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

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Abstract

This study is the first to explore long-run trends of numeracy for the 1820-1949 period 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 enrolment 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. In a variety of specifications, numeracy mattered quite strongly for growth patterns around the globe.

JEL Code: I21, N01, N30, O15.

Keywords: human capital, age heaping, growth, industrial revolution, numeracy.

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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 centre 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. Their predictions being inconsistent with broad historical evidence, more recent growth theories have accepted the empirical argument of Mitch (1991) and Mokyr (1983) that some countries' growth paths do not fit into this demographic-educational pattern: for example, Britain might have experienced stagnating literacy between the mid-18th and mid-19th century, while France experienced an early fertility decline already around 1800 without becoming a driving force of growth in 19th-century Europe. While education and a slowing down of population growth cannot explain the first Industrial Revolution satisfactorily, many long-run growth economists 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 1870-1913 period, concluding that globalization forces were in fact a much more important influence on comparative development.[1] When going further back in time to the early nineteenth century and beyond, schooling data dry up even for Europe, and literacy must generally be inferred from a proxy - the ability to sign one's name on marriage registers and legal documents (Reis 2005). Leaving Europe, it becomes increasingly difficult to find systematic, comparable data. Crafts (1997) reports enrolment and literacy rates for 17 advanced economies since 1870 while Lindert (2004) provides school enrolment 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 1870-1940 time period. 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 data is scarce for the developing world prior to the end of the 19th century, the authors had to assume enrolment rates of 1 or 0.1% for the LDC world in 1820.

Although these studies represent a clear improvement of our knowledge, about half of the existing 165 countries with populations above 500,000 are not yet documented for the late 19th century. In consequence, we think that 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 attempt to achieve almost global coverage since the late 19th century. Moreover, quite a number of additional countries can be included for the 1820-1890

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

period. Another aim of this article is to broaden the human capital literature by constructing a numeracy index. Why can numeracy be seen as a historical measure of human capital? We would argue that number knowledge and number discipline are even more crucial for economic growth than the ability to sign one's name in a marriage register. Numeracy is highly complementary to technological abilities, and it is a precondition for the modern commercial economy. 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 enrolment 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 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 they perceive age heaping mainly as a data problem because it leads to biased vital rates on the one hand, and the degree of heaping as a measure of data quality only on the other hand, we use it as a proxy for non-numeracy.

Already a half-century ago, 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 of age. Myers (1976) found a correlation at the individual level between age awareness 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 nineteenth 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 (which are also a 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 data 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 the following, we will first discuss important methodological aspects in the second section. The third section takes a look at the (non-interpolated) country level data especially for the Islamic world and the industrialized countries. The following section will attempt a first estimate for eight world regions, using quite a bit of interpolation, in order to describe the global development of numeracy during the period 1820-1949. Section 5 will discuss the potential determinants of numeracy. Finally, section 6 tests the implications for economic growth, and the seventh part concludes.

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 enrolment lists, legal or hospital records, and tax data. However, care must be taken as to who asked questions regarding age and how, and whether self-reported ages were counterchecked with birth registers. Counterchecked age information does normally not reflect any age-heaping besides minor, random fluctuations and can hence not be used. If the enumerator asked for both age and birth year, the resulting data became sometimes unusable for our purposes due to mixed-age and birth-year heaping. In consequence, we used only census data, which lacked such problems in order to maximize the representativeness of our numeracy proxies.

The Whipple Index as a measure of age heaping 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 sums 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 multiple of five-digit. The Whipple Index is linear, and a 50% increase in the share of ages ending in multiples of five translates into an increase of the Whipple Index by 50%.[2]

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 less 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, for instance. The age-group-specific Whipple Indexes were used as proxies for the numeracy levels of the decades in which most individuals were born. For example, individuals belonging to the age-group 23-32 enumerated in the 1881 census were born between 1849 and 58. The corresponding Whipple Index was used to proxy the numeracy level for the birth decades of the 1850s. We also considered the question of

