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Numeracy in Early Modern Korea, Japan, and China: the Age-Heaping Approach

This is the last working paper version before this study was submitted and accepted. Please cite as Baten, Jörg and Sohn, Kitae (2017). “Numeracy in Early Modern Korea, Japan, and China: The Age-Heaping Approach”, *Japan and the World Economy* (2017). Online: https://doi.org/10.1016/j.japwor.2017.08.001

This study first draws on a unique data set, *hojok* (household registers), to estimate numeracy levels in Korea from the period 1550–1630. We add evidence from Japan and China from the early modern period until 1800 to obtain human capital estimates for East Asia. We find that numeracy was high by global standards, even considering the potential sources of upward bias inherent in the data. Therefore, the unusually high level of numeracy in East Asia in the early 21st century was already present in the early modern period, with implications for our understanding of Asian growth processes.

Keywords: Human-Capital, Development, Growth, Numeracy, Korea, China, Japan

JEL: O15, O40, I21, N35, N30

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I. Introduction

This study first employs Korean household registers (*hojok*) to measure numeracy levels during the period of the 16th and 17th centuries. We further compare Japanese and Chinese numeracy figures to obtain general estimates of early East Asian numeracy. We find that numerical human capital was quite high in East Asia in the early modern period (1550–1800).

Why did this not result in early economic growth in East Asia? After all, the relationship between human capital and growth in GDP per capita is well established in modern growth regressions (Hanushek and Woessmann 2012). The impact of human capital on income growth has also been confirmed for historical periods. For example, focusing on the second half of the 18th century, Baten and van Zanden (2008) found that higher human capital (measured by books per capita) caused higher GDP growth over the following period (Figure 1).[1] Countries with low levels of human capital formation were unable to participate in the industrialization process that transformed the global economy, whereas countries with better starting positions managed to catch up with or even to overtake Great Britain.

It is an important motivation for our study that China is clearly an outlier in this

[1] Baten and van Zanden (2008) examined whether human capital—proxied by an indicator of advanced human capital, 'book production'—can account for economic growth in the 19th century. Their data set included a number of European and non-European countries. Relatively reliable GDP estimates were available for the period 1820–1913 (Figure 1). Using regression analyses, Baten and van Zanden also examined whether a higher rate of book production in the 18th century implied more rapid GDP growth in the 19th century. To address this question, they controlled for the initial level of GDP per capita, which was available for 15 countries, and tested the book variable against this initial level effect (their Table 4). Book production was positive and significant.

type of growth regression for the 18th and 19th centuries. China already accumulated a substantial stock of human capital, but did not manage to grow in the period from 1820 to 1913. However, China has grown substantially since 1978. Japan already started its impressive catch-up growth after the Meiji Restoration in 1868 and achieved convergence to the rich countries during the mid-20th century; South Korea followed shortly thereafter. Japan was able to transform human capital into growth relatively early, whereas the process occurred later in China. Arguably, institutional and cultural factors prevented these East Asian countries from joining early the club of rapidly growing countries, despite their high numerical human capital (Acemoglu, Johnson, Robinson, 2005, but see Li and van Zanden, 2012). Our findings imply that in East Asia, the foundations for human capital-based rapid catch-up growth were laid very early. Future studies might explore whether Korea, Japan, and China returned to the growth path because of their early numeracy development.

The main value-added of this study, however, is to measure basic mathematical skills in early-modern Korea and Japan. We then compared the results with China and Europe and eventually obtained a global evaluation of early human capital development. In this endeavour, we need to define that we actually identify a very basic form of numeracy here, which represents the ability to add and subtract small integer numbers. In the agricultural society of the early modern period, it was not self-evident that even basic numeracy developed in all countries. For example, in many countries of West Asia and South Asia, numeracy was surprisingly low even in the 19th century (Crayen and Baten 2010). The inability to perform simple mathematical operations was a hurdle in developing new (and often calendar-based) techniques in agriculture. But we would not expect more advanced math skills, such as differentiation, for large parts of the early modern population. This cannot be expected for Korea, Japan, or China, and also not for any other country of the early-modern period.

Not many studies focused on mathematical skills in early modern Korea. Two short studies described the evolution of the mathematical elite and mathematics in Korea (Kim 1986, 2008; on Japan and China, see Bréard and Horiuchi 2014). Kim (1986) found that Korea did not have a high number of mathematical geniuses during the early modern period. Instead, Korean mathematics before the 20th century was mostly oriented towards the needs of agriculture and governmental bureaucracies, following similar ideals as traditional Chinese mathematics. While the development of academic mathematic research was limited in early modern Korea, the advantage was that a division between a mathematical elite and the other parts of the population was not as rigid as in other countries, such as in France during the 18th century, for example. The pragmatic mathematical insights of the elite could be more easily communicated to decision-makers, such as farmers, in the normal Korean population. However, this positive aspect of mathematics in modern Korea lacked quantification. We attempted to present rough estimates of this aspect.

In the following Section II, we first explain the age-heaping methodology. In Section III, we discuss the new evidence on Korea. Section IV presents new evidence on Japan and compares it with existing studies on China and Europe. We then assess the plausibility of our results by comparing them with the literature on East Asian education and human capital (Section V), and we present our conclusions in Section VI.

II. Age-heaping

The so-called age-heaping strategy allowed us to obtain insights on numerical abilities of Koreans living during the period 1550–1800. It employs a set of methods that developed around the phenomenon of "age-heaping," i.e., the tendency of poorly educated people to erroneously round their ages. For example, less educated people are more likely to state their age as "30" if they are actually 29 or 31 years old compared with people who have a greater human capital endowment (Mokyr 2006). The most widely used numerical index to measure this is the Whipple index:

$$(1)\quad Wh = \left(\frac{(Age25 + Age30 + Age35 + \ldots + Age60)}{1/5 * (Age23 + Age24 + Age25 + \ldots + Age62)} \right) \times 100$$

A'Hearn et al. (2009) suggested an index called the ABCC index.[2] It is a simple linear transformation of the Whipple index. It is easier to interpret and yields an estimate of the share of individuals who report their ages correctly[3]:

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[2] The name results from the initials of the authors' last names plus that of Gregory Clark, who suggested the transformation in a comment on their paper.

[3] We excluded ages below 23 and above 72 because a number of possible distortions affect those specific age groups, leading to age reporting behavior different from that of the intermediate adult group. On the one hand, young individuals are likely to have recently passed landmarks at which their ages were ascertained, such as marriage, military service, or immigration. In other cases, parents respond to the age question for children, so the evidence does not allow one to measure the basic numeracy of children. Old individuals on the other hand may firstly be more likely to forget their ages. Secondly, the healthier and perhaps more educated might survive longer. Thirdly, the extremely old sometimes deliberately exaggerate their ages and round them to 100 or similar numbers. Hence, it is common in the literature to exclude very young and old individuals from the sample (for more, see A'Hearn et al. 2009).

$$(2)\quad ABCC = \left(1 - \frac{(Wh - 100)}{400}\right) \times 100 \quad \text{if} \quad Wh \geq 100\text{; else } ABCC = 100\,.$$

A'Hearn et al. (2009) found that the relationship between illiteracy and age-heaping for Less Developed Countries after 1950 was very close. The correlation coefficient with illiteracy was as high as 0.7. The correlation with the PISA results for numerical skills was as high as 0.85. Hence, the age-heaping measures are strongly correlated with numerical skills.[4]

III. Data on Korea

Measuring Korean numeracy for the early period of 1550–1800 required age statements in sufficient numbers. The data for this study were collected from a system of household registers implemented for the purposes of taxation and corvee labor service, called *hojok* (Table 1). The system attempted to collect data from all individuals, including slaves.

The creation of hojok registers was influenced by the Confucian idea that the king owned all land in his territory and all people in the territory were his subjects (Sohn, 2007, for a detailed description of hojok registers). An implication is that his subjects should be grateful to the king for the use of the land and repay the king with their products and labour. Therefore, the main aim of hojok registration was to identify individuals who could contribute goods and services to the king. Since Confucianism affected Korea early in history, it is not surprising to find that hojok was already administered in the Three Kingdom period. The earliest extant hojok was

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4 Sohn (2014) also applied the index and found that it provided reasonable estimates of the human capital of black soldiers during the American Civil War.

administered in Silla between the late 7th and the 9th century. This system was continuously maintained, so the form of hojok early in the Joseon dynasty was similar to that of the previous dynasty.

Hojok registers contained information on the family relationship, typically tracing even the husband's and wife's fathers, grandfathers, great-grandfathers, and maternal grandfathers. This long tracing reflects the importance of ancestors in Confucianism and of hojok itself. In fact, Joseon laws regarding hojok were very strict. If even one individual or household was found to be omitted, dictated the laws, not only the head of the household but all local government officials involved in the administration were subject to severe punishment. However, it is uncertain how strictly the laws were implemented. The later reform of hojok by King Sook Jong in 1675 indicates that the laws were not always strictly followed. Nevertheless, the severe laws as well as the effort to reform them indicates the importance of hojok in the dynasty, and the long history of hojok suggests that the system was indispensable.

Which procedure was used to create the hojok registers? Local government officials in the smallest administration unit (*myeon* or *ri*) collected hojok information by distributing the hojok form to each household. Usually the household head completed the form—helped by officials, if the household head was unable to fill the forms independently. Unfortunately, the number of women in hojok was relatively small. Only 4.4. percent of the 1606 register were female, for example (Table 2). After the completion in the household, the officials collected the completed forms and aggregated the individual information to a larger unit (*gun* or *hyeon*). One copy of the aggregate information was stored in the local office, and additional copies were stored in the central or provincial government office to assess taxes and corvee labor service for each *myeon* or *ri*.

Hojok was supposed to be conducted every three years, but only a small share of the hojok documents survived. Over most of the period 1606-1888, the county of Dansung provided hojok data at more or less regular intervals (Table 3). Relatively fewer hojok documents have survived for the early part of the period, but this does not necessarily mean that they were not taken every three years. Individual-level data for Dansung were digitized by the Daedong Institute for Korean Studies. Dansung was a rural county, and literati sharing the same family names resided alongside commoners.

