Farmers at the Heart of the "Human Capital Revolution"? Decomposing the Numeracy Increase in Early Modern Europe

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Abstract: Did the early development of skills and numerical abilities occur primarily in urban centers and among the elite groups of society? In this study, we assess the human capital of different occupational groups in the early modern period and partially confirm this finding: the skilled and professional groups had higher skills than persons in unskilled occupations. However, there was another large group that developed substantial human capital and represented around one-third of the total population: farmers. By analyzing numeracy and literacy evidence from six countries in Europe and Latin America, we argue that farmers significantly contributed to the formation of human capital and, consequently, modern economic growth.

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JEL: J13, J24, N30, O14, Q12

Acknowledgements: We thank Luis Bértola, Price Fishback, Beverly Lemire, David Mitch, Jan Luiten Van Zanden, participants in the WEHC and EHES congresses and the members of the Tuebingen economic history research group for their useful comments on an earlier version. The NWO (Clio Infra Project) provided financial support for the collection of some of the background data. The data support and useful comments provided by Gregor Babrowski, Daniel Grad, Sarah Hueller, Ana-Carmela Melone, Jan Neu, Frank Neupert and Carolina Vicario are gratefully acknowledged. We thank Gerhard Tollnek for his graphical support.

Introduction

A'Hearn et al. (2009) observed an enormous increase in numeracy in early modern Europe between the fifteenth and eighteenth centuries, which preceded the Industrial Revolution. They studied the numeracy development in a number of European countries using the ABCC index, which is based on the share of people able to report their ages exactly.[1] Modern evidence indicates that this heaping idea can be used to develop an indicator of basic numeracy. This method considers the share of individuals who are able to state their precise age on an annual basis, in contrast to those who report an age rounded to a multiple of five (stating, for example, "I am about 35" when they might be 34 in reality). Numeracy increased from below 50 per cent before 1500 to more than 90 per cent in the nineteenth century (figure 1). This was the most rapid increase in human history observed until now, hence some authors termed it the "human capital revolution"[2] (Baten 2016).

[Insert figure 1 here]

This substantial increase in numeracy did not occur as early in other world regions. We

[1] The age-heaping technique to measure numeracy is explained in greater detail in section 3. The name of the ABCC results from the initials of the last names of A'Hearn, Baten and Crayen plus Gregory Clark's who commented on their paper.

[2] This is a true revolution because the nearly 50-per cent increase is comparable to the difference between the poorest and wealthiest economies of the early twentieth century (Crayen and Baten 2010: South Asia had a numeracy of 52 per cent in the 1940s, whereas the wealthiest countries had achieved full numeracy). Thus, Europe was transformed from a half-numerate into a mostly numerate continent during this revolution. The differences between the European regions are also interesting: Southern Europe evolved the fastest in the late Middle Ages, but the well-known overtaking of Northwestern Europe is also visible in the numeracy record. Africa and most of Asia did not experience a strong increase in numeracy until approximately 1800. Thus far, we know little of conditions in East Asia or North America, but China's position declined circa 1860. In Latin America, there was a trend towards increasing numeracy, but this continent also partially declined in relative numeracy after 1800 (relative to Europe).

would like to more thoroughly understand this dramatic change, as it is arguably one of the core developments in human history.[3] A potential strategy to gain insights into the process of this educational revolution is to disaggregate the population by occupational groups and answer the following question: Which occupational groups served as the basis for the early modern human capital revolution? Based on the emphasis that numerous studies place on urban skills, the most likely candidates would be urban occupational groups such as merchants or skilled craftsmen (Epstein 1998, van Zanden 2009, Minns and Wallis 2012). In a similar vein, Gregory Clark suggested that the wealthy and 'capitalist' groups of society provided their offspring with favorable skills. We expect that numeracy and literacy were crucial to the successful completion of an apprenticeship. Houston (2002, p. 146) summarizes this stating a "generally superior literacy of towns and cities". On the other hand, other scholars argued that also rural populations experienced a strong increase in education (Graff #). A closer look might provide a large value added. Therefore, our initial hypothesis is the following:

(1) The early human capital revolution primarily occurred in urban centers. The relatively well-educated groups of craftsmen, traders and professionals took the lead, whereas the farming (and unskilled) population groups followed after a long delay.[4]

While we partially confirm this hypothesis below (skilled urban residents developed well), there could be a second hypothesis about farmers:

(2) Farmers had developed substantial human capital by the eighteenth century. They were roughly on par with craftsmen and – as their population share was large –

[3] In this study, we will not discuss whether it was the cause or the consequence of institutional developments, trade and high wages (see Acemoglu et al. 2005, Allen 2003).

[4] We refer to "farmers" or the "farming group" here as those individuals whose livelihoods came from farming activities. Thus, these individuals had medium-sized or larger farms or lived at least self-sufficiently. Persons for whom the information indicated that they did not control land were not included in the farmer category. We did not include day laborers or servants who might have worked or lived on a farm. In section 5, we discuss the heterogeneity of the farmer group and construct subcategories.

substantially contributed to the early modern human capital revolution in Europe.

The theoretical model behind this second hypothesis is the following: the proximity to food production implied that farmer´s offspring did suffer less from malnutrition, which was an obstacle to cognitive development. We present evidence about the relatively low level of protein malnutrition of farmers. We assess the relative numeracy of farmers using the now-established method of age-heaping analysis. In our analysis, we include a number of countries in Europe and Latin America: Austria, Germany, Spain, Southern Italy, and Uruguay. We intentionally include a New World economy to which Europeans emigrated in substantial numbers, as emigration was an option available to many Europeans during this period. Considering only those who remained in Europe could be regarded as analyzing a biased sample. To assess the education of farmers using an additional human capital indicator, we also compare literacy evidence from Switzerland and Northern Germany. Our strategy to assess these hypotheses is to consider evidence from the early modern period – primarily the eighteenth century – that contains both age and occupation and study the relative positions of farmers and other occupational groups. Focusing on the numeracy towards the end of the revolutionary process (but before it ended in the nineteenth century) has the advantage of allowing us to create a robust database with substantial variation. If we assume that initial levels were low for most of the occupational groups before the human capital revolution began, we can interpret an increase in the numeracy of the groups as a result of this process. In a final section, we present preliminary evidence on occupation-specific numeracy before the early modern human capital revolution – while also highlighting the limitations of these early sources.

