age distribution with a "filled gap" for the influenza year declined only by 9 Whipple Index points. This is a very low difference for one of the most terrible epidemic disease outbreak in human history. If this example is representative, the distortion of Whipple Index from epidemic disease effects is probably not large.

This might also be explained by the fact that the effect of infant mortality caused by epidemics has to be viewed in joint perspective with infant mortality due to other causes. Clearly, infants and young children died in large numbers from epidemic diseases. However, the share of infants dying from other causes, such as non-epidemic digestive or respiratory diseases, was often even higher. In other word, although the number of infants dying from epidemics is terribly high, the share of excess deaths of these particular age groups was not as large, compared to the high infant mortality rates of other years. Clearly, this applies only to high-mortality populations, but those countries and years for which we can use the age-heaping method typically had much higher mortality than, say, today’s OECD countries.