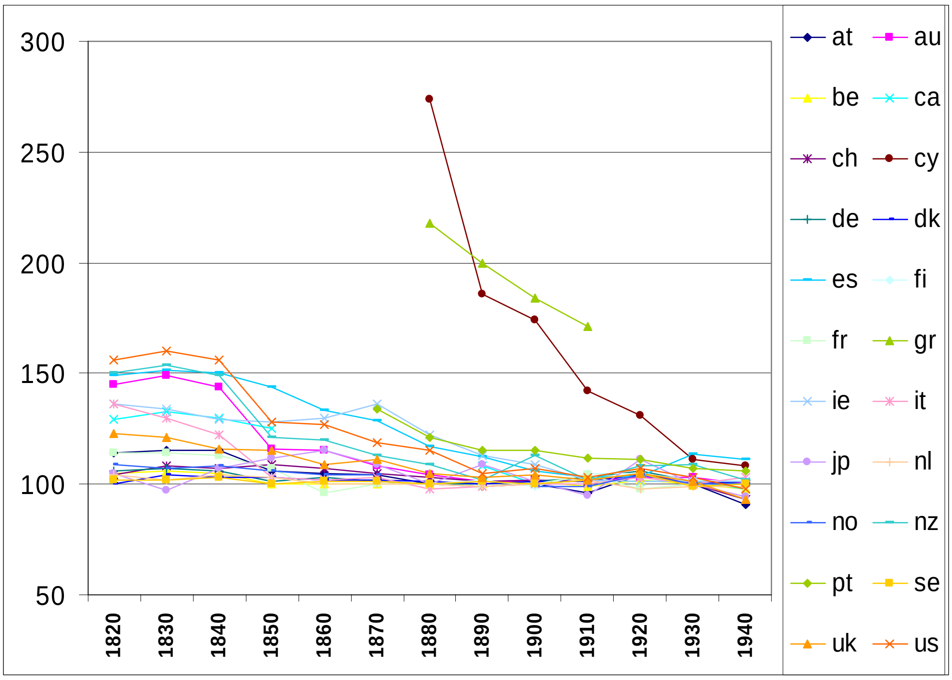
[2] An even more intuitive linear transformation of the Whipple Index (WI) is the ABCC Index which reports a society's share of individuals who probably know their true age (named after A'Hearn, Baten and Crayen as well as Greg Clark, who first gave us this comment for our 2006 paper). The formula is 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.

different ages having different age-specific Whipple indices, as described in the appendix below.

3 A first glance at country level data

For the industrialized countries, the coverage of our data set is very good (Figure 1).

Figure 1: Age heaping levels in industrialised countries



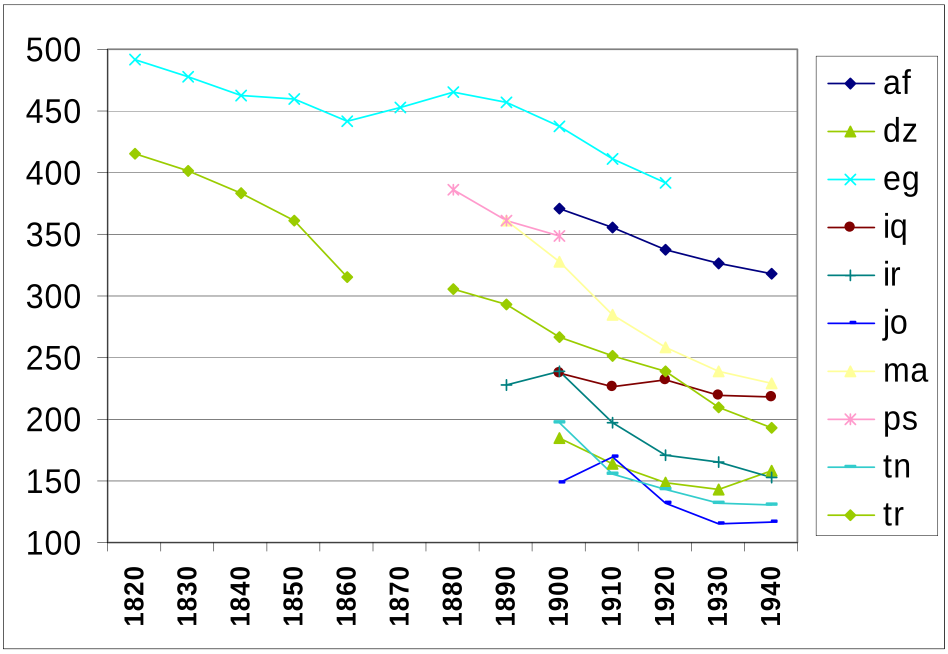
Sources: see text.