How did we select the sources for the study? Analyzing early modern data also has the advantage of allowing us to consider the period before the Industrial Revolution. Thus, if there was a causal relationship between human capital development and the Industrial Revolution, the direction of causality would be clearer. We collected all available evidence that contained both occupation and age statements for this period.

[Insert table 1 here]

A further requirement that we considered was that our sources should not be socially selective, but instead the recording personnel sought to interview every individual in a given regional unit (specifically, every male, as we decided not to include females in our analyses[5]) (table 1). The third requirement was that the sources should not be substantially regionally biased. Thus, we included various regions of a given country and urban and rural locations. However, for Italy we were only able to representatively address the southern part of the country. Consequently, our results are informative on the southern part of Italy. Unfortunately, for some of the European countries, no sources were available that included both age and occupation. For example, Russian and Polish sources do not contain occupational information and could thus not be included in our study (Baten and Szoltysek, 2013). However, by applying these strict criteria, we were able to nevertheless cover a substantial set of countries.

[Insert Table 2 here]

How representative are the countries included of the European human capital landscape, including European settlements in the New World? We provide insights into the study's representativeness by comparing the list of countries included in our study with the distribution of European numeracy during the early nineteenth century (Table 2).[6] The Scandinavian countries had already achieved complete basic numeracy by approximately 1820, while the Western European countries were close behind. In contrast, Eastern Europe and parts of Southern Europe exhibited a substantial deficit. Comparing our sample countries (indicated by bold letters in the table) to this distribution, we find that our data were

[5] This was done because it was less clear whether the occupational statements of females reflected their real situation. Some of the females might not have reported an occupation even if they worked jointly with their husband in this occupation. Including all female occupations yields nearly identical results, as can be seen in an earlier working paper version of this study.

[6] A comprehensive set of numeracy estimates for the period before the 1820s does not exist.

representative of the middle three-quarters of European countries and European settlements, sorted by numeracy. We are able to consider the share of the European distribution that ranges between Switzerland and Uruguay in our study.

1. Literature review and theoretical model

Between the eighteenth and twentieth centuries, the world changed fundamentally, from a world of agriculture to a world of industrial and service sector employees. During the twentieth century, the agricultural sector suffered from low income and declining shares of national output. Industrialization was the key to income growth, and economists and economic historians subsequently used the share of the employment outside agriculture as a proxy indicator for income.

In prior studies, the authors often assumed that the basis for economic growth and increasing income emerged almost exclusively in urban centers; Bosker, Buringh and Van Zanden (2013, p. 1418) stated that numerous authors who analyzed long-term trends in economic development empirically employed “the number of cities, or urbanization rates as the most reliably available proxy of economic success”. Acemoglu et al. (2002, p. 1232), for example, used urbanization in 1500 as their “main measure of economic prosperity”, presuming a strong relationship between per capita income and urbanization. Consequently, Acemoglu et al. (2005, p. 552) employed urbanization as a proxy indicator for GDP per capita. North and Thomas (1973, pp. 114–5) assumed that the Western World experienced “a decline in productivity in agriculture, constant productivity in manufacture and increasing productivity in the transaction sector of the market” during the sixteenth century. All of these assumptions and proxy indicators imply declining productivity in rural areas, while growth in urban sectors was set to be equal to total income growth. This literature tends to support our hypothesis (1) that urban population groups were the sole driver of the enormous increase in human capital in early modern Europe. Does this reasoning also apply to the early modern period? How educated were farmers before the Industrial Revolution fundamentally changed the world? While the history of education has succeeded in obtaining a wider variety of insights, there is not much evidence about occupation-specific human capital in continental Europe.

Recent research stressed the impact of nutrition on cognitive skills (Baten, Crayen, Voth, 2014). For example, during the “natural experiment” of the Napoleonic blockade in the early 1800s, the cognitive ability and hence the numeracy of the British “blockade cohorts” was lower. Those who suffered the most from this episode during their first decade of life subsequently developed lower numeracy rates than others and thus were only able to find work in low-income occupations when competing with cohorts born before or after them.[7] This development was the more pronounced the more vulnerable an English county was.[8] One of the least vulnerable population groups during the early modern period were farmers, as they could decide to consume a certain share of their products, even in periods of famine. During famine periods they were able to sell a lower share of their products on the market such that their family would have a more or less sufficient amount of food to consume. Farmer children had a clear advantage relative to other occupational groups that had no direct access to nutrition in times of crisis. Consequently, we argue that the nutritional proximity advantages of farmers allowed their offspring to develop significant cognitive abilities in a very stable and persistent manner. Thus, farmers were able to develop favorable cognitive skills – and numeracy – that have not been recognized by previous research.

One strategy to assess the relative nutrition of farmers has been the anthropometric history method. Most scholars who were able to differentiate between occupations in their

[7] Myers (1976) also finds a strong relationship between numerical skills and earnings.
[8] Baten et al. (2014) considered counties with a higher share of farmers or above-average income earners to be less vulnerable. Farmers were able to live self-sufficiently and thus suffered less from external shocks. Above-average income earners could afford to buy a sufficient amount of food even in high-price periods.

studies, particularly those that could determine parental occupations, found that farmers and farmers' sons were significantly taller than individuals from other occupations (figure # for example, see Floud, Wachter and Gregory 1990, Komlos 1987, Humphries and Leunig 2009, Baten 1999, 2000).

One reason might be that farmers gained high incomes during the early modern period. We have to admit that we cannot disentangle the relative importance of this hypothesis relative to the nutrition and child labor hypothesis, because there is no dataset that combines age, occupation and income in the early modern period for continental Europe. The evidence about farmer incomes in early modern continental Europe that are directly comparable to urban skilled artisanal incomes is too scarce to draw inferences. Even if farmers had enough income to pay for schools or for private teachers, the logistic situation of rural areas was more adverse than urban environments, where children and teachers could meet more easily. This logistic factor would support the role of nutrition being more favorable for farmer children. Moreover, social differences grew in the countryside over the early modern period. Rural day laborers and rural craftsmen did not have income to support schools, and schooling needs a critical mass of pupils in rural areas, as there were scale effects. A potential additional factor could be the work load imposed on children. Quite likely, the children of the poor suffered more from work during early youth, which certainly prevented them from learning, inside and outside of school.