Potential caveats

It is necessary to discuss potential caveats regarding the data and how to cope with them. One issue is whether household heads reported ages with or without asking the other household members. Earlier studies on other countries raised the question whether household heads might have responded to age questions without asking their spouses or other family members (Földvari et al. 2012). As a first approach to this question, we calculated the ABCC index for household heads alone, rather than for all household members (Table 4).. The former displayed a moderate advantage of 4-5 percent, which could be caused either by the high numeracy of the household head or by the possibility that some household heads rounded the ages of other members.[5] Below we find that this difference is actually not statistically significant (see the discussion of Table 6 below). The estimate for the whole population of 89–90 percent

[5] Please note that we calculated adjusted values for the age 23-32, following the coonvention in the age heaping literature (Crayen and Baten 2010, see also notes to our Tables 4 and 6). A higher share of the non-household heads fell into this age group.

might be considered as a lower bound, whereas the 94 percent estimate for household heads an upper bound.[6]

A more important caveat relates to the possibility of counterchecking. The officials could compare the ages given, say, in 1681 and 1684 to those given in 1678 If an individual stated his age as "I am 30" in 1678, then the officials would not have accepted the answer "I am 35" in 1681. However, they might have written some number that was not rounded (e.g., 36) and not reported by the individual; the documented age would not be a rounded number. The ABCC index cannot identify such calculated age information because "age 36" simply looks as if the individual could determine his age with a yearly resolution. Therefore, the usual strategy is to focus exclusively on years for which such a counterchecking option is not a problem. For Korea, such a year is 1606. Following a massive Japanese invasion during the late 16th century, a number of hojok documents were destroyed. Instead of using data from the whole period from 1606 to 1888, we hence focused only on 1606 for the regular Korean population, as we only want to report estimates of numeracy which are

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[6] We considered only including the heads of household in our statistics because those persons were most likely to correctly report their own ages. However, because our main argument in the present study is that East Asian basic numeracy was high in the early modern period, we include the "lower bound" estimate of the whole population in the following figures because it represents a "conservative" value that does not risk providing inappropriate support for our argument.

This is also a promising strategy because there are other potential sources of upward bias. For example, some individuals avoided being registered to avoid taxation and corvee labor service despite heavy punishments and monitoring systems. Some hid in the mountains, and others remained transient. We do not know whether this could have led to a positive or a negative bias.

beyond doubt. Although Korean household registers were more or less continuously maintained long before 1606, the Japanese invasion had very adverse effects on Dansung, and many official documents, probably including hojok documents, were destroyed (Kim 2001). Note that Dansung was one of the earliest and most intense victims of the Japanese invasion (Figure 2). Thus, it is likely that hojok was re-started from scratch after 1606. This suggests that more realistic age-heaping values could be obtained after the break in the system.

In contrast to 1606, authorities were subsequently able to verify responses with age statements from previous years, resulting in an upward bias in numeracy values. The lower three lines of Table 4 report numeracy estimates for later years, i.e. when hojok was taken regularly every three years and counterchecking was possible. The estimates were very high, ranging from 97.4 to 98.4 percent.

There are of course two possible interpretations that may serve as an explanation for these very high estimates. First, age statements may have been counterchecked in the way described above. Second, one could imagine that in fact numeracy increased to values around 98 percent. However, this might seem as an implausibly high level for this period, even considering the fact that numerical skills in East Asia were without doubt very high in comparison to other world regions. Nowhere, including Europe, were such values recorded before the 19th century (Crayen and Baten 2010). Hence, given that the possibility of counterchecking bias exists, it might seem likely to many observers that the high numeracy estimates reported in Table 4 were upwardly biased. Unfortunately, we cannot finally judge whether counterchecking or an actual increase in numeracy (or a combination of the two) explains the very high estimates. Dropping the later evidence avoided the risk of including biased data. The Korean example of 1606, however, is in line with other historical evidence on realistic numeracy values after a “break” in age reporting for various political and economic reasons, e.g., due to the Japanese invasion (Hayami 2001).

Number preferences

Another issue is number preferences (e.g., favoring eight or avoiding four) or zodiac preferences (e.g., favoring a dragon year). Figure 3 displays the distribution of the last digits of reported ages for all individuals in the hojok for the year 1606. The high proportions of the digits zero and five confirm that a substantial part of the early modern Koreans rounded their ages. Furthermore, the percentage for the digit four is not discernibly low, indicating that four (which sounds as the word “death” in pronounciation) was not particularly avoided.

We also considered the distribution of end-digits (Table 5). The digit eight is usually associated with positive values in east-Asian cultures, but it is not overrepresented (8.1% vs. the expected value of 10 %). The proportion was higher for the strongly avoided age ending with four. Overall, the digit zero was reported the most, followed by the digit five. We obtained similar results whichever group we considered. More interesting, if we included all the hojok years (1606-1888), the end-digit of eight was reported in 9.9 percent of the sample, hence very close to the “normal” 10 percent. The difference from the “non-counter-checked” hojok of 1606 was that the digits of zero and five were more selected in 1606.

We further assessed whether certain groups of people were more likely to culturally prefer special ages and whether this affected the rounding behaviour. The rounding behaviour was similar between women and men, and between non-household heads and household heads. However, it differed by birth animals (Table 6). We thus further examined these findings by regressing their ages ending in multiples of five on dummy variables for all zodiac animals (Table 7). Some zodiac animals related to age rounding. Compared to individuals born in the year of rat, those born in the years of ox, rabbit, snake, horse, monkey, and dogs were more likely to round their ages, as the coefficients of these zodiac animals were statistically significant in the regression analysis. However, as we considered only one census year here, some years of zodiac animals were mechanically related to certain ages that were multiples of five. For example, a very high number of cases was observable for the age 35, and this happened to represent one of the best-represented zodiac animals (the monkey). We would need more observations from different census years to assess the popularity of all zodiac animals in a representative way. However, we can at least say that the perhaps most attractive zodiac animal, the dragon, did not affect the age rounding behaviour of early modern Koreans: its coefficient was not statistically different from zero, and the share of dragon-year born Koreans was actually close to the expected 1/12th, or 8.3% (Table 2). When we considered all the years 1606-1888, the percentage of people born in the dragon year was similar to the expected one. As the dragon year is assigned to every 12th year, we can identify 1556 as the as the earliest year in our sample, then 1568 and so on. Please note that there might actually be an upward bias, because perhaps more children would be born in fact in dragon years, as the birth in the dragon year is regarded as a positive effect.[7] If these effects would not be strong, however, the expected frequency of a dragon year would be close to 1/12 or 8.3%. The observed frequency was actually only 8.1%. Hence, there is no dragon year effect for the whole dataset. If we are breaking down the dataset by age groups, we observe a mild dragon year effect for the youngest age group between 23-32, but no dragon year effect for the average of the older age groups for the whole period. In conclusion, dragon years could not have a very strong effect on the heaping patterns.

Additional sources for Korea: evidence on monks

We complemented the hojok of 1606 with another hojok dataset of monks. This dataset also possessed a “break” for the following reasons. A series of adverse events threw 17th-century Korea into complete disarray. The negative consequences of the Japanese invasion still lingered, and the Manchu invaded Korea in 1627 and 1636. Small and large rebellions were not uncommon across the country, and one of the largest rebellions was that led by Lee Kwal in 1624. To make matters worse, natural disasters, famines, and diseases abounded. All of these adverse events can be understood as part of the general crisis of the 17th century (Parker and Smith 1997). A large number of people died, hid in the mountains, or became vagabonds. The registration system failed to keep pace with the changes. As a result, each individual who had been properly registered suffered even more from corvee labor service that was imposed on the Korean population. One way to circumvent this aggravating situation was to register and recruit monks for the service. This idea was appealing because monks had already experienced corvee labor service on a few occasions (albeit unsystematically). In addition, a growing number of people simply became monks to avoid permanent corvee labor service. Registering them would allow the dynasty to identify, control, and exploit monks more systematically. Hyu Yun proposed the idea of registering monks in hojok, and King Sook Jong approved of the plan on May 9, 1675 (Sook 1675).

The registration of monks was one aspect of the overhaul of the hojok system. In 1675, King Sook Jong issued a law (o-*ga-tong-sa-mok*), according to which five (*o*) households (*ga*) were grouped into a higher level of an administrative unit called a *tong*. The law was an attempt to strengthen the system by correcting inaccurate entries and rebuilding the hojok that were lost during the Manchu and Japanese invasions. Our data concern the year 1678, which was the first registration year after the law was passed. Hence, the data may include the first registration of monks in Dansung.

Admittedly, monks were most likely an upwardly biased sample of the Korean population in terms of education. However, the dataset of monks is useful for our research because it provides numeracy values from the beginning of the registration process and is therefore unlikely to be biased by the possibility of counterchecking. Moreover, because many ordinary people became monks to avoid corvee labor service, the potential upward bias of this group might not be large.

Because age-heaping reflects a very basic skill that is obtained during the first decade of life, we organized all evidence by birth decades. The 1606 hojok enabled us to identify the regular Korean population born from the 1550s to the 1570s and the monk hojok monks born in the 1630s (Figure 4, Table 8). Numeracy values for these groups, approximately 80 to 90 percent, were quite constant over time and, more importantly, relatively high by historical standards.

IV. Comparison of Human Capital Development in Korea, Japan, China, and

Europe

We conducted similar analyses of age-heaping and numeracy for the eastern neighbor of Korea by analyzing Japanese population registers. In Japan, population registers started very early (already in the 7th and 8th centuries CE), which is remarkable since such detailed registers were created so early in almost no other region of the world. After the year 1000, however, there was a gap of around 600 years, in which these population registers were not recorded anymore. It is “the dark age” of the history of population surveys (Hayami 2001, p.18-21). Only at the end of the 16th and at the beginning of the 17th century did the population registers start again. Around the time of the Toyotomi Hideyoshi and Tokugawa shogunate, there were two types of surveys, religious and population censuses. The main reason for this new wave of population censuses was military because the change of military technology and strategy implied that the samurai were not fighting alone anymore, but had to mobilize a large amount of manpower. It was thus necessary to identify the size of the population, especially of the young men who could be included into military units. The oldest extant survey relates to the Bungo and Buzen province in northern Kyushu of the early 17th century, supplying a very detailed list of names and ages. The survey was performed by the Kokura domain, now Beppu City of the modern Oita prefecture. It is very fortunate for our analysis that there was no previous census taken in this region. Only this exceptional situation allows the age heaping analysis here.

Japanese age statements are reported in Table 9 (based on Hayami 2001). Assuming that the median age group of those 21 and older at that time was the group aged between 30 and 40, the data are centered on those born in the 1590s. This makes the data suitable to compare Japanese human capital formation to the newly estimated numeracy levels for the Korean population in 1550–1570. The reported age statements indicate clear age-heaping in zero (21.4%) and five (13.8%).

A graphical comparison of human capital development in Korea, Japan, and China is displayed in Figure 5 and Table 10. For China, Baten et al. (2010) used the censorial section of the board of punishment, in which information on age statements were found for all Chinese administrative regions; ages were self-reported by persons in court. Although the age reports for the Korean population and the monks came from different centuries, the numeracy values indicate similar human capital levels. The Japanese numeracy levels are approximately 10 percentage points lower than the Korean levels.