Most 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 cluster together strongly 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 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 may still have impacted on 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.

Notable exceptions are the U.S., Canada, and Italy, which initially had quite strong age-heaping, and Spain, Portugal, and Ireland, which experienced an adverse development during the mid-to-late 19th century (on the age heaping increase in Spain during the mid-19th century famine period, see Manzel 2007). For the U.S., age heaping was mainly a Southern phenomenon (Crayen and Baten 2006). 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 thon the absolute level of age-heaping (Figure 2).

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



Sources: see text.

However, we must note here that our sources vary in quality over time. We have a number of censuses from the 1930s-1950s period; hence the oldest groups that we could analyze for this region were born in the 1880s or 1890s. Two 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 are 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? Of course, literacy and numeracy were presumably much lower in the countryside than in the metropolis Istanbul. But 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, they are not too far apart. Those two early series are both very high, although Egypt had much worse values than the Turkish Kars region.

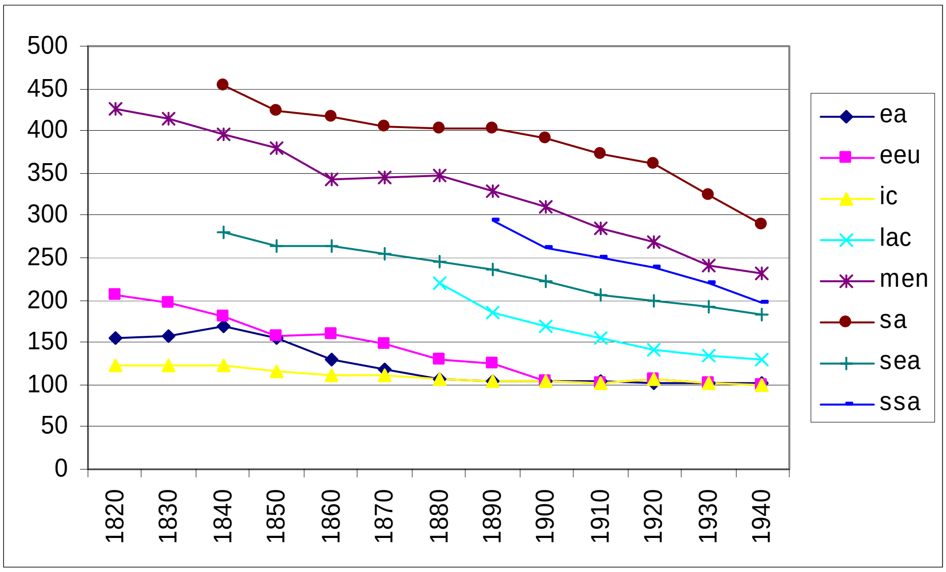
In general, the countries in this world region had high age heaping values that remained so during the early 20th century. But there are also exceptions. For example, Algeria (abbreviated as 'dz'), Tunisia and Jordan had much better (i.e. lower) values than the other countries. It might be the case that the French educational policy had some positive effects on the former 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 Arabic and Berber majorities of those countries. Iran performed fourth-best in the region. Iraq did also quite well initially, but was then overtaken by countries such as Turkey, Morocco, Bahrain (abbreviated as 'bn'), and Kuwait later on. Afghanistan and Egypt performed worst in the early 20th century.

To sum up our evidence for the Middle East and North Africa, age heaping was quite high and improvement slow during the 19th century. During the early 20th century, numeracy improved strongly but was still far from the European (or East Asian) level in the mid-20th century. This is quite an astonishing result, given that Arabic numerals were a huge innovation in Europe in the later Middle Ages and early modern period. In this era, the Islamic world must thus have been far advanced in terms of numeracy compared with the Europeans, also because other important innovations also 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, Jordanian and Tunisian cases.

4 World region estimates

We also present a very preliminary estimate of numeracy trends for the regions of the world (Figure 3). Our basic strategy consisted of collecting as many census data as possible and calculating the Whipple Index for the age-groups 23-32, 33-42 and so on, until 63-72. 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 more sparse, especially before the 1880s. 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 data were available. The idea here is that trends in neighboring countries were often quite similar, although they might have differed in levels (the interpolation decisions are documented in an appendix available from the authors). The final step was to calculate population-weighted averages for the eight world regions.