However, were numeracy and education at all desirable in an agrarian economy? Would education not be a burden if a farmer were required to perform dull and manual tasks in the field? We would argue that while a high share of manual labor is clearly characteristic of farm work, numeracy could increase productivity. A productive farmer was a person who would consider numerous weather indicators, for example. An incorrect decision regarding the specific day when the hay cutting or the grain harvest should begin could cause substantial income or welfare losses for the farming family. In addition, the treatment of cattle diseases and the protection of crops against insects and parasitic plants were more efficient if a farmer was more educated and numerate (on fertilizer use, see Huffman 1974). Moreover, farmers who were able to count could negotiate the prices for their goods with intermediaries or directly with consumers on the market. While this is more of an advantage for larger farmers, smaller subsistence farmers also had incentives to be numerate: Zuijderduijn and De Moor (2012) demonstrate that smallholders in the Netherlands who lived in a market town and possessed at least a house or a small piece of land actively participated in asset markets. Houston (2002) outlines that with the increase in trade and commercialization during early modern times, farmers with an interest in profits started to keep account books and followed price changes on the markets. Being able to count strongly increased their chances of participating in such activities.

Further evidence of farmers being educated is provided by Lorenzen-Schmidt (2002), who mentions the existence of loans between peasants in Northern Germany from at least the sixteenth century onwards. Stoklund (2002) describes the existence of ‘Weather-books’ in Denmark that contained not only guidelines for weather forecasting but also practical advice on farming, which were written by peasants and first published in the sixteenth century. A better understanding of the environmental conditions required to maximize output is a strong motive for farmers to acquire basic skills.

Clearly, counting skills would also have been advantageous for a laborer. However, we conclude from the anthropometric literature that only farmers could provide a degree of nutritional quality to their children sufficient to obtain the required cognitive preconditions.

In summary, we argue that farmers – a group that represented a substantial population share, as we will describe below – had the advantage of sufficient food security, as they were able to determine the share of their products that they would sell on the market. The Church and feudal lords initiated legal attempts to constrain farmers’ decision making, but the farmers found means of concealing a share of their production. In addition, as discussed in this section, basic numeracy provided benefits for farmers, and we arrive at the conclusion that the myth of the farmer who only engages manual labor is clearly an oversimplification.

However, the question remains: In which way did farmers and other groups of rural population acquire their basic education in times in which schooling was rare, particularly in rural areas? As many numeracy studies conclude, basic numeracy is not only obtained in schools, but prominently in the household, if, for example, children play games that stimulate their numeracy (Baten et al. 2010). Any child that does not suffer from malnutrition, enormous child labor or other constraints, develops a natural curiosity and wants to learn a certain amount (Reis (#) emphasizes the joy aspects of learning).

A large strand of the literature focused on the regional and religious differences in education. Among the countries studied here, the educational situation of the northern and western countries was better than for the southern and eastern areas. In many of the German states, the educational situation was relatively favorable in terms of schooling. A further, intermediate group consisted of Spain and the Habsburg Empire. Southern Italy, on the contrary, belonged to the least favored European regions related to formal education (Houston 2002, pp. 52-53).

In general it is possible that Protestantism has a positive influence on numeracy. Houston (2002) repeats that Protestants were usually better in reading and writing than their Catholic counterparts (see also the large literature for example Becker and Woessmann 2009). For Protestants, reading books – particularly the Bible – was an important part of their faith. However, Houston (2002) notes that there also were some Catholic areas with high literacy levels. Therefore, we also test for the impact of religion in the German data below.

2. Data characteristics and potential selectivity issues

The dataset we use for the age-heaping analysis contains data from five countries in Europe and Latin America: Austria, Germany, Spain, (Southern) Italy and Uruguay. In the numeracy analysis, we only include individuals aged between 23 and 62 and born in decades from 1700 to 1800. To complete our analysis, we use evidence on literacy from Switzerland and Northern Germany. The Swiss and German data for the literacy analysis cover the birth decades 1560 to 1730 to guarantee a sufficient number of observations.[9] It would have been possible to include England as well, but this would have exceeded the format of an article, given that the literature on England is extremely well developed. We restrict our analysis to male individuals to ensure that we only measure the variation between occupational groups, not gender-related differences. Moreover, it is possible that the occupational statements of women tend to reflect their husbands' occupation.

[Insert table 3 here]

With a total number of 24,025 observations (table 3), this comprehensive dataset provides us with the possibility to study the differences in basic education between various occupational groups.

[Insert table 4 here]

Because the process of numeracy formation within farming groups is a core issue of our study, a sufficient number of farmers and other farming-related occupations is important. With a total number of 6,154 individuals with farming occupations (table 4, A), this analysis is feasible on a broad and representative basis.[10] The large group of farmers is subsequently divided into a group of medium-sized or larger farmers and another representing smallholders (table 5).

[9] To make the data comparable, we divided the Swiss data into two main periods for the analysis of reading skills, 1560-1650 and 1660-1730. Furthermore, we include those aged between 23 and 72 to guarantee a sufficient number of observations in the groups. Concerning the acquisition of literacy skills, age does not play an important role as it does in the case of numeracy. However, to test the robustness of the chosen age range, we also performed the literacy analysis with restricted to those aged 23 to 62; the results remain unchanged in sign and significance level; there is only a minor change in the size of the coefficients.

[10] 'Farming occupations' does not relate to servants or day laborers who might work on a farm.

[Insert table 5 here]

The datasets on the various countries stem from surveys in which information on families and households is reported. Our sources originate from governmental censuses on the one hand and from church censuses ("Libri Status Animarum": soul registers) on the other (table 1). The only difference between those two types of sources is that the governmental surveys include the entire population of a given place or region while the church censuses only include members of a certain confession. Nonetheless, this difference is negligible because the territories under study were religiously homogenous. In German Protestant and Catholic territories only one of the religious groups was represented in a given territory.[11] In Switzerland and Northern Germany, priests visited the families in their homes and asked them explicitly about their reading and writing skills, which they had to prove in most cases. This allows us to study literacy by occupational group. The data we include from the censuses taken by the church or the local government are not socially selective to a significant degree. However, we need to carefully discuss the possibility of regional selectivity. The countries in our dataset are represented by a substantial number of regionally diverse observations, even if the availability of sources generates a stronger focus on certain regions in some of the countries (figure 2).