When the three East Asian countries were compared with three European regions, the former's levels were similar to those of the most advanced European region (Figure 5 and Table 10). In Europe, the centuries between the late 15th and early 19th centuries represent a human capital revolution. European numeracy rates grew from approximately 50% to approximately 95%. This is a true revolution because the nearly 50 percentage point magnitude of change is comparable to the difference between the poorest and the wealthiest economies of the early 20th century (Crayen and Baten 2010: South Asia had a numeracy rate of 52% in the 1940s, whereas the richest countries had reached full numeracy). Therefore, Europe transitioned from a half-numerate to a mostly numerate continent during this revolution. The differences between the European regions are also interesting: Southern Europe was the most advanced region in the late Middle Ages and the early Renaissance, but the well-known ascendancy of northwestern Europe is also visible in the numeracy record. In the 16th and 17th centuries, Korea and Japan had already covered half of the distance of this human capital revolution, even if we consider the potential biases mentioned above. China was even more developed during the late 17th and 18th centuries.

V. Discussion: are the high numeracy estimates plausible on the background of the literature on East Asian education?

Ronald P. Dore's (1965) landmark study offered an optimistic reassessment of Japanese education in the Tokugawa period (1603–1868. On this and the following review, see Baten et al. 2010). The school enrollment data for 1868 led him to estimate a literacy rate of 43% for males and 19% for females, a remarkably high level by nineteenth-century standards (Hayami and Kitô 2004). Another piece of evidence was provided by studies assessing the existence of a dynamic book publishing industry and book rental market. These studies also concluded that business and private households were familiar with earlier forms of accounting and bookkeeping and the use of farm manuals (Hayami and Kitô 2004; Smith 1988). Rawski (1979) extended these findings to the case of China, although she emphasized that her results were based on fragmentary and circumstantial evidence. She observed a literacy rate of 30–45% for males and 2–10% for females (Rawski 1979). Rawski also reported that educational and schooling opportunities improved during the Ming (1368–1644) and Qing (1644–1911) periods. Due to an increased demand for commerce, local administration, and agricultural production, there was an educational spillover to the broader society, which implied that not only the elites had access to education but other groups of society could obtain basic skills (Rawski 1979; Li 2004).

Rawski argued that Chinese demand for education and literacy should be greater than, or at least similar to, that of Japan in the Tokugawa period. This is because Chinese society, in which education was an important condition for upward social mobility, was relatively open, compared with the more status-oriented Japanese society.

Rawski (1985) and Li (2004) also addressed the issue of a growing and prosperous publishing industry in China, with book publication ranging from encyclopedias or histories to romance novels or Buddhist sutras. In addition, cities and towns "had an abundance of posted regulations, shops signs, advertisements, and other material to read for profit and amusement" (Naquin and Rawski 1987, 58–59). Furthermore, Li (2004) accounted for the spread of arithmetic textbooks and abacuses and the spread of numerals for bookkeeping and accounting during the Ming and Qing periods, which provided direct evidence of numeracy in this period. More evidence of numeracy can be found in other studies on China and Korea that demonstrated the use of traditional accounting techniques by analyzing the surviving account books (Guo 1982, 1988; Gardella 1992 for China; Jun and Lewis 2006 for Korea). Ronan and Needham (1978) argued that the importance of a lunar calendar, numerology, and number-mysticism in daily life numerically influenced Chinese thinking (Ronan 1978).

Further supporting evidence that the high numeracy estimates for Korea, Japan, and China are plausible come from the comparison of early modern human capital with estimates for the last decades of the 20th century. Baten and Juif (2014) observed that in many world regions, numeracy differences persisted over centuries. They found that early numeracy rates from approximately 1820 were highly correlated with contemporary cognitive skills, especially in the areas of math and science. If this applies to East Asia as well, one would expect a high level of numeracy even today. Chinese students at present perform very well on international standardized tests and are consistently ranked near the top of all students worldwide. This fact holds even when compared with rich countries (Hanushek and Woessmann 2012). Moreover, Korean and Japanese math and science test results were among the highest ranked. We conclude from this review that general human capital (numeracy in particular) was remarkably developed in East Asia and that our numeracy estimates are thus not implausible.

VI. Conclusion

We employed a unique data set to estimate the numeracy levels in Korea in the late 16th and 17th centuries, using age-heaping as a proxy. We assessed a number of potential caveats, such as cultural preferences for reporting an enddigit 8 for the own age, or reporting an age that corresponds with dragon years (or other zodiac animals). These cultural preferences were visible in Japan and China, but not to a significant extent in Korean hojok registers of the 17th century. We find that their impact on the age-heaping based numeracy estimates was not substantial. The main result is that while Koreans during this period exhibited clearly age-heaping, the extent of inaccurate age reporting was relatively small. Hence we estimate that basic numeracy was high already in the early modern period.

We compared these numeracy levels to those of Japan and China and found that all three countries were relatively numerate by global standards of the 16th to 18th centuries. East Asians achieved their high levels of numeracy remarkably early. On the background of the East Asian Growth Miracle of the 20th and 21st centuries, this historical research has implications for understanding the Asian and global growth process today.

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Table 1: Numbers of cases of age statements used in this study

Country	Source	Reporting year	Birth decades	N
Korea	Hojok, Dansung, population	1606	1550s-1570s	1,133
Korea	Hojok, Dansung, monks	1678	around the 1630s	70
Japan	Population register, Bungo Province	1622	around the 1590s	551
China	Board of punishment	1735–95	1660s-1700s	163
			1710s-1740s	383
			1750s-1770s	56

Table 2: Descriptive statistics of the hojok register 1606 (birth decades 1550s-1570s)

Variable	%
Not rounded last digit	71.8
Last digit zero or five	28.2
Woman	4.4
Man	95.6
Not household head	89.0
Household head	11.1
Birth decade: 1550s	34.2
1560s	39.3
1570s	26.5
Birth Animal: Rat	8.7
Ox	7.3
Tiger	5.5
Rabbit	10.4
Dragon	7.7
Snake	9.5
Horse	11.1
Sheep	6.7
Monkey	10.5
Rooster	7.5
Dog	8.8
Pig	6.3
N	1,133

Table 3: Number of observations per year in Korea

Year	N of Obs.	Year	N of Obs.	Year	N of Obs.
1606	1,428	1750	9,760	1828	5,533
1678	7,984	1756	4,242	1831	8,002
1681	3,015	1759	14,486	1834	7,878
1684	9,674	1762	19,178	1837	11,646
1690	8,217	1765	4,369	1840	6,424
1696	6,970	1768	7,826	1843	2,514
1705	7,998	1774	8,296	1846	14,755
1708	3,841	1777	5,216	1849	4,680
1714	7,819	1780	10,809	1852	1,420
1717	18,331	1783	15,966	1858	16,052
1720	16,191	1786	16,319	1861	9,441
1723	3,953	1789	22,233	1864	3,970
1726	4,557	1792	3,503	1867	9,638
1729	16,264	1795	12,436	1870	14,829
1732	22,344	1801	7,303	1873	2,671
1735	16,827	1804	1,161	1876	6,280
1736	1	1810	5,336	1879	1,962
1738	7,512	1813	2,593	1882	1,904
1741	3,520	1816	4,563	1885	1,574
1747	9,647	1825	19,854	1888	846

Note: This table contains years in which hojoks were conducted and the corresponding numbers of observations. Of those observations, only those aged 23-72 were included in the ABCC calculations in Table 2.

Table 4: ABCC values of various groups in Korea

Subsample	ABCC Index	N of Obs.
Without Counterchecking		
All Household Members (birth decade 1550s)	90.1	387
All Household Members (birth decade 1560s)	89.3	445
All Household Members (birth decade 1570s)	89.7	301
Household heads	94.1	174
Monks	94.6	70
Potentially With Counterchecking		
All Household Members (birth years 1600-1699)	98.4	134,031
All Household Members (birth years 1700-1799)	97.9	210,697
All Household Members (birth years 1800-1866)	97.4	84,417

Note: Following the literature, we first calculated ABCC values by age group (23-32, 33-42, etc.) and then determined birth decades by selecting those in which the majority of individuals were born. We also performed an adjustment for the 23-32 age group, as suggested by Crayen and Baten (2010). For the later (potentially biased) data, we calculated ABCC values by birth centuries.

Table 5: End-digit preferences by subgroups

	1550s -70s	1550s -70s	1550s only	1560s only	Males only	Non-HH only*	All hojoks
Digit	N	%	%	%	%	%	%
0	171	15.1	18.9	16.1	15.1	14.9	10.7
1	99	8.7	10.0	8.1	9.1	8.3	9.5
2	92	8.1	8.1	7.4	8.1	8.3	8.6
3	134	11.8	4.6	13.7	11.6	12.0	11.0
4	105	9.3	6.2	8.1	9.0	9.5	10.1
5	149	13.2	6.2	13.2	13.3	13.2	11.0
6	81	7.1	5.4	6.5	7.2	7.5	9.8
7	98	8.6	12.3	9.4	8.8	8.3	10.0
8	89	7.9	9.6	9.2	7.4	7.7	9.9
9	115	10.2	18.9	8.3	10.4	10.2	9.6

Note: Non-HH: non-household heads only. All hojoks refers to 1606-1888.

Table 6: Percentage of rounded ages in the hojok register 1606 (birth decades 1550s-1570s)

	% of rounded ages	Group difference[a] (p-value)
Woman	26	No (0.719)
Man	28	
Non Household Head	28	No (0.767)
Household Head	29	
Rat	0	Yes (<0.000)
Ox	60	
Tiger	0	
Rabbit	61	
Dragon	1	
Snake	45	
Horse	28	
Sheep	0	
Monkey	45	
Rooster	0	
Dog	60	
Pig	0	

Notes: a: The decision was made based on a p-value<0.05. Birth animal is missing for two observations. We used t-tests to determine the group difference between men and women and between non-household head and household heads and one-way analysis of variance models to determine the group difference by birth animals. The different estimate of the heaping gap between household heads and non-household heads between this Table and Table 4 results from the adjustment procedure applied in Table 4: It is convention in the age heaping literature to adjust the numeracy estimate of age group 23-32 by minus 25%, because in this group, heaping often occurred on ages 24, 26, 28 and so (Crayen and Baten 2010). This rounding on multiples of two is not captured by the Whipple/ABCC index, which only reflects the rounding on multiples of five. Hence the adjustment. The t-tests in the Table above can only be performed on the raw data, of course.

Table 7: Regression of age-rounding on Zodiac year-born characteristics (Hojok 1606, birth decades 1550s-1570s)

Variable	Coefficient (Standard Error)
Ox	0.630 (0.057)*
Tiger	0.040 (0.062)
Rabbit	0.655 (0.053)*
Dragon	0.042 (0.056)
Snake	0.478 (0.053)*
Horse	0.302 (0.051)*
Sheep	0.035 (0.058)
Monkey	0.487 (0.052)*
Rooster	0.046 (0.057)
Dog	0.626 (0.054)*
Pig	<-0.000 (0.058)
Constant	-0.022 (0.069)
N	1,131
Adj. R squared	0.324

Notes: A linear probability model was applied. The dependent variable is a binary variable with 1 representing those who reported an age ending with a multiple of five, and 0 otherwise. *: p-value<0.05. We included controls for gender, household head, and birth decades (not shown).