Figure 3: Age heaping in the different world regions



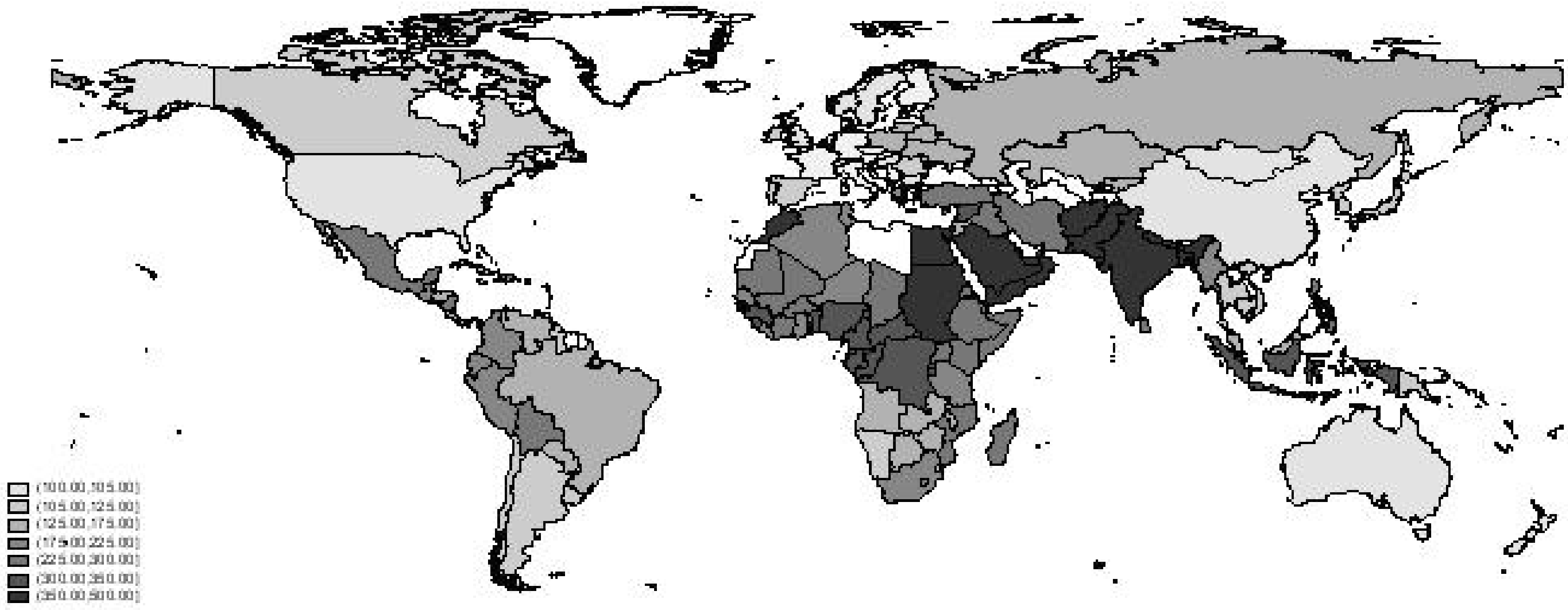
Sources: see text

East Asia (clearly dominated by China, as Japan was put in the group of the industrialized countries) is the only region for which we partly relied on sample information. Census data 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. to the conclusion that age heaping levels were substantial during the early and mid-19th century, culminating in the civil war and famine period of the 1840s and 1850s. During the 1870s and 1880s, in contrast, 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 number abilities and number discipline. For Southeast Asia (SE 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, as we did not have representative data for the preceding period.

What we can infer from these world regional trends is that the Middle East/North Africa and South Asia had the highest age heaping (low numeracy) during most of the 19th century, whereas a substantial improvement took off in the 20th century. On the other extreme, the industrialized countries displayed noticeable age heaping until the 1880s, although it was quite moderate and disappeared around 1880. Eastern Europe/Central Asia[3] (EEU) was similar to the industrialized countries after 1900, and had only slightly higher values in the two decades before. Between those five extreme 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.

[3] 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 minutely.

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



Sources: see text.