[Insert figure 2 here]

Italy is represented by its southern regions, primarily covering rural areas and villages and a small city, Monteleone.[12] For eighteenth century Southern Italy, the data are fairly representative, as various regions are included. The German age-heaping evidence contains data from throughout the country, including its southern, western and northern regions. We have slightly more evidence from the northern region because a larger number of sources on

[11] We have German data on Protestants and Catholics. But there is only one of the religious groups per place included, meaning that we do not have substantial religious minority groups within one place.
[12] A city is defined as a location with more than 5,000 inhabitants.

the north were available. All of the German regions contain rural observations and villages. For the south and the north, the data include one city each, Ludwigsburg and Kiel. The German data on literacy skills stem from a rural parish in Lower Saxony in Northern Germany, Abbehausen. For Spain, we have data from several provinces of the country, including its northeastern, central and southern regions. The data cover a number of rural areas and villages and two representative cities, one in the center of the country, Toledo, and another in the south, Granada. Granada had a substantial service sector that was important for trade and administration, while Toledo was a center for the production of swords and other metal-related products. The Uruguayan data stem from three different provinces in the south of the country, including both rural observations and urban observations from Montevideo. As the country was rather scarcely inhabited in the northern region during the period considered, the population from the southern areas can be considered representative. For Switzerland, we have literacy evidence from the canton of Zurich, which lies in the center of the country, containing a number of rural locations.

To assess the representativeness of our data, the map (figure 2) contains the numeracy levels of the European countries in the 1840s and the location of the urban and rural places in our data. It is clear that urban and rural observations are relatively scattered across the educational types of regions within the countries considered. Where only data from a single urban place were available (as in Southern Italy), it was located in the center of the rural regions, and hence the urban and rural samples are comparable. Because we are principally interested in occupational differences, slight deviations from regional representativeness should be less crucial, but we need to take care that the urban and rural sample components are appropriately weighted.[13] By weighting the observations, we ensure that a potential

[13] The samples are weighted such that urban observations precisely represent the respective urban shares of the countries in the early modern period. Thus, the rural observations receive a higher weight to ensure that the

oversampling of urban observations, for example, does not lead to an overrepresentation of urban occupations.[14]

The classification we use to organize the occupational groups is based on the HISCLASS and Armstrong scheme (1972). The Armstrong scheme suggests six different occupational categories. The professionals, primarily individuals with a higher education, are represented in the first group, the most prominent examples of which would be large merchants, doctors and lawyers. Additionally, the remaining members of the upper strata of society were included in this group (mayors, the nobility). Individuals with occupations such as administrators and clerks represent the second group, the semi-professionals (or intermediate). The third group contains skilled persons who typically completed several years of apprenticeship, including blacksmiths, craftsmen and persons with similar professions.[15] In the following section, we categorize partly skilled individuals, such as herdsmen (who do not own animals), rope makers, and carriage drivers in the fourth group. Unskilled persons without any education, such as servants and day laborers, are classified into the fifth group.

Finally, the individuals with farming occupations are allocated to their own category.[16] Differentiating whether a person is a farmer or a large landowner, for example, is achieved using the term employed in the respective language. Typically, a large landowner was indicated by different term than a farmer. If we consider the Spanish census, for example, a

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urban samples are not overrepresented. For additional information on the urban shares, please see our Internet Appendix A.

[14] Due to data availability, urban locations are oversampled in Germany, Austria and Spain, whereas the Southern Italian data approximately represent the appropriate urban share.[14] If we apply representative, country-specific weights to the samples, the share of farmers increases to approximately 32 per cent in Austria, 25 per cent in Germany and 24 per cent in Spain, while Southern Italian farmers represented 53 per cent of the occupational groups. Overall, the share of farmers amounts to approximately 31 per cent in all of the European countries considered in this study (table 4, C).

[15] When assigning individuals to the occupational groups, we followed Armstrong's suggestion and accounted for the numbers of servants a person employed. For further information, see Internet Appendix D.

[16] Large landowners, in contrast, are assigned to the professional group.

farmer, as we define the term in this study, was always indicated by the word "*Labrador*", while a large landowner would be indicated by the word "*Hacendado*". In contrast, persons indicated as "agricultural laborers", who may have also had a small garden at their disposal but one not large enough to provide subsistence, were classified into the unskilled group, following the term "laborer" or "worker".[17] The farmers, however, were able to nourish themselves and their families, even during times with higher food prices, while persons from lower social classes suffered from malnourishment during such periods (Appleby 1975).

Among the individuals included in the dataset, approximately 6 per cent were professionals, 9 per cent semi-professionals (intermediates), about 26 per cent were skilled laborers, and 26 per cent were farmers. Approximately 33 per cent of the overall population consisted of unskilled or semi-skilled persons (table 4, B).

The HISCLASS scheme (developed in the HISCO project) considers not only the task of the occupation by industry, but also the skill level, the level of supervision, and whether the job requires manual or non-manual tasks (Van Leeuwen and Maas 2011). It is a newer approach, hence it might seem logical at first glance that it could be applied here as well. HISCLASS consists of twelve major groups. In our case these need to be aggregated into seven groups because some of the highly skilled groups were represented by very small numbers in our sample: higher managers and professionals; lower managers and professionals, clerical and sales personnel; foremen and skilled workers; farmers and fishermen; lower-skilled workers; unskilled workers; lower-skilled and unskilled farm workers (Maas and Van Leeuwen 2005, p. 3). Divided into seven major groups, the HISCLASS scheme resembles the Armstrong groups to a large extent apart from the division into manual and non-manual labor.

[17] When distinguishing between occupational groups, we were forced to rely on the expressions used for the occupations in the original surveys. The groups are formed as homogeneously as possible based on the translation. In the case of Southern Italy, the differentiation between an agricultural worker and a farmer is not as clear-cut as in other countries (see Galt 1986). For all of the other countries, the difference between the terms for laborer and farmer is clear from the definitions of the labels.

However, there are slight differences between the schemes: First, HISCLASS differentiates between unskilled workers and unskilled farm workers. As in our data the vast majority of workers (or, mostly “day laborers”) is not further defined, it is very difficult to decide whether a person works on a farm or for a rural craftsman. One potential, but not satisfactory way to address this problem is to keep the workers in urban areas in the unskilled (non-farm) group, and allocate all rural (unskilled) workers to the “unskilled farm group”. However, this ignores that many worked for rural craftsmen. It also leads to a bias of the “unskilled non-farm group”, as this group contains only urban individuals that generally have higher skill levels than rural individuals. The second option is to assign all of the day laborers to the unskilled workers. As we assume that none of the two options correctly represents the unskilled (farm) workers, we think that the Armstrong groups are actually better suited for our dataset. Second and even more important for our study, small subsistence farmers are assigned to the group “lower and unskilled farm workers” in HISCLASS. Hence, there is no differentiation made between a poor day laborer who works on a farm and a small subsistence farmer who has at least a small piece of land at his disposal and some animals, for which he has the decision power. The subsistence farmer clearly has more responsibility than an unskilled farm laborer. We therefore arrived at the conclusion that the Armstrong scheme is better suited for our analysis (see also appendix H in which we calculate HISCLASS categories for Spain).