Table 8: New evidence on numeracy in Korea and Japan

Birth decade	Korean common population	Korean Monks	Japanese common population
1550	90.1		
1560	89.3		
1570	89.7		
1580			
1590			81.0
1630		94.6	

Table 9: Japanese population distributions by the last digit of a person's age

Last digit of age	Total 21 or older (N)	% of population
0	118	21.4
1	67	12.2
2	45	8.2
3	61	11.1
4	18	3.3
5	76	13.8
6	37	6.7
7	20	3.6
8	82	14.9
9	27	4.9

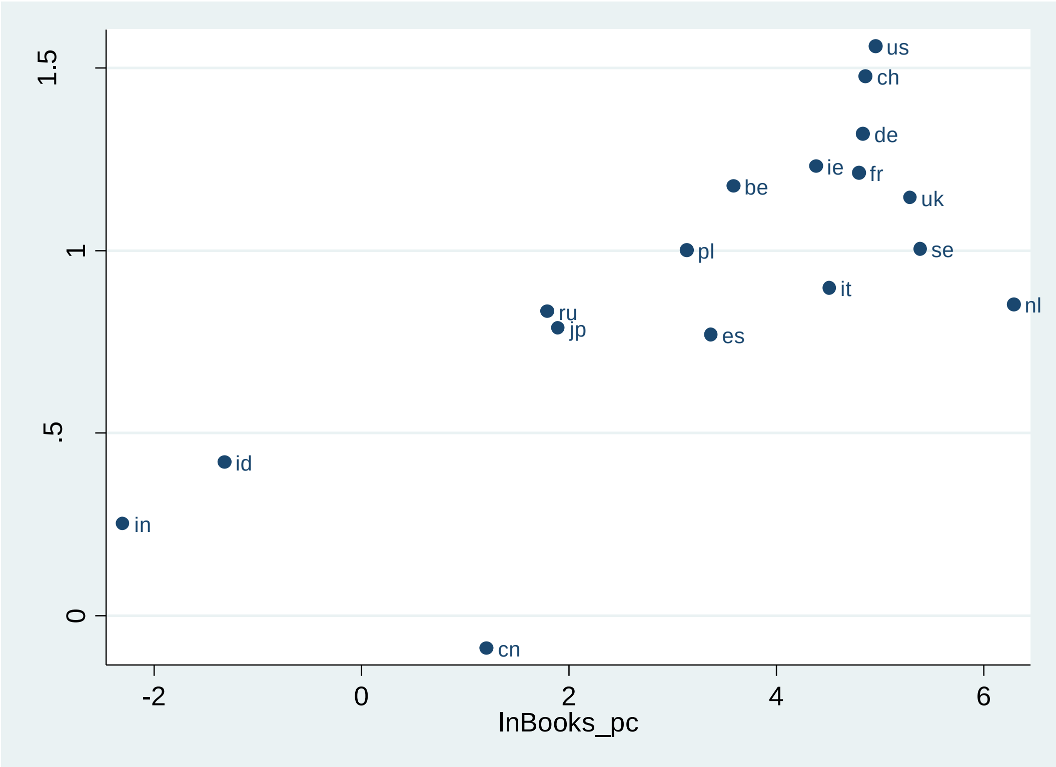
Source: Hayami (2001, p. 25) (based on the population register, Hayami gun, Bungo Province, 1622.)

Table 10: East Asian and European numeracy comparison

Birth years	Southern Europe	Eastern Europe	Northwest Europe	China	Korea	Japan
1450-99	55.0		46.7			
1500-49	60.7		59.2			
1550-99	66.3		71.8		89.7	81.0
1600-49	72.0	60.0	84.3			
1650-99	77.7	67.7	86.1	93.6		
1700-49	83.3	83.7	93.4	99.2		
1750-99	89.0	82.0	98.3	98.2		
1800-49	87.0	90.3	97.6			

Notes: Korea refers to the birth decades 1550s-70s, Japan around the 1590s.

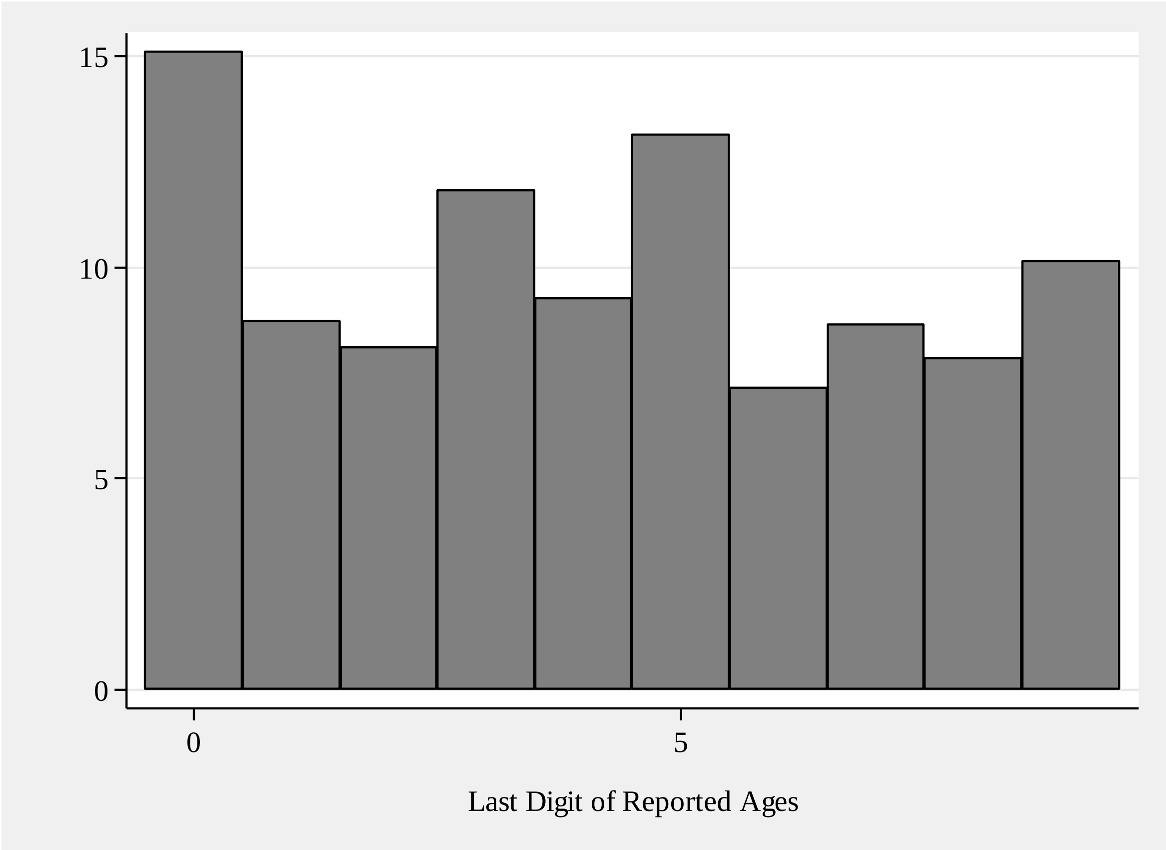
Figure 1: Book production per capita between 1750 and 1800 and GDP per capita growth 1820-1913 (books on log scale).



Source: Baten and van Zanden (2012)

Figure 2: The location of Dansung

Figure 3: Distribution of the last digits of reported ages



Notes: The number of observations was 1,133 for the year 1606. Only evidence for this year is included above.

Figure 4: New evidence on numeracy in Korea and Japan

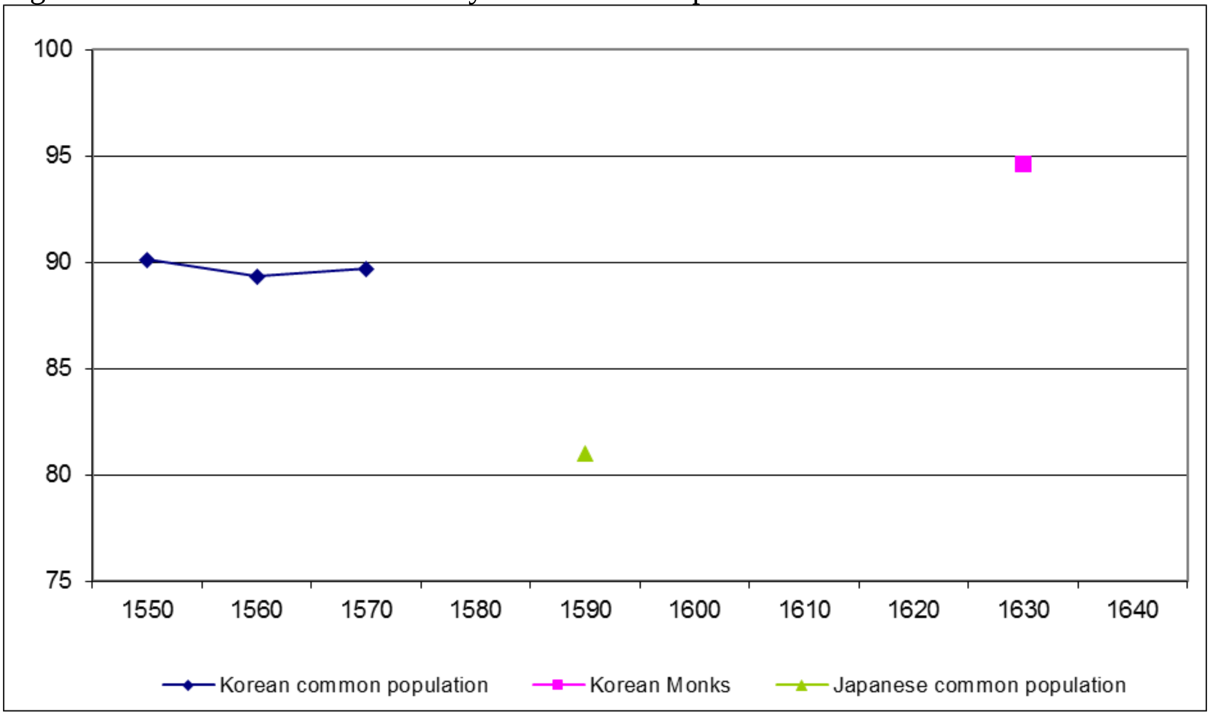
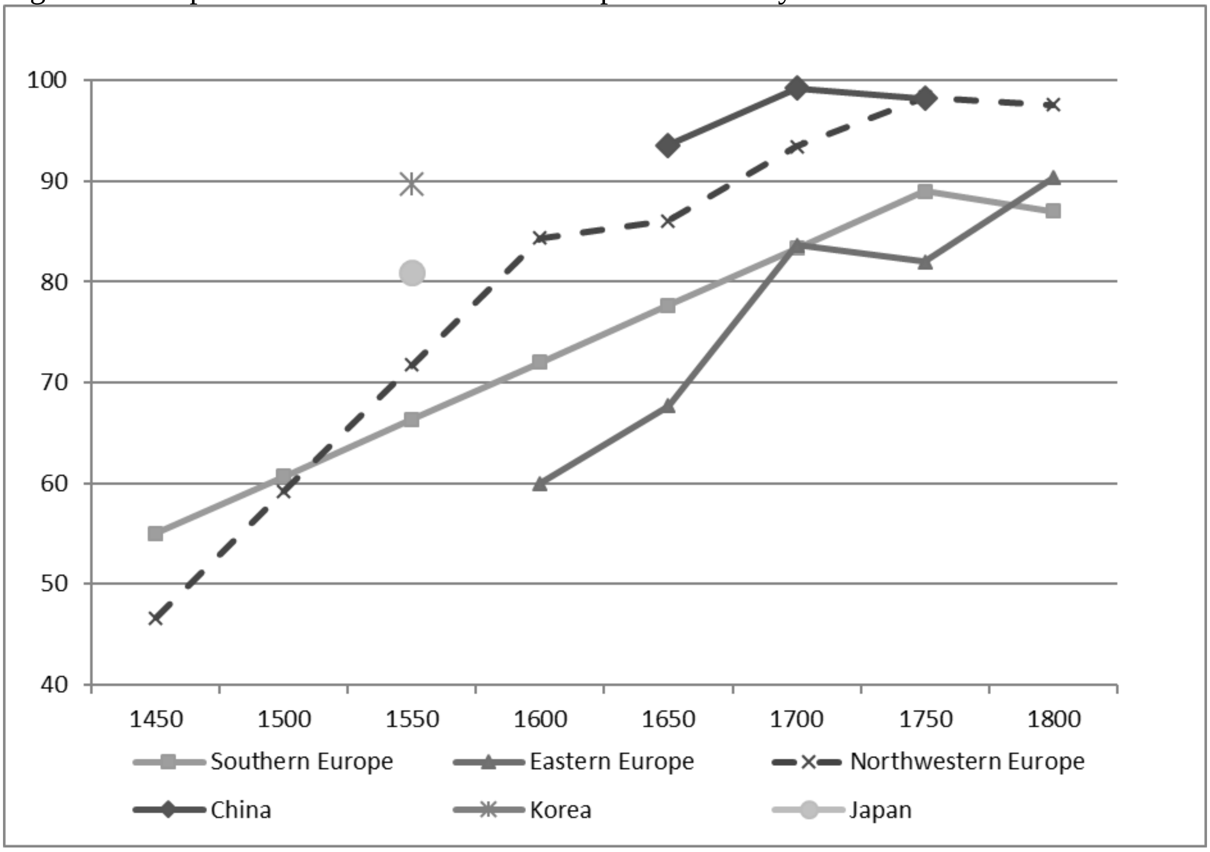