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, Tadzhikistan and Laos (and countries with less than 500,000 inhabitants), 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 following decades and could estimate growth rates by using the growth rates of similar countries. As a result, we find that the least numerate populations of this period lived on the stretch between Egypt, Sudan, southern Arabia, India and what today is 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 are also interesting differences. Africa had much better values for its southern part, which reached as far northward as Angola. The Sahel zone did slightly better 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, but what is even more interesting is that 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 (the industrialized countries, Eastern Europe after 1880, and East Asia). Among the three medium regions, the case of Africa is particularly remarkable, as it performed better than South Asia and the Middle East in terms of numeracy. 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 number discipline. Nowadays, we can assume that most people living in industrialised countries know their exact age or their year of birth, and otherwise that they can check this information in registers, 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, age-awareness can still be quite low (Kaiser and Engel 1993). As discussed above, 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 number 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 since it limits an adult's cognitive abilities. This factor is especially important 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 Manzel 2007 on the Spanish regions; Baten, Crayen and Voth 2007 on the English 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, age awareness yields valuable information both about individuals and the society they inhabit.

To explore the correlation of age heaping with schooling, protein malnutrition, and state development, we included primary school enrolment data from the famous Lindert data set, supplemented by Benavot and Riddle (1988) in our model specification. As our age heaping data were organised by birth decades whereas primary school enrolment takes place at approximately age 10, we lagged the Whipple Index by one decade. To approximate state development, we used the data on state antiquity by Bockstette, Chanda and Putterman (2002) who argued that state antiquity proxies 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.[4] Following Domschke and Goyer’s *Handbook of National Population Censuses* the highest score for 1880 was assigned to Greece, where as much as 16 censuses had been conducted until 1889. In our model, we use 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

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[4] 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.

Chinese calendar/astrology/culture.[5] Finally, we used the recent global height estimates by Baten (2006) to control for infant protein malnutrition (also lagged by one decade). In order to measure non-constant marginal effects, we included square and square root terms but found the log specification to perform best. Unfortunately, the inclusion of these variables led to a decline in the number of cases. Moreover, we included only those age heaping data points, which were not interpolated here – using not even the benchmark method described above.

As a result, all specifications yield that schooling is by far the strongest determinant of age heaping patterns (Table 1).

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
R squared	0.76	0.57	0.64	0.59	0.63	0.55	0.61

Notes: 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: schooling: Primary school enrolment in logs. height: Height lagged by 10 years. State Antiquity: State history and authority. East Asia: Dummy for East Asia. Sources: see text.

In the birth decade-specific OLS regression, schooling 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

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

for the decades for which we have the largest number of observations (1920s-1940s, plus the 1900s). The state history variable which proxies the authority of the state is never significant in this series of cross-sections, and East Asia has the expected reducing effect: in China and its neighbouring countries, we observe less schooling but more age awareness. We also tested several panel regression models and found our results confirmed (Table 2).

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

Coefficient	RE (general)	RE (specific)	FE (general)	FE (specific)
Schooling	-0.17	-0.16	-0.14	-0.15
	(0.02)	(0.02)	(0.01)	(0.01)
Height	-0.64		-0.12	
	(0.24)		(0.37)	
State Antiquity	-0.18			
	(0.09)			
Censuses (1 or 2)			-0.01	
			(0.02)	
Censuses (3 to 5)			-0.01	
			(0.02)	
Censuses (6 or more)			-0.05	
			(0.02)	
East Asia	-0.44			
	(0.2)			
Cons.	7.11	5.85	5.92	5.76
	(0.38)	(0.10)	(0.60)	(0.05)
Obs	402	477	471	477
Number of countries	73	91	90	91
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: schooling: Primary school enrolment in logs. height: Height lagged by 10 years. State Antiquity: State history and authority. Censuses: Dummy variables indicating the number of censuses taken up to and including the specific birth decade. East Asia: Dummy for East Asia. Sources: see text.

Notably, schooling is closely correlated with age heaping in the fixed-effects regression, which controls for unobserved heterogeneity between countries as well. The schooling investment variable is statistically and economically significant: a change of one standard deviation of the schooling variable (1.193) in the random-effects specification, multiplied with the coefficient, accounts for 44% of the standard deviation of the dependent variable (0.472). In contrast, the same procedure for the height and state history 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 variable. In the case of the height variable, we also have to admit the possibility of endogeneity (numeracy might improve the welfare level), but this should bias the significance levels upwards. 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). 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: an one standard deviation increase in the census variable improves the logarithm of the Whipple Index by 3% of its standard deviation only.