3. Methodology

To assess our hypothesis that farmers enjoyed numerical advantages, we perform several steps of analysis. First, we conduct descriptive analyses in which we measure the human capital levels of the various occupational groups and countries using the age-heaping technique. Second, we analyze literacy by occupational group to test our hypothesis using an additional human capital indicator. Third, we conduct regression analyses to determine the significance of our results.

We employ the age-heaping technique as an estimator of numerical skills. The underlying concept is that in less developed countries of the past, only a certain share of the population was able to precisely report their own ages when they were asked to do so. The remaining population stated ages ending in a zero or five, for example, 45 when they were in reality 44 or 46. The resulting age distribution typically spikes at ‘round’ ages ending in a five or a zero, while other ages are underrepresented, which does not reflect the true age distribution. We are able to calculate the percentage shares of the rounded and the precise ages using an index, such as the Whipple.[18] The Whipple index measures the proportion of individuals reporting a rounded age, under the assumption that only 20 per cent, or one-fifth, of all ages end in a five or zero in the true age distribution.[19]

$$(1)\ Wh = \left(\frac{\sum (n_{25} + n_{30} + ... + n_{55} + n_{60})}{\frac{1}{5} * \sum_{i=23}^{62} n_i} \right) \times 100$$

For a more intuitive interpretation, A’Hearn, Baten, and Crayen (2009) developed the ABCC index, which is a linear transformation of the Whipple index. It yields an estimate of the proportion of individuals who report their age correctly:

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

Of course, age heaping based indicators are not immune to potential biases. One concern could be, whether the census taker influenced the level of heaping, for example, by

[18] A’Hearn et al. (2009) found that this index is the only one that fulfils the properties of scale independence (it delivers comparable results for two samples with the same heaping patterns but different sample sizes) and reliably ranks samples with different degrees of heaping.

[19] A value of 500 results in an age distribution with ages ending only on multiples of five, while a value of 100 indicates no heaping patterns on multiples of five, meaning that precisely 20 per cent of the population reported an age ending in a multiple of five.

correcting age statements that seemed implausible to him.[20] Another doubt could refer to questions such as ‘Do you know your year of birth?’ in case the person seemed not to know his (precise) age. If the person knew his correct year of birth, the interviewer would – in case he was numerate – be able to calculate the exact age. If ambitious census takers asked for more detailed information and received it, it is possible that we observe numeracy on the upper bound of the strata (on literacy estimates see Núñez 2003).[21] In this case, the interpretation of differences between occupational groups is still valid. However, it is unlikely that such questions led to more precise age statements for several reasons. First, in societies with considerable heaping because of age non-awareness, it is likely that people did not know their exact year of birth either (Crayen and Baten 2010a). Second, A’Hearn et al. (2009) show that even when individuals were asked for both age and year of birth, such as in the US census of 1900, considerable age heaping was still present. In fact, it did not make any difference. Last but not least, we find substantial differences between occupational groups and regions; if all of the people would have known either their age or year of birth precisely, and the interviewer helped them calculate, we would not be able to measure any differences between occupational groups.

The share of persons able to report an exact age is highly correlated with other indicators of human capital, such as literacy and schooling, across countries, individuals, and over time (Bachi 1951, Myers 1954, Mokyr 1983, A’Hearn et al. 2009). A’Hearn et al. (2009)

[20] A potential hint therefore could be, if many statements were crossed out and corrected by different numbers. However, this is not the case in the original documents we were able to look through. Moreover, if the age-heaping results were influenced by the individual numeracy level of the census taker, the results of different censuses should vary within one region or country for the same birth cohorts. However, in their large sample of different countries, Manzel and Baten (2009) find that the results of different censuses display very similar levels of age heaping for the respective birth decades. Manzel, Baten and Stolz (2012) also find evidence in favor of the self-reporting of individuals, which is based on results from the 1744 census of Buenos Aires. Related to a certain person who reported to be 30 years old, the interviewer noted, “[…] but looked considerably older” (Manzel et al. 2012, p. 940). More information on potential biases is provided in Internet Appendix C.

[21] Núñez (2003) finds that in many surveys people were asked for their reading and writing skills, but they usually did not have to prove them. Hence, the sole answer “yes” to the question about reading skills or the ability to sign a document, when the people were in fact not able to read or write a text (and understand it), might lead to the observation of upper-bound estimates of literacy.

observed a very close relationship between illiteracy and age heaping for less developed countries after 1950.[22] The correlation coefficient with illiteracy was as high as 0.7, while the correlation with the PISA (Programme for International Student Assessment) results for numerical skills was as high as 0.85. Consequently, the Whipple index is more strongly correlated with numeracy. This has been analyzed for a large number of countries, and the correlation was consistently statistically and economically significant.[23]

To determine the differences in the numerical skills via a regression analysis, we create a binary variable "numerate" that takes a value of zero if the person reported a rounded age ending in zero or five and, otherwise, a value of one for the numerate. Clearly, 20 per cent of the population may have correctly reported ages ending in zero or five. To account for this bias, we proceed as follows: The regression coefficients reflect the case in which the dependent variable's conditions are met ("numerate"=1), meaning that the person reported an exact age. However, we know that this outcome only represents 80 per cent of those who reported their age correctly, as 20 per cent of those who reported a multiple of five ("numerate"=0) were also doing so correctly. Thus, they should be counted as 'successful'. By increasing the coefficient of the accurate responses by 20 per cent, we account for the downward bias of correct age statements ending in a zero or five. We achieve the additional 20 per cent by multiplying the coefficients by 1.25 (and by 100 to obtain percentages).