Figure 5: Comparisons of East Asian and European numeracy



Notes: Values refer to half centuries of birth around the years noted. The evidence is based on A'Hearn, Baten and Crayen (2009), Table 4. We included all the countries for which longer series or at least early values were available: "Northwestern Europe" is the UK, the Netherlands and Protestant Germany, and "Southern Europe" is northern Italy. "Eastern Europe" is the average of Russia, Bohemia and Austria (from approximately 1600). "Average" is the average of those three regions. When values between the benchmark dates were missing, they were interpolated. Weak estimates (in italics in Table 4 of A'Hearn et al.) were omitted. For the UK and the Netherlands before 1600, the benchmark year is 1600 in the UK, and the changes are calculated based on Protestant Germany.

Appendix A (Internet-appendix, not to be included in the print version): Age-heaping

The use of age-heaping measurements in the context of modern economic history has recently experienced spectacular growth.[8] Age-heaping measurements have been employed to understand numeracy in France and the US from the 17th to the 19th centuries and in China from the 18th to the 20th centuries (Crayen and Baten 2010a; Baten et al. 2010). Beyond individual countries, scholarly interest has extended to Latin America, Europe, and even worldwide (A'Hearn, Baten, and Crayen 2009; Crayen and Baten 2010; Manzel, Baten, and Stolz 2012).

Measuring the 'human capital' production factor has never been simple, as advanced forms of skill are difficult to compare. Therefore, economists have resorted to the use of proxy indicators, such as years of schooling or, in long-run studies, the share of individuals signing a marriage register. We will explain the advantages and caveats in somewhat greater detail, as the application of this method in economic history is still relatively new.

This approach employs a set of methods that developed around the phenomenon of "age-heaping," i.e., the tendency of poorly educated people to erroneously round their ages. For example, less educated people are more likely than people with a greater human capital endowment to state their age as "30," even if they

[8] Mokyr (2006) pioneered their use. Duncan-Jones (1990) applied them to study ancient economies.

are in fact 29 or 31 years old (Mokyr 2006).[9] The ratio between the preferred ages and the others can be calculated using several indices, one of which is the Whipple index.[10] Thus, the index measures the proportion of individuals reporting an age ending in a five or zero, assuming that each terminal digit should appear with the same frequency in the "true" age distribution.[11]

$$(1)\quad Wh = \left(\frac{(Age25 + Age30 + Age35 + ... + Age60)}{1/5 * (Age23 + Age24 + Age25 + ... + Age62)} \right) \times 100$$

For an easier interpretation, A'Hearn et al. (2009) suggested another index called the ABCC index.[12] It is a simple linear transformation of the Whipple index and yields an estimate of the share of individuals who report their ages correctly:

$$(2)\quad ABCC = \left(1 - \frac{(Wh - 100)}{400} \right) \times 100 \quad \text{if} \quad Wh \geq 100\text{; else } ABCC = 100 \text{ .}$$

A'Hearn et al. (2009) found that the relationship between illiteracy and age-heaping for Less Developed Countries after 1950 is very close. They calculated age

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[9] Among demographers, this specific type of age misreporting constitutes "one of the most frustrating problems" (Ewbank 1981, 88). It is treated as a source of distortion in age-specific vital rates that needs to be removed, or at least minimized, to study family or household variables.

[10] A'Hearn, Baten and Crayen (2009) found that this index is the only one that fulfils the desired properties of scale independence (a linear response to the degree of heaping) and that it reliably ranks samples with different degrees of heaping.

[11] A value of 500 means an age distribution with ages only ending in multiples of five, whereas 100 indicates no heaping patterns on multiples of five, that is, exactly 20 percent of the population reported an age ending in a multiple of five.

[12] The name results from the initials of the authors' last names plus that of Gregory Clark, who suggested this in a comment on their paper.

heaping and illiteracy for no fewer than 270,000 individuals who were organized into 416 regions, ranging from Latin America to Oceania. The correlation coefficient with illiteracy was as high as 0.7. The correlation with the PISA results for numerical skills was as high as 0.85; hence, the age-heaping measures are more strongly correlated with numerical skills.

A'Hearn et al. (2009) used a large U.S. census sample to perform a detailed analysis of the relationship between age-heaping and illiteracy. They subdivided the sample by race, gender, high and low educational status, and other criteria. In each case, they obtained a statistically significant relationship. It is also remarkable that the coefficients are relatively stable across samples, i.e., a unit change in age-heaping is associated with similar changes in literacy across the various tests. Those results are not only valid for the U.S.; there was substantial age-heaping in all countries that have been explored thus far, and the correlation was found to be both statistically and economically significant.[13]

To assess the robustness of these results from the U.S. census and the similar conclusions that could be drawn from the less developed countries of the late 20th century, as mentioned in the introduction to this study, A'Hearn et al. (2009) also assessed age-heaping and literacy in 16 different European countries between the Middle Ages and the early 19th century. Again, they found a positive correlation between age-heaping and illiteracy, although the relationship was somewhat weaker than for the 19th- or 20th-century data. It is likely that the unavoidable measurement error when using early modern data produced the reduced statistical significance

[13] On Argentina's regions, see, for example, Manzel et al. (forthcoming).

(Baten and Szołtysek 2012).[14]

The broadest geographical sample studied thus far was created by Crayen and Baten (2010), who were able to include 70 countries for which both age-heaping and schooling data (and other explanatory variables) were available. In a series of cross-sections between the 1880s and 1940s, they found that primary schooling and age-heaping were closely correlated, with R-squared values between 0.55 and 0.76 (including other control variables, see below). Again, the coefficients were shown to be relatively stable over time. This large sample also allowed for the examination of various other potential determinants of age-heaping. To assess whether the degree of bureaucracy, birth registration, and government interaction with citizens are likely to influence the knowledge of one's exact age, independent of personal education, Crayen and Baten used the number of censuses performed for each individual country up to the period of study as an explanatory variable for their age-heaping measure. Except for countries with a very long history of census taking, all of the variations in this variable were statistically insignificant, which would suggest that an independent bureaucracy effect was rather weak. In other words, it is likely the case that societies with a high number of censuses and an early introduction of birth registers had a high degree of age awareness. Those societies also introduced schooling early, and this

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[14] The experience of historical demographers shows that data from premodern periods were often very rough, imprecise, or fragmentary. Even 18th-century statistical materials still contain a host of uncertainties and traps, as they were frequently collected haphazardly and analyzed without skill; as a result, they often only encompass a part of the phenomenon, which is incomplete (Szołtysek 2011). This refers in particular to the quality of data on age.

variable clearly exhibited greater explanatory power than the independent bureaucracy effect. Crayen and Baten also tested whether the general standard of living influenced age-heaping tendencies (using height and GDP per capita as welfare indicators) and found a varying influence: in some decades, there was a statistically significant correlation, while in others, there was none.

In conclusion, the correlation between age-heaping and other human capital indicators is well established, and the 'bureaucratic' factor does not invalidate this relationship. A caveat relates to other forms of heaping (apart from the heaping on multiples of five), such as heaping on multiples of two, which is quite widespread among children and teenagers and to a lesser extent among young adults in their twenties (Baten and Szołtysek 2012). This demonstrates that most individuals knew their ages as teenagers, but only in well-educated societies are they able to remember or calculate their exact age later in life. At higher ages, this heaping pattern was mostly negligible, but it was, interestingly, somewhat stronger among populations who were numerate enough not to round to multiples of five. We will exclude those below age 23 and above 72, as a number of possible distortions affect those specific age groups, leading to age reporting behavior different from that of the intermediate adult group. Many young males and females married in their early twenties or late teens, when they also had to register as voters, military conscripts, etc. On such occasions, they were, in some instances, subject to minimum age requirements, a condition that gave rise to increased age awareness. Moreover, individuals in this age group were growing physically, which makes it easier to determine their ages with a relatively high level of accuracy. All of these factors tend to deflate age-heaping levels for children and young adults, compared to the age reporting of the same individuals at higher ages. The aged should also be excluded because the age-heaping pattern of very old individuals is subject to upward and downward bias for the reasons mentioned above.