In order to provide a schooling estimate based on age heaping, we also performed the regression with schooling as the dependent variable (see Table 3).

Table 3: Age heaping as a determinant of student enrolment 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
R squared	0.72	0.50	0.58	0.62	0.53	0.51	0.56

Notes: Robust standard errors in parentheses. The dark shaded areas denote significance at the 1% level. Dependent variable: schooling (primary school enrolment in logs). Independent variable: Whipple Index (logarithm), lagged by 10 years.

The results apply to all world regions except East Asia. Again, the coefficients are very stable 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? In the following we argue that this is indeed the case. We employ all available GDP growth figures between 1820 and 1870, as well as between 1870 and 1913, and combine them with our numeracy estimates of the respective periods. We can identify a set of 62 GDP growth figures for those two crucial periods in the 19th century that can also be documented with initial numeracy. The sample is quite comprehensive, as it does not only include 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). We can also account for later oil exporters such as Iraq and Iran, and some growth successes of the 20th century (Korea, for example). In a set of regressions, we follow the standard procedure developed by Barro (1991, 1999) and many others, who regress growth rates on a set of “growth capabilities” measured in levels. The level of human capital is such a “growth capability”, since theory suggests that after controlling for the initial welfare level (which might also proxy a country’s capital stock, as Barro (1991) has argued), only countries with high human capital can achieve successive welfare growth.

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)
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			-0.0003	-0.0004	-0.0004
			(0.0002)	(0.0002)	(0.0002)
East Asia			-1.06		-1.12
			(0.28)		(0.27)
Period 1870-1913					0.23
					(0.13)
State Antiquity			-1.62	-0.33	-1.67
			(0.64)	(0.45)	(0.64)
Constant	2.57	0.68	6.18	-44.90	6.47
	(0.46)	(0.42)	(1.74)	(1.07)	(1.75)
Observations	62	25	55	22	55
R-squared	0.05	0.05	0.47	0.18	0.49

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 growth rate (geometric mean of $GDPC_{1820}$ and $GDPC_{1870}$ or of $GDPC_{1870}$ and $GDPC_{1913}$). The first three independent variables are in logs and 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: AM (1820), AT, AU, BE, CA (1820), CH, CN, DE, DK, EG, ES, FR, GR, IN (1870) IQ, IR, IT, JP, KP, KR, MA, MM (1870), MY (1870), NL, NO, NZ, PL (1870), PS, PT, SE, TR, TW, UK, US.

The numeracy estimates given in the Whipple Index have considerable explanatory power: its coefficient is consistently negative, as expected, and highly significant. In a general regression (column 3 in Table 4), we control 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 state antiquity. A standard deviation of the logarithm of the Whipple index of those 62 cases which we could include in column (1), (3) and (5) amounts to 0.53. Hence, the difference in annual growth rates between average cases and those that feature age heaping levels one standard deviation higher is 0.37 percentage points (column 3), which is clearly economically meaningful, as the standard deviation of the dependent variable is only 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 include 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 control for initial human capital and other variables. State antiquity has a negative effect here (quite the opposite to its effect in the 1960-90 period). This might suggest 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.

Unfortunately, we are not able to provide a matching test for schooling effects on growth, as schooling is available for only 25 cases in the 1870-1913 period. For this period, schooling is consistently insignificant at the 5% level. But 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) comprises 16 cases only, the reduced sample size leading to insignificance of all potential explanatory factors. However, we can conclude that the age-heaping strategy allows capturing the human capital impact on 1820-1913 growth successes and failures, whereas our knowledge about schooling is insufficient to do so. Measuring numeracy is clearly an important activity in order to understand long-run economic growth.

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 enrolment as an input measure is conceptually problematic, as 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 to establish 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). Also, 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 industrialised countries. This would have suggested good prospects for the future economic development of China, had it not been for the civil war and other political obstacles to economic and social development.