In the regression analysis, we include the occupational groups, the countries and the birth half-century dummy variables as independent variables to control for possible changes in numeracy over time and across space.[24] As there are both Protestant and Catholic areas in

[22] See A'Hearn et al. (2009), Appendix available from the authors.
[23] See our Internet Appendix C for further references. For a very detailed overview of the age-heaping technique, see also Tollnek and Baten (2014).
[24] All of the regressions only contain individuals for whom an occupation was reported in the survey. Those without an occupation are dropped to avoid collinearity. We also control for individual age because younger individuals tend to know their ages more precisely, whereas older individuals might exaggerate their ages (A'Hearn et al. 2009).

the German data, we also include a dummy variable "Protestant" in the German regression. Moreover, we perform the regression analyses using sampling weights to correct for possible biases due to rural-urban composition issues as mentioned above. By applying the sampling weights, we ensure that our regressions represent the actual urbanization rates and thus the correct ratios of the occupational groups of the countries in the respective period.[25] The robustness check without sampling weights delivers relatively homogeneous results: the coefficients under certain modifications change slightly, whereas the significance remains.[26]

4. Human capital of farmers and other occupational groups

In this section, we measure the ability to count approximated by a person's ability to report his age correctly in a survey. Under normal conditions, we expect the occupational groups with higher incomes and social status to correlate with higher values of human capital relative to groups with lower social status. This finding holds for the weighted ABCC values of all the countries in the age-heaping dataset. The values of the professional groups are consistently higher than those of the partly skilled and unskilled individuals (figures 3.1-3.5).[27]

[Insert figures #.1-#.5 here]

While these results reflect our expectations regarding occupational differences in numeracy, there is one phenomenon that deserves particular attention. In nearly all of the countries in our dataset, the farmers have fairly high ABCC values. The farmers' values are,

[25] For further information, see Internet Appendix A.

[26] Another problem may occur when implementing logit regression models because we cannot control for those individuals stating an exact age (not a multiple of five) incorrectly. As this type of bias may be more problematic in logistic models than in linear models, we also estimated all of our regressions using an Ordinary Least Squares (OLS) model (see, for example, Hausman 2001). We find that the relative proportions and the significance of the coefficients remain nearly the same as those in the logit models. Consequently, we can assume that this type of bias is negligible.

[27] In Germany, there is no large observable difference among the intermediate, skilled, partly skilled and unskilled individuals, which might be the case because the ABCC level is already relatively high in general.

in most of the countries, equal or similar to those of the skilled group.[28] This is the case for Austria, Spain, Southern Italy and Uruguay. In Germany, the value obtained for the farmers is higher than that of the skilled and unskilled groups and similar to the value of the professional group.

To check the robustness of our observation of favorable farmer numeracy, we use Swiss and German data on literacy as further measures of human capital.[29] In figures #.1 and #.2, the ability of Swiss persons to read is displayed for the birth decades from 1560 to 1650 and from 1660 to 1730, respectively.[30]

[Insert figures #.1-#.3 here]

As stated for the ABCC values of the other countries, we observe a difference in reading ability between the two highest groups and the unskilled and partly skilled groups. Again, the farmers exhibit higher values than most of the other groups. The same trend is observable in the literacy data from Northern Germany (figure 4.3). In general, the literacy level of Germany and Switzerland seems relatively high in the seventeenth century. This might be due to the origin of the data, which stem from Protestant areas in Germany and Switzerland.

In summary, in all of the samples under study the farmers represent a large group with literacy and numeracy values above the partly skilled and unskilled, although a modestly sized elite of professionals and semi-professionals is slightly better educated, and the skilled craftsmen are on a similar level to that of the farmers.

In the following section, we estimate a set of logit regressions to determine whether the skill

[28] Because the farmers' ABCC values were relatively similar to those of the skilled group in most of the countries, we ranked them between the skilled and partly skilled.

[29] The Swiss and Northern German occupational groups are also constructed using the Armstrong taxonomy. Because there were no data available on the number of servants, the groups are exclusively based on the occupational information.

[30] On writing abilities, see our Internet Appendix A.

differences were significant and whether group composition effects could play a role (such as a higher share of one occupational group among subsequent cohorts). Models L1 and L2 include all of the countries for which age-heaping evidence was available, whereas L3 and L4 only include the European countries (table 6).

[Insert table 6 here]

If we examine models L1 and L2, it becomes clear that the two upper groups and the skilled and the farmers had a significant advantage over the two least skilled groups of society (the pooled reference category comprising the unskilled (L1) and partly skilled groups (L2)). Being a member of the professional class increased an individual’s likelihood of being numerate by approximately 17.6 per cent (model L2). Considering the European sample, a farmer had the second best chance for success in both models L3 and L4: his probability of being able to count was approximately 9.4 (L3) or 9.1 per cent (L4) higher than that of the two lowest groups. This coefficient is slightly higher than that of the intermediate individuals and approximately 2 percentage points higher than that of the skilled. If we also include Uruguay in the sample, the farmers have approximately the same probability of being numerate as the skilled group (approximately 8.7, model L2).

To determine whether the differences between the occupational groups are significant in each of the countries, we estimate logit regressions on numeracy for the individual countries. The weighted models for the European countries again confirm the above results (table 7).

[Insert table 7 here]

In Germany and Southern Italy, only the farmers and the professionals have a significant advantage over the reference category (table 7, models M2 and M3), while in the other countries the upper two groups, the skilled and the farmers clearly perform better than the two lower groups. In Uruguay, the size of the farmers’ coefficient is only slightly smaller than the coefficient of the skilled (model M5), while in Spain the farmers perform better than the skilled group (M4). In Italy and Germany, the farmers’ coefficient is higher than that of the skilled, which is not significant. Only in Austria is the farmers' coefficient clearly smaller than that of the skilled. Nevertheless, the Austrian farmers have a significantly higher probability of being numerate than the two lowest groups. In Germany, we additionally control for Protestantism, which has a positive but insignificant influence on individual numeracy when also controlling for the provinces.[31]

We find further evidence for our hypothesis of favorable skills among farmers using the literacy evidence from Northern Germany (table 7, model M6), for which we obtain very similar results. The probability of being able to read was approximately 45 per cent higher for a farmer than for an unskilled or partly skilled person – and thus also two per cent higher than for a person from the highest three groups taken together. Related to the reading abilities of the Swiss, we observe the same result as in all of the other regressions (M7). The farmers have a significantly higher probability of being able to read than the two lowest occupational groups, and their coefficient is again larger than the coefficient of the skilled.

5. The heterogeneity of the farmer group

As we classify the farmers into a single category, one could object that farmers are a fairly heterogeneous group, with small-scale subsistence farmers on the one hand and large farms with a high number of farmhands on the other.