There remains some uncertainty over whether age-heaping in the sources contains information about the numeracy of the responding individual or about the diligence of the reporting personnel who wrote down the statements. The age data for the relevant age groups 23–72 were normally derived from statements directly from the person. However, it is possible that a second party, especially the husband, may have made or influenced the age statement or even that the enumerator estimated the age without asking the individual. If the latter occurred, we would not be able to measure the numeracy of the person interviewed. In contrast, if the enumerator asked and obtained no response, a round age estimated by him would still measure basic numeracy correctly. A large body of literature has investigated the issue of people reporting on others' age. Recently, Friesen, Prayon, and Baten (2012) systematically compared the evidence of a gender gap in numeracy and literacy for the early 20th centuries, and found a strong correlation. They argued that there is no reason why the misreporting of literacy and age should have yielded exactly the same gap between genders. A more likely explanation is that the well-known correlation between numeracy and literacy also applies to gender differences. For our study, the question of whether the women themselves responded is slightly less important, as we only seek to estimate male numeracy.

Of course, a potential bias always exists if more than one person is involved in the creation of a historical source. For example, if literacy is measured by analyzing the share of signatures in marriage contracts, there might have been priests who were more or less interested in obtaining real signatures, as opposed to crosses or other symbols. We find it reassuring that previous studies have generally found much more age-heaping (and less numeracy) among the lower social strata and among the half of the sample population who had lower anthropometric values (Baten and Mumme 2010). Moreover, the regional differences in age-heaping are similar to the regional differences in illiteracy. It can be concluded that the method of age-heaping is a useful and innovative tool for assessing human capital.

Appendix B (Internet-appendix, not to be included in the print version):

During discussions of the long-run impact of basic numeracy, the question arose whether an impact over long periods, such as a century, was possible at all. This has been previously studied by Baten and Juif, and in order not to repeat, we asked the authors to reprint a part of their working paper as additional online material (and the authors agreed on this). We only excerpt those parts which relate to the long-run impact of numeracy.

Excerpt from A STORY OF LARGE LANDOWNERS AND MATH SKILLS: INEQUALITY AND HUMAN CAPITAL FORMATION IN LONG-RUN DEVELOPMENT, 1820-2000 (by Joerg Baten and Dácil Juif). A newer and more complete version is forthcoming in the Journal of Comparative Economics.

“Which measure of human capital should be employed as a dependent variable? We argue that a measure should be used that is most conducive to economic growth. For example, school years have often been criticized because the productivity of a school hour differs between countries and cultures and, thus, is not a perfect growth predictor. Recently, the leading human capital economists Hanushek and Woessmann (2012) argued that cognitive skill test results related to math and science abilities are the strongest correlates of economic growth. They extended the famous PISA results from the 2000s into the period 1964-2003 by recalibrating a large number of international math and science tests; they also developed a comprehensive index of those core skills that will be our dependent variable.

A major contribution of our study is our assessment of the long-run persistence of numerical cognitive skills, which are an important component of the Hanushek-Woessmann measure. We include a new measure of numeracy around 1820 that is constructed on the basis of age-heaping estimates. We argue that countries with early investments in numerical education (and perhaps cultures that promoted numerical skills) entered a path-dependency of human capital-intensive industries, including skill-intensive agriculture and services. Those countries that took the numerical lead (but not necessarily the lead in living standards) in the 1820s were situated in Scandinavia, Central and Western Europe, and East Asia. In the second wave, North American, Southern and East-Central European countries followed. Other world regions lagged behind.

Fertility choice is another potential determinant of human capital accumulation, especially during the 20th century: The famous quantity-quality trade-off might determine the level of educational investment because if a family decides to have more children, the human capital investment per child might be lower (see Becker 1960, Easterlin 1980). However, Clark (2007) recently presented historical evidence that this result does not necessarily hold for early societies in which richer individuals had more surviving children (Galor and Moav 2002) proposed a theory of natural selection earlier than Clark).

Human capital clearly has endogenous as well as exogenous components. Exogenous factors (not influenced by economic variables) include, for example, religious educational values (Botticini and Eckstein 2007, Becker and Woessmann 2009). Selective migration (in terms of skills) can affect the human capital development of a country, both positively and negatively (Glaeser et al. 2004). For example, when we speak of a "brain drain" phenomenon, the home country's average human capital is negatively affected by emigration of high skilled workers, while the host country benefits from positively selected immigration (and sometimes vice versa).[15]

Our study contributes to this research stream by providing empirical evidence on the causal link between numeracy more than one hundred years ago and recent human capital levels for a large cross-section of countries.

3. Data

Our equation for human capital determinants includes the ABCC-Index values for 1820 – the earliest year for which we obtained a sufficiently large set of country data – to assess the path-dependence of education reflected in numeracy skills.

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[15] Stolz and Baten (2012) find the opposite – arithmetic "brain gain" for the home countries which "lost" many their less skilled inhabitants -- for a number of countries during the 19th century era of mass migration.

The dependent variable *cognitive* is our measure for the cognitive skills of human capital. This output measure of human capital reflects the knowledge and abilities that are most favorable for subsequent success. Hanushek and Woessmann (2012a) constructed this variable from test scores in mathematics and science for 77 countries between 1964 and 2003. More specifically, they calculated the simple average of all math and science scores on International Student Achievement Tests conducted by the Organization for Economic Co-Operation and Development (OECD) and the International Association for the Evaluation of Educational Achievement (IEA) during that period. With linear regressions, they found that by adding cognitive skills to a growth model with school attainment as a dependent variable, the model explains three quarters of the variance in growth rates (instead of one quarter if only school years are included). Further, the coefficient for school years turns statistically insignificant in the presence of cognitive skills. When testing the correlation between test score improvements and growth rates by world regions – conditional on the initial level of real GDP per capita in 1960 – they find an R^2 of 0.98 (see Figure II, albeit with N=5). To control for possible endogeneity of cognitive skills, which might be present if the factors leading to growth are also related to high cognitive skills and have been omitted from the estimation, they instrument cognitive skills with institutional measures of schooling and confirm that schooling-induced differences in cognitive skills are significantly related to economic growth.

This measure of human capital is said to best explain economic growth because, unlike other measurements such as schooling, it controls for differences in the quality of education across countries. A second test for the impact of the cognitive skills measure on economic performance was carried out in a case study on US-migrants. The authors looked at the performance in the labor market of US-migrants educated in the US and US-migrants educated at home, holding constant cultural and other country-of-origin fixed effects. The study again confirmed the growth-inducing effect of the *cognitive skills* measurement.[16]

Further variables included in our dataset are as follows: initial GDP in 1910, income and inequality which is the variable of special focus in this paper, population density (logarithm), a measure of institutional quality, fertility in 1950 (the earliest estimates available for a sufficient number of countries), the share of the population living in the tropical zone in 1995, ethnic fractionalization, and a measure of physical capital that could proxy industrial development, constructed by Enflo and Baten (2006). Population density was included because visiting schools is less costly in countries with high population density.

4. Base Regression Results

Our model for the estimation of human capital has the following form:

$$Cognitive_i = \alpha + \beta_1 \textit{ land ineq}_i + \beta_2 \textit{ income ineq}_i + \beta_3 \textit{ early ABCC}_i + \gamma X_i + \varepsilon_i$$

The dependent variable *cognitive* is our measure for cognitive skills. This output measure of human capital best reflects the knowledge and abilities that are favorable for subsequent success. Hanushek and Woessmann (2012a) constructed this variable from test scores in mathematics and science for 50 countries between 1964 and 2003.

We test both income inequality around 1890 and early land inequality as

[16] The finding that numerical cognitive skills are most conductive to economic growth further corroborates the argument of Schumpeter for the use of “numeracy” as an important proxy of human capital (see also Baten 2010).

determinants of cognitive skills. We add numerical abilities ("early ABCC") to assess the persistence of numerical skills. This measure also proxies to a certain extent the GMV factor of industrialists promoting basic education because countries that were numerate in 1820 also tended to be industrial.

In the econometric specification above, the additional vector of explanatory variables *X* captures other factors that could have an effect on human capital for all countries *i*: initial GDP in 1910, population density (logarithm), institutional quality, fertility in 1950, the share of the population living in the tropical zone in 1995, ethnic fractionalization and physical capital in 1925.

Based on the basic model of human capital introduced in the last section, we perform cross-country analyses of the effect of inequality and early human capital on cognitive skills (Table III). A large part of the variation in cognitive skills in the period 1964-2003 – as much as 54 percent – can be explained by early numeracy from the ABCC-Index in 1820 (see specification (1)).

6. Conclusion

A major contribution of our study was to assess the persistence of numerical cognitive skills, which are an important component of the Hanushek-Woessmann measurement. Our results confirm that countries with early investments in numerical education (and perhaps cultures that promote numerical skills) entered a path-dependency of human capital-intensive industries, including skill-intensive agriculture and industries. Early numeracy explained a considerable portion of recent cognitive skills.

Sources of the ABCC 1820 estimates in detail (for reference abbreviations, see below)

Western Europe:

Austria 1880 (Rothenbacher); Belgium 1856, 1866, 1880, 1890 (Rothenbacher); Switzerland 1860, 1870, 1880, 1888 (Rothenbacher); Denmark 1870, 1880, 1890 (Rothenbacher); Finland 1880, 1900 (Rothenbacher); France 1851, 1856, 1861, 1866 (Rothenbacher); Germany 1880 (Hippe and Baten); Ireland 1851, 1861 (Hippe and Baten); Italy 1871, 1931, 1936 (Rothenbacher); Netherlands 1849, 1859, 1869, 1879, 1889, 1899 (Rothenbacher); Norway (Crayen and Baten), using: Norway. Census of Norway 1865 and 1900. Statistics Norway, Oslo; Portugal: Stolz, Yvonne, Baten, J. and Jaime Reis, "Portuguese Living Standards 1720-1980 in European Comparison – Heights, Income and Human Capital", *Economic History Review 66-2* (2013), pp. 545-578; Spain 1900 (Hippe and Baten); Sweden 1880, 1900 (Rothenbacher); Switzerland 1860, 1870, 1888, 1900 (Rothenbacher); United Kingdom 1851 and 1881 (Crayen and Baten), using: 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;

Eastern and Southeastern Europe:

Albania 1918 (Hippe and Baten), using: Eberhart, Helmut et al. (2010), Preliminary dataset "Albanische Volkszaehlung von 1918", entstanden an der Karl-Franzens-Universita¨t Graz unter Mitarbeit von Helmut Eberhart, Karl Kaser, Siegfried Gruber, Gentiana Kera, Enriketa Papa-Pandelejmoni und finanziert durch Mittel des Oesterreichischen Fonds zur Foerderung der wissenschaftlichen Forschung; (FWF). On early 19th C numeracy trends in the Balkans, see (Habsburg 1880); ; Armenia (Russian Empire 1897); Azerbeidshan (Russian Empire 1897); Belarus (Russian Empire 1897); Bulgaria 1893 (Hippe and Baten); Croatia 1880 (Rothenbacher); Czech lands 1880 (Rothenbacher); Cyprus, first benchmark decade is the 1870s (Crayen and Baten), on the change of numeracy in the region 1820-70, see Turkey; Estonia (Russian Empire 1897); Georgia (Russian Empire 1897); Greece 1903 (Hippe and Baten). Values are for the 1830s; Hungary 1880 (Rothenbacher); Kazakhstan (Russian Empire 1897); Kyrgystan (Russian Empire 1897); Lithuania (Russian Empire 1897); Latvia (Russian Empire 1897); Moldova (Russian Empire 1897); Poland 1880 (Habsburg part: Rothenbacher), 1880 (Prussian part: Hippe and Baten) and 1897 (Russian part: Russian Empire 1897)); Romania 1880 (Habsburg part: Rothenbacher; Romanian part assumed equal); Russia (Russian Empire 1897); Serbia 1867 (Crayen and Baten), based on 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"; Slovenia 1880 (Habsburg 1880); Slovakia 1880 (Habsburg 1880); Tajikistan (Russian Empire 1897); Turkmenistan (Russian Empire 1897); Ukraine (Russian Empire 1897); Uzbekistan (Russian Empire 1897)

Asia/ Oceania and Africa:

Australia: Meinzer, Nicholas (2013) "The selectivity of migrants to Australia: a new methodological approach". Unpubl. Master thesis Univ. Tuebingen; China: Baten, J., Debin Ma, Stephen Morgan and Qing Wang (2010) "Evolution of Living Standards and Human Capital in China in the 18-20th Centuries: Evidences from Real Wages, Age-heaping, and Anthropometrics", *Explorations in Economic History* 47-3: *347-359*; Egypt: 1848 (Census of Cairo), 1907 (Census of Egypt: The Statistical Department of the Ministry of Finance Egypt, 1907. Statistical yearbook of Egypt. 3rd census of Egypt 1905. Cairo, The Government Press; Hong Kong Baten, J., Debin Ma, Stephen Morgan and Qing Wang "Evolution of Living Standards and Human Capital in China in the 18-20th Centuries: Evidences from Real Wages, Age-heaping, and Anthropometrics", *Explorations in Economic History* 47-3 (2010): *347-359*; India: 1891 (Census of India, 1891 (Bombay, Madras, North-Western Provinces) Indian Empire Census of 1891, 1901, 1911 and 1921. The Superintendent of Government Printing India, Calcutta; Indonesia: Southeast Asia estimate of Baten, J, and Johan Fourie "Numeracy in the 18th Century Indian Ocean Region"): ERSA Working Paper No. 270, complemented with evidence used also in the study Baten, J., Mojgan Stegl and Pierre van der Eng (2013). The Biological Standard of Living and Body Height in Colonial and Post-colonial Indonesia, 1770–2000", *Journal of Bioeconomics 15*: 103-122; 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; Korea: Deleted to keep anonymity; New Zealand: Meinzer, Nicholas (2013) "The selectivity of migrants to Australia: a new methodological approach". Unpubl. Master thesis Univ. Tuebingen; Philippines: Southeast Asia estimates of (Crayen and Baten) and Baten, J, and Johan Fourie "Numeracy in the 18th Century Indian Ocean Region," ERSA Working Paper No. 270, complemented with evidence by Kathrin Grether (2012), Langfristige Humankapitalentwicklung auf den Philippinen im international Vergleich. Unpubl. BA Thesis Univ. Tuebingen; Thailand: Southeast Asia estimates of (Crayen and Baten), and Baten, J, and Johan Fourie "Numeracy in the 18th Century Indian Ocean Region," ERSA Working Paper No. 270; Turkey (Russian Empire 1897): evidence on the province of Kars; see the discussion in Crayen and Baten (2010) about the representativeness of the province. See also on the Ottoman census of 1831 Starbatty, Peter (2011). Humankapitalentwicklung im Osmanischen Reich 1760-1810. Regionale und ethnische Unterschiede. Unpubl. BA Thesis Univ. Tuebingen.

The Americas:

Argentina (Manzel, Baten, Stolz 2012), based on 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; Brazil (Manzel, Baten, Stolz). ; Canada: (Crayen and Baten), using the 1852 and 1881 Historical Censuses of Canada (Canada East, Canada West, New Brunswick and Nova Scotia). Université de Montréal, Montréal; Chile : Robert Pertschy (2012), Regionale Unterschiede der langfristigen Humankapitalentwicklung in Chile im 19. Jahrhundert. Unpubl. BA Thesis Univ. Tuebingen; Colombia (Manzel, Baten, Stolz); Ecuador (Manzel, Baten, Stolz); complemented with new evidence by Christian Schneider (2011), Das Humankapital in den Regionen Ecuadors, Unpubl. Diploma Thesis Univ. Tuebingen; Mexico (Manzel, Baten, Stolz); Peru (Manzel, Baten, Stolz); Complemented with evidence by Sabin Guettler (2011), Verbreitung der Bildungsinnovationen in Peru und Ecuador im 18. und 19. Jahrhundert, Unpubl. Diploma Thesis Univ. Tuebingen; United States: 1850, 1860, 1870, 1880, 1900: Ruggles, S., Alexander, J.T., Genadek, K., Goeken, R., Schroeder, M.B., and Sobek, M. (2010). Integrated Public Use Microdata Series: Version 5.0 [Machine-readable database]. Minneapolis: University of Minnesota; Uruguay (Manzel, Baten, Stolz).

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(Crayen and Baten): Crayen, D., and Baten, J. (2010). Global Trends in Numeracy 1820-1949 and its Implications for Long-Run Growth. Explorations in Economic History, 47(1): 82-99.

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(Hippe and Baten): Hippe, R. and Baten, J. (2012) "The Early Regional Development of Human Capital in Europe, 1790 – 1880, *Scandinavian Economic History Review*, 60, Number 3, 1 November 2012 , pp. 254-289

(Manzel, Baten and Stolz) Manzel, K., Baten, J. and Stolz, Y. (2012) "Convergence and Divergence of Numeracy: The Development of Age Heaping in Latin America, 17th to 20th Century", *Economic History Review* 65, 3 (2012), pp. 932–960. Detailed sources are listed in their online appendix p.4/5

(Rothenbacher): Rothenbacher, F. (2002). The European Population 1850-1945. Basingstoke: Palgrave Macmillan.

(Russian Empire 1897): First General Russian Empire Census of 1897. издание центрального статистического комитета министерства внутренних (1899).

Baten, Jörg, and Christina Mumme. 2010. "Globalization and Educational Inequality in Long-Run Development during the 17th to 20th Centuries: Latin America and other Developing World Regions." *Journal of Iberian and Latin American Economic History* 28 (2): 279-305.

Baten, Jörg, and Mikołaj Szołtysek. 2012. "The Human Capital of Central-Eastern and Eastern Europe in European Perspective." MPIDR Working Paper no. 2012-002, Max Planck Institute for Demographic

Research, Rostock, Germany.

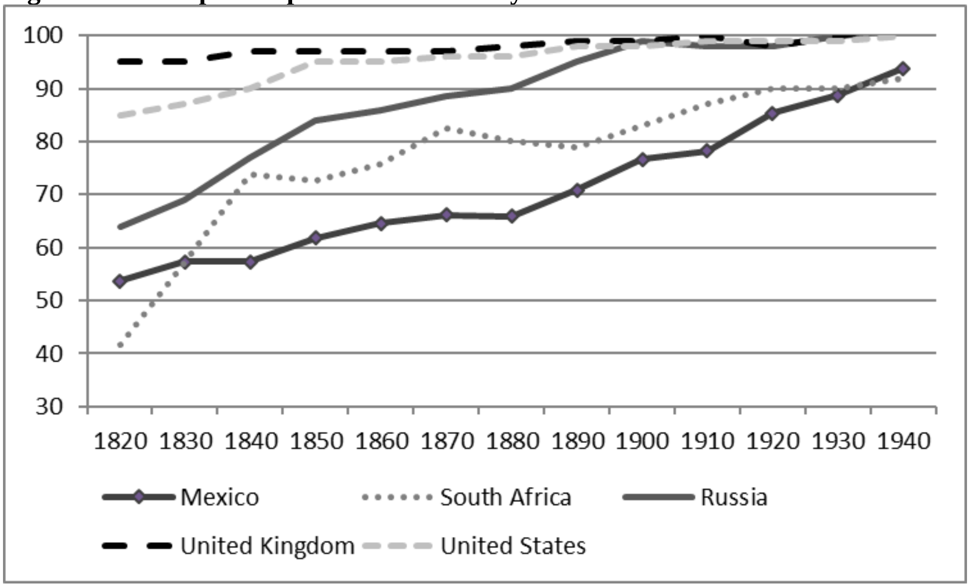
Crayen, Dorothee, and Jörg Baten. 2010a. “New Evidence and New Methods to Measure Human Capital Inequality before and during the Industrial Revolution: France and the US in the Seventeenth to Nineteenth Centuries.” Economic History Review 63 (2): 452–478.

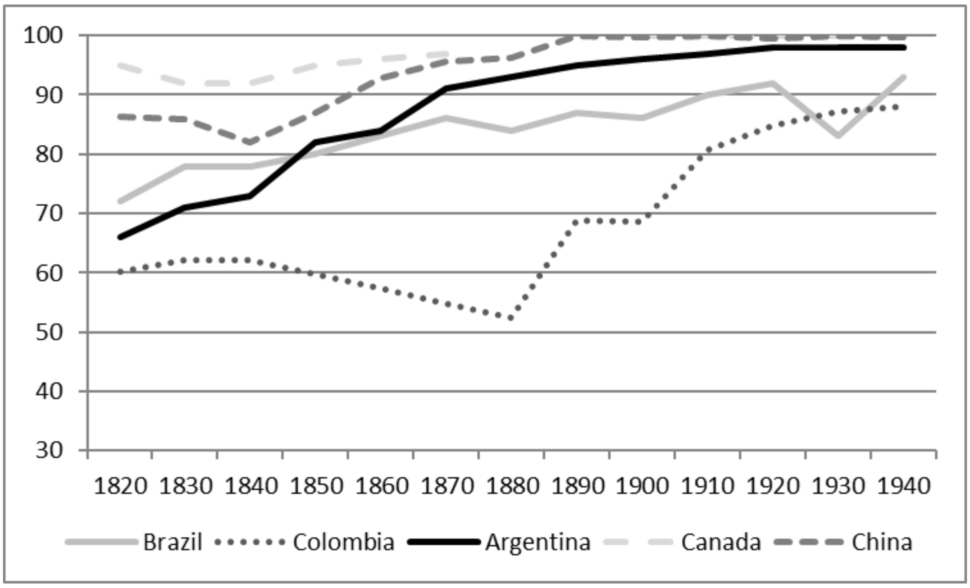
Friesen, Julia, Valeria Prayon, and Jörg Baten. 2012. “Women count. Gender (In-)Equalities in the Human Capital Development in Asia, 1900-1960.” Working Papers in Economics and Finance no. 29, University of Tuebingen, Tuebingen, Germany.