It is remarkable that the northern Islamic countries stretched between Iran and Turkey, and 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 already in the 17th and 18th centuries. The United States (or rather its

Southern part) took a position of lagging 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 much less 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 number 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-run economic growth. In a variety of specifications, numeracy mattered strongly. We can conclude that age-heaping allows capturing the human capital impact on 1820-1913 growth successes and failures, whereas our knowledge about schooling is insufficient to do so. Measuring numeracy is clearly an important activity in order to understand long-run economic growth around the globe. 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 century.

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Appendix 1: Age adjustment: society-induced age awareness and survivor bias issues

A'Hearn, Baten and Crayen (2006) found evidence for significantly lower heaping levels among young people, i.e. for the age-group 23-32, compared to higher ages. 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.[6] 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.[7] Thirdly, young people may be more aware of their exact age since they are 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 third decades of life. This point is illustrated by Keith Thomas (1987) who states for early modern England that "[…]ages were reported with precision for people under twenty, because differences in age could be of considerable social and administrative importance for young persons. But when people reached adulthood their exact numerical age had much less social meaning; and it was much more vaguely reported". In accordance with this argument, 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.

6 See the discussions in Kaiser and Engle (1993) and Ewbank (1981).

7 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, people might tend to pay less attention to their age or forget it, as described above. But there might also be a small positive selection effect with regard to older people, as more educated people might have a lower mortality risk. Although we omitted the age-groups with high mortality rates (such as children and adolescents below 23 as well as old people above 72), there is the possibility of a survivor bias among the older age-groups. 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 we did not have multiple age-groups for certain birth decades. Nevertheless, the data did not suggest any survivor bias in these cases: the Whipple Index for Turkey stagnates in spite of the shift from the youngest group in the earlier census (birth decade 1860) to the oldest age-group in the later census (birth decade 1880), while the Whipple Index even increases for the Egyptian time period 1870 to 1880, which marks the line between the two succeeding censuses. As a second reason for a potential old-age-effect, the literature reports the observation that beyond a certain age, people begin to be proud of their age. This pride might either lead to more mental investment into recalling one's exact age, or to bragging about an extremely old age ("I'm already 100 years old" was a frequent statement in Soviet Central Asia, which biased life expectancy estimates upwards). Although individuals of 73 years and older were excluded from the sample, it is not clear whether the positive or the negative effect prevails.

In sum, all of the above boils down to the following question: is there a systematic deviation of one particular age-group's Whipple Index from the other Whipple Indexes measured for different age-groups, holding birth cohorts constant? That is, do people – with a certain level of education/numeracy given - heap more or less in different stages of their life due to changing number discipline and demand for the knowledge of their age? For many countries, we have several numeracy estimates for the same birth decade because of successive census taking. These estimates are based on the self-reported ages of varying age-groups, depending on the census year and the birth decade. If heaping behaviour changes with age, the "true" numeracy of the whole population in a given country could thus be under- or overestimated.

We would expect that the degree to which individuals change their heaping behaviour over time, and in particular the degree to which they round less in the age-group 23-32 depends on the overall numeracy level at a given time. Hence, we formed groups of different heaping levels and then ran regressions separately for each group. We distinguished the following heaping categories: Whipple Indexes of 105-124, 125-149, 150-174, 175-224, 225-299, 300-349, and 350 and above (see Table A.1 for the distribution).

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

heaping category	sample size
105	420
125	306
150	183
175	302
225	184
300	148
350	51

Sources: see text.

Birth decade dummies were included to account for cohort effects. Over the long run, heaping patterns changed considerably. Russia started out with high heaping values - around 250 in some regions - which declined over the century to almost no heaping. We therefore grouped the countries not only by their overall heaping level across the entire data set, but generated a category which grouped them by half-century and country (or region in the case of large countries).

We then 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 1920 (chosen based on the highest number of observations). Following the reasoning above, we particularly 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. We might also observe higher heaping values for the oldest age-groups due to lower memory abilities and declining number discipline, or lower heaping values due to positive selection and pride of one's old age.