To assess these potential objections, we examine the terms used for farmers in the various countries in the dataset in greater detail. These terms (such as 'Bauer', 'Häusler' and similar terms in other countries) might provide insights into the social structure of the farmer group. In most of the countries in our dataset one to three or four labels may indicate a farmer,

[31] We also calculated the ABCCs by religion and province (see Internet Appendix A). We find that the Protestant areas have on average higher ABCC values than the Catholic areas. However, the differences appear mainly between different provinces; in Baden-Wuerttemberg, for which we have both Protestant and Catholic data, the two groups have a very similar numeracy level. Consequently, we assume that the different values are, to a certain degree, due to regional differences. This is in line with Houston (2002) who notes that Catholic entities in Baden Wuerttemberg had literacy rates similar to those of the Protestants.

and the division into smallholders and medium-sized or larger farmers is relatively clear. However, we have to be more precise about the terms in Germany, as there is a greater variety than in other countries..[32] To adequately analyze the different categories of farmers, we construct subcategories following the most relevant terms (table #).[33]

In the Austrian dataset, we have two main subcategories: more than 83 per cent of the Austrian farmer group consists of those for whom the term "*Bauer*" is used, denoting medium-sized or larger farmers. In contrast, the subcategory of smallholders ("*Haeusler*", "*Halbbauer*"[34]) corresponds to approximately 16 per cent of the entire farmer group (Heinsius 1840).

In Germany there are a few terms indicating a farmer. The most prominent terms for the farmers in Northern Germany (Holstein) differentiate between smallholders ("*Kaetner*") and medium-sized or larger farmers ("*Hufner*") (Lorenzen-Schmidt 1996 and Heinsius 1840).[35] We decided to include the individuals with at least half of a "*Hufe*" in the medium-sized or larger farmer group and the ones with smaller pieces of land in the smallholder group. Because the division of partial "*Hufner*" is less clear-cut, we additionally control for different farmer groupings by including the individuals with at least 1/12 of a "*Hufe*" in the medium-sized or larger farmer group.[36]

In western and southwestern Germany several terms designate persons with larger or medium-sized farms ("*Ackersmann*", "*Landwirt*", "*Bauer*", "*Colonus*"). We contrast these

[32] In our analyses, we jointly consider farmers owning and renting their land, as their contemporaries considered control over land to be the most decisive criterion, and this control was also given for those renting the land. Moreover, 'ownership' was not a clear-cut concept in the early modern period in most continental European countries.

[35] The "*Hufner*" is denoted by the size of the land he owns or rents – the "*Hufe*". Heinsius (1840) notes that the "*Hufe*" consisted of 30 to 42 acres of land in most areas.

with a group of smallholders ("*Kaetner*" or "*Casettarius*") (Heinsius 1840).[37] In total, we identify approximately 71 per cent of the German farming group as medium-sized or larger farmers and approximately 27 per cent as smallholders.

In the Uruguayan data, the medium-sized or larger farmers are called "*Labrador*" and amount to 90.6 per cent. The group of smallholders "*Chacarero*" accounts for only 9.4 per cent because inhabitants of this Latin American country could often gain access to medium-sized farms. The only term indicating a farmer in Spain is "*Labrador*". He may be the owner of a larger, medium-sized or smaller farm. There was no special term for smaller farmers in Spain in the census.

The differentiation between medium-sized farmers and smallholders in Southern Italy is more complicated, particularly because of the land tenure structure in this region. On the one hand, there were a limited number of very wealthy landowners owning a large share of land. The smallholders, in contrast, were relatively poor (Galt 1986). In our dataset, we are able to identify two terms that can classify a farmer: "*Massaro*" and "*Bracciale*". While the former describes a yeoman, the latter relates to a smallholder.[38] Nevertheless, the differentiation between the two terms in the census does not necessarily reflect the actual position or wealth of the person. The only clear difference is that a "*Bracciale*" did not have herd animals by definition, whereas a "*Massaro*" generally did (Galt 1986).[39] Though the differentiation between the two subcategories is less clear-cut than in other countries, we assume that "*Bracciale*" stands for a smallholder, representing 92.7 per cent of the farmers, and a "*Massaro*" is a farmer with slightly more land, corresponding to 7.3 per cent of the Southern Italian farmers.

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[37] "Colonus" and "Casettarius" are the Latin words for "Bauer" and "Kaetner".

[38] The word "*Bracciale*" can also indicate an agricultural laborer who controls some land. Nonetheless, as Galt (1986) describes, the "*Bracciale*" in eighteenth century Southern Italy indicates a smallholder. In the twentieth century, the term only stands for a laborer.

Smallholders in Switzerland represent approximately 70.7 per cent, whereas the medium-sized farmers correspond to 29.3 per cent of the entire farming group. The distribution of the smaller and larger farmers here seems to differ from the observations of most of the neighboring European countries. However, a large number of the Swiss farming households in this area were engaged in dairy farming, which can be managed more efficiently in small-scale farming than on very large farms.[40]

In general, we observe a strong relationship between the medium-sized or larger farmers and the presence of servants in the households.[41] More than 91 per cent of all servants in the farming group worked on farms of medium or larger size, whereas the remaining share of the servants were reported to live in the households of smallholders (see Appendix A). This finding strengthens the assumption that there is a correlation between the labels for the medium-sized or larger farmers and the existence of capital in their households.

In the following, we analyze whether there are (significant) differences in the numeracy levels between farmer groups. Under normal conditions, we would *a priori* expect the medium-sized or larger farmers to have higher numerical skills than the smallholders.

[Insert figures 5.1-5.4 here]

The results in figures 5.1-5.4 reflect this assumption in most of the cases considered: in Austria, Germany and Uruguay, the smallholders have lower numeracy values than the larger farmers. For Germany, we also tested the results for alternative farmer groupings with a shift of about 4 per cent of the farmer observations from one group to the other. This is an important robustness test, as one could imagine the occupational classifications to be slightly arbitrary. However, the results remain almost the same as for the original farmer groups and can thus be considered robust (figure #).[42]

The same difference is reflected by the literacy values of the two farmer categories in Switzerland and Northern Germany (figures 4.1-4.3). However, the smallholders also have fairly high values, exceeding those of the lower skilled groups. The only country for which we cannot verify the expected difference between larger farmers and smallholders is Southern Italy. In this country, we observe the opposite relationship: the group of smallholders seems to have a higher numeracy value than the medium-sized farmers. However, as we noted above, the distinction between smallholders and medium-sized farmers in Southern Italy is less clear than that in other countries, as the average farm size was small for both groups.