Glaeser, Edward L., Rafael La Porta, Florencio Lopez-de-Silanes, and Andrei Shleifer. 2004. “Do Institutions Cause Growth.” *Journal of Economic Growth* 9 (3): 271-303.

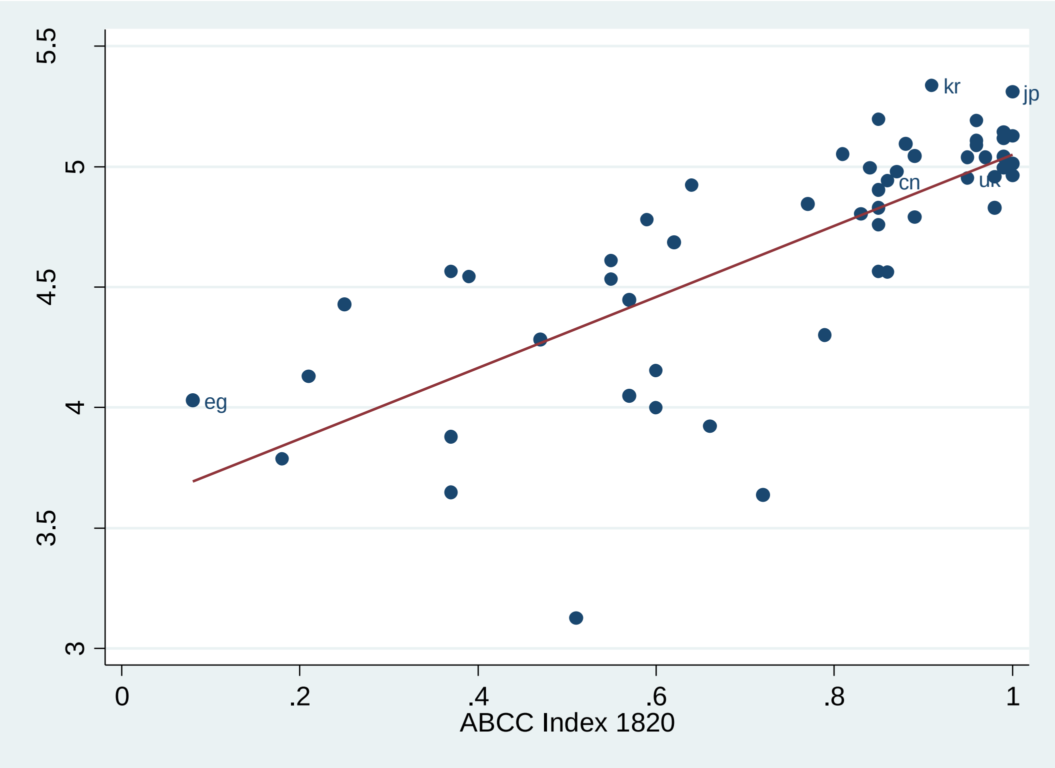
Manzel, Kerstin, Jörg Baten, and Yvonne Stolz. 2012. “Convergence and Divergence of Numeracy: The Development of Age-heaping in Latin America from the Seventeenth to the Twentieth Century.” *Economic History Review* 65 (3): 932-960.

Figure B.1: How path-dependent is numeracy over time?





Numeracy (ABCC) in 1820 and math- and science-oriented skills during the late 20th century.



Source: Baten and Juif (2014)

Table B.1: How path-dependent is numeracy over time? (Pairwise correlations for dataset used in the Figures above. All correlation coefficients are statistically significant at the 10% level)

	1820	1830	1840	1850	1860	1870	1880	1890	1900	1910	1920	1930	1940
1820	1.00												
1830	0.98	1.00											
1840	0.83	0.91	1.00										
1850	0.83	0.90	0.96	1.00									
1860	0.79	0.87	0.93	0.98	1.00								
1870	0.68	0.78	0.87	0.95	0.98	1.00							
1880	0.65	0.75	0.84	0.94	0.98	1.00	1.00						
1890	0.76	0.83	0.85	0.95	0.97	0.96	0.96	1.00					
1900	0.70	0.76	0.82	0.93	0.96	0.96	0.97	0.98	1.00				
1910	0.76	0.82	0.87	0.95	0.95	0.93	0.94	0.99	0.97	1.00			
1920	0.74	0.79	0.83	0.94	0.95	0.94	0.95	0.99	0.98	0.99	1.00		
1930	0.61	0.61	0.65	0.76	0.75	0.73	0.74	0.80	0.86	0.84	0.86	1.00	
1940	0.73	0.75	0.77	0.88	0.90	0.87	0.89	0.91	0.95	0.89	0.91	0.91	1.00

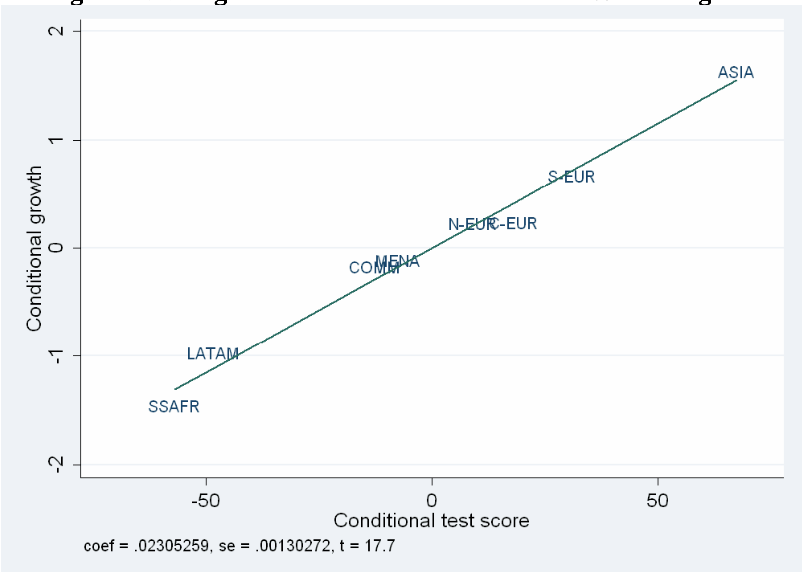
Table B.2: Inequality and Early Numeracy as determinants of modern Human Capital in OLS Regressions

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Robust regression	No	No	No	No	No	No	No	Yes	Yes	No	No	No	No	No
WLS	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes	No	Yes	Yes
Early numeracy	1.48***	1.47***	1.30***	0.91**	0.93**	1.16**	1.05***	1.34***	1.03***	0.91***	0.95***	1.27***	1.16***	0.81***
	(0.00)	(0.00)	(0.01)	(0.01)	(0.02)	(0.02)	(0.00)	(0.00)	(0.00)	(0.00)	(0.01)	(0.00)	(0.00)	(0.00)
Early land inequality (around 1890)		-1.37*	-1.50*	-1.39**		-1.44**		-0.81***		-1.19**		-1.43*	-1.22*	-1.10***
		(0.07)	(0.07)	(0.02)		(0.04)		(0.00)		(0.02)		(0.05)	(0.05)	(0.00)
Income inequality (1890)					-1.93**		-2.28*		-0.88		-1.85**	-0.93	-0.37	-0.83
					(0.04)		(0.06)		(0.27)		(0.04)	(0.16)	(0.59)	(0.41)
GDP/c 1910			0.16	0.21	0.08	0.46	0.28	-0.07	-0.10	0.01	-0.08			-0.02
			(0.16)	(0.14)	(0.60)	(0.13)	(0.39)	(0.35)	(0.407)	(0.80)	(0.40)			(0.68)
Tropic share				-0.27	0.10	-0.42*	0.00	-0.85***	-0.59***	-0.49***	-0.15	-0.46***	-0.52***	-0.44**
				(0.21)	(0.68)	(0.06)	(0.98)	(0.00)	(0.007)	(0.00)	(0.38)	(0.00)	(0.00)	(0.02)
Population density				0.03	0.05	0.04	0.04	0.03	0.07*	0.05	0.06			0.05
				(0.38)	(0.30)	(0.48)	(0.51)	(0.15)	(0.078)	(0.21)	(0.22)			(0.24)
Institutional quality				-0.00	0.00	-0.00	-0.00	-0.00	0.00	-0.00	-0.00			-0.00
				(0.70)	(0.81)	(0.68)	(0.86)	(0.95)	(0.626)	(0.81)	(0.98)			(0.43)
Fertility				-0.02	-0.09	0.03	-0.04	0.03	-0.05	-0.04	-0.10*			-0.09**
				(0.75)	(0.10)	(0.62)	(0.60)	(0.53)	(0.372)	(0.27)	(0.09)			(0.04)
Ethnic Fractionalization				-0.07	-0.34	-0.14	-0.78	0.30*	0.03	0.09	-0.22			0.13
				(0.81)	(0.52)	(0.75)	(0.28)	(0.07)	(0.919)	(0.75)	(0.54)			(0.65)
Physical capital						-0.17	-0.16							
						(0.30)	(0.29)							
Constant	3.57***	4.39***	3.36***	3.24***	4.30***	2.36*	4.10**	4.14**	4.49***	4.68***	5.57***	4.97***	4.74***	5.43***
	(0.000)	(0.000)	(0.000)	(0.006)	(0.000)	(0.089)	(0.015)	(0.03)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)

Observations	54	44	37	35	32	31	27	35	32	35	32	34	34	30
Adj. R-squared	0.54	0.68	0.71	0.71	0.71	0.69	0.71	0.61	0.82	0.81	0.81	0.76	0.82	0.85

Notes: Dependent variable: Cognitive Skills, average test scores 1964 to 2003. Early numeracy: ABCC 1820; Early land inequality: Gini coefficient; Institutional quality: Polity 2; Fertility: refers to 1950; Fractionalization: Index from Alesina et al. (2003); Population density and GDP/c are in logs; Specifications (8) to (14) are weighted by the square root of population numbers of each country. Models 8 and 9 were estimated with R-command mlrobust and the option weights=popsqrt to include weights by population. Robust p-values in parentheses: ***p<0.01, **p<0.05, *p<0.10

Figure B.3: Cognitive Skills and Growth across World Regions



Source: Hanushek and Woessmann (2012a) Notes: Region codes are East Asia and India (ASIA), Central Europe (C-EUR), Commonwealth OECD members (COMM), Latin America (LATAM), Middle East and North Africa (MENA), Northern Europe (N-EUR), Southern Europe (S-EUR), Sub-Saharan Africa (SSAFR).