Table A.2: Coefficients of the age-group specific dummy variables

heaping category	age-group effect				
	23-32	43-52	53-62	63-72	constant
105	-5.19	2.23	-2.38	-5.65	112.37
	(1.39)	(1.88)	(1.96)	(1.65)	(1.73)
125	-8.74	2.53	-10.3	-7.65	138.48
	(3.41)	(3.80)	(4.87)	(7.44)	(5.73)
150	-25.42	1.6	-3.18	-7.37	166.31
	(12.41)	(10.67)	(9.20)	(9.18)	(10.66)
175	-23.03	4.81	-1.16	16.42	194.62
	(8.99)	(8.23)	(8.49)	(13.76)	(8.67)
225	-42.39	-3.98	10.39	5.92	271.89
	(15.78)	(17.35)	(19.08)	(14.14)	(27.53)
300	-43.22	19.7	31.3	-0.27	318.1
	(15.15)	(16.11)	(18.47)	(27.02)	(17.70)
350	-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). The age-group coefficients reported above were obtained through regressions including birth decade dummy variables. Sources: see text.

In general, those aged 23-32 did heap systematically less (Table A.2).[8] The result is consistent for all levels of age-heaping. For those aged 23-32, marriage and similar events took place or

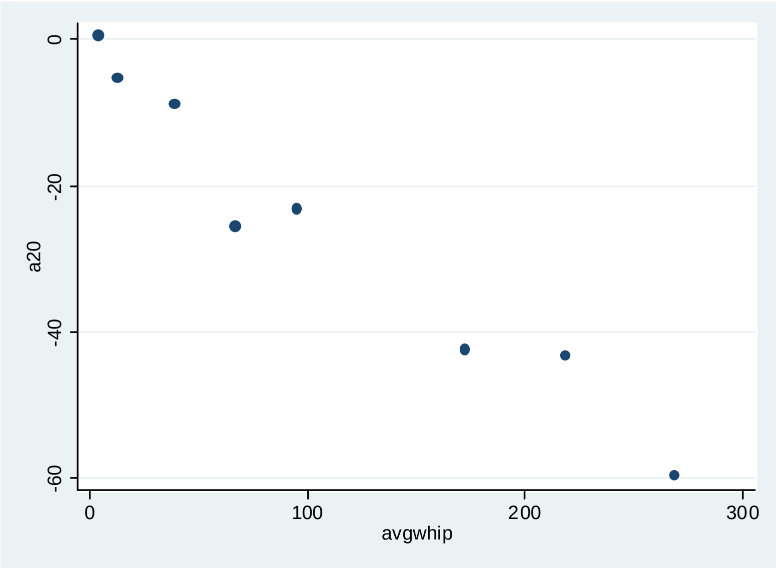
[8] Below 105, age heaping can be regarded as randomly fluctuating around 100. Hence, we omitted this group in our age effect analysis.

had taken place not too long before, resulting in a better knowledge of their age or better number discipline and less heaping for this age-group than the 33-42 age-group in the same birth decade. The results for the 53-62- and 63-72-year-olds living in relatively numerate societies were not consistent. Two level-specific coefficients of these age-groups indicated that 53-62-year-olds and 63-72-year-olds heaped in fact slightly less than the reference category (represented by the constant).[9] 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 conclusion, to create a data set which is comparable to estimates from other age-groups on the basis of the 23-32 age-group, we need an adjustment. For this aim, we used the coefficients of the 23-32-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 way (see Figure A.1).

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

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



Note: avgwhip is the level-specific regression constant minus 100, which refers to age heaping in the age-group 33-42. Sources: see text.

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 23-32-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 33-42 year-olds (Table A.3). For example, if the level of age heaping in a given country and period can be described by a Whipple Index of 150 for those aged 33-42, the Whipple Index for 23-32-year-olds should be adjusted upward by 50*0.2=10 units, leading to an age-adjusted Whipple Index of 160.[10] We counterchecked this adjustment for regions for which we had overlapping birth cohorts, and it yielded plausible results.

[10] Alternatively, if the Whipple Index is 150 for the 23-32-year-olds, then the “unbiased” level of the older age-groups is around 160. Hence, the adjustment should be 60*0.2=12, resulting in a Whipple Index of 162 for those aged 23-32. We applied this adjustment to the data above.

Table A.3: Age adjustment for the age-group 23-32: OLS-regression of the 23-32 age-group effect on the general heaping level in 8 heaping categories

	Coefficient
Age Heaping level	-0.21
Constant	-3.03
N	8
Adj. R^2	0.95

Note: the independent variable is the level-specific regression constant minus 100, which refers to age heaping in the age-group 33-42. The dependent variable comprises the coefficients for the age-group dummy for 23-32-year-olds from the level-specific regressions.

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