[Insert table 8 here]

In a regression analysis for Switzerland and Northern Germany, the smallholders had a significantly lower chance of being able to read than the medium-sized or larger farmers (table 8, models F5 and F6). For all of the other countries, we do not find a significant difference between the two farming groups (models F1 to F4).

Hence, in Austria and Germany, the group of farmers does not seem to be as heterogeneous in terms of their numeracy, at least with respect to the hierarchy of terms used in the sources. While the difference between smallholders and farmers in Southern Italy and Uruguay seems to be relatively clear in the descriptive figures, there is no statistically significant difference in the regression model (models F2 and F4).

These findings are not necessarily surprising if we consider the incentives for the farmers to acquire certain skills: most of the smallholders also had control over land and animals and operated on their own account. The small holders thus had substantial motivation to provide numeracy skills to their offspring; as these needed to correctly calculate their prices or the size of their land. This is confirmed by the findings of Zuijderduijn and de Moor (2012),

[42] The same holds for the regression analysis (see Internet Appendix A).

who reveal that smallholders saved or invested capital. Moreover, as we previously argued, it is likely that factors such as nutritional advantages and permanent access to adequate nutrition could be an explanation for the high numerical skills exhibited by all the farmers. For England, Thirsk (1989, p. 735 and 2000, p. 166) outlines that milk production in the early modern period was primarily done on small-scale family farms. Thus, milk was included in the "poorer" farming family's diet. This finding provides further evidence in favor of our theory because nutritional advantages in terms of milk consumption not only relate to farmers with large holdings but also and especially to smaller family farms.

6. The situation before the early modern human capital revolution

Theoretically, one could imagine that farmers had a high numeracy level before the human capital revolution. This would be a potential contradiction to our hypothesis (2), as under this assumption the numeracy increase could only be attributed to the other large population groups, the professionals/ intermediates/ skilled and the partly skilled/ unskilled. Even if this might not seem *a priori* plausible, we prefer to assess this possibility of high initial numeracy among farmers.

Therefore, we ask: Was the relatively favorable situation of the farmers always the case? How did the occupational groups rank before the human capital revolution began? Unfortunately, there are very few sources that list both age and occupation from the fourteenth and fifteenth centuries. One exception is the famous Catasto of Tuscany in Central Italy of 1427. The Catasto was performed with the aim of collecting information about the tax revenue of the population. Included are the important city of Florence and some other cities in Central Italy. The largest part of the data stems from rural areas in Tuscany. Given the low percentages of unskilled workers, it is possible that this type of census is slightly more socially selective than a census performed with the aim of counting the population.[43]

Regarding the descriptive analysis, we find that farmers in Central Italy were certainly not on par with skilled craftsmen; on the contrary, the farmers had the lowest numeracy level of all of the occupational groups (figure 3.6).

[Insert figure 3.6 here]

The professionals exhibited the highest numeracy index with an advantage of nearly 20 per cent relative to the farmer group. The partly skilled occupations in Tuscany represented a relatively high level of numeracy. The individuals in this group were generally employed in the textile trades, which were unusually highly developed in Tuscany during the late Middle Ages (Herlihy and Klapisch-Zuber 1978). For other countries, evidence containing both ages and occupations representing a substantial number of observations of farmers has thus far not been found for the fourteenth and fifteenth centuries.

Given the results for fourteenth century Tuscany, it seems unlikely that farmers occupied a similarly favorable situation before the human capital revolution as they did in the eighteenth century. However, we must bear in mind the important caveat of the local nature of this early source. Clearly, more research is needed to identify additional sources for the fourteenth and fifteenth centuries containing both age and occupational information. Thus, we arrive at the preliminary result that the farmers significantly contributed to the human capital revolution before the eighteenth century. The farmers' contribution was at least as high as their population share (approximately one-third), but probably higher. If we compare the Italian ABCC values from the fourteenth century with the Italian evidence from the eighteenth century, the farmers seem to have increased their numeracy level by approximately 20 per cent (figures 3.5 and 3.6) The contribution of the professionals, intermediates and

[43] There are a number of individuals for whom no occupation is reported. See Internet Appendix A for the number of observations by group.

skilled might have been approximately one-third because this population group maintained or increased their numeracy advantage and represented approximately one third of the population. The partly skilled and unskilled occupations had a significantly lower numeracy rate than the other groups during the eighteenth century – i.e., towards the end of the human capital revolution. As they did not begin from a very low level, at least in the Italian case, and reached less impressive numeracy levels during the eighteenth century, we conclude that they probably contributed less than their population share (of around one third) to the human capital revolution.

7. Conclusion

The eighteenth century corresponds to the second – last phase of the human capital revolution: there were still substantial differences in numeracy between occupational groups and countries, but most of the transition was already accomplished. Using a new and large dataset containing several countries and more than 24,000 observations with information on occupations, ages and household members, we demonstrated that farmers enjoyed a favorable position with respect to basic education during the eighteenth century. Our findings suggest that a high share of farmers was able to process simple numerical tasks, an ability that was far from widespread in the early modern period. The favorable human capital skills enjoyed by the farmers were also illustrated by their ability to read and write. One could imagine that in some countries, such as England, farmers developed particularly high human capital skills due to occupational shifts – they became a minority that produced the food for the majority of the population. However, interestingly, the phenomenon of high human capital among farmers does not only apply to England or Northwest Europe in general, which were characterized by rapid occupational change. We instead find that the 'farmer effect' applies to the center and the periphery of Europe (including the European settlements in the New World).

While Gregory Clark has suggested that the wealthy groups in society, such as merchants, provided their offspring with favorable skills, we argue that farmers – who represented one of the largest occupational groups from an historical perspective – accounted for at least one-third of the change experienced during the human capital revolution. In this study, we also described the mechanism supporting our basic model: farmers often had the opportunity to provide a sufficient amount of nutrition to their families, even during periods of famine, as they were able to reduce the share of their products that they sold on markets to consume a constant share themselves. As there is a surprisingly strong link between nutrition, or nutritional deprivation, and cognitive abilities, it seems likely that farmers were one of the groups of society that contributed significantly to the numeracy revolution achieved in Europe during the early modern era.