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New Evidence and New Methods to Measure Human Capital Inequality before and during the Industrial Revolution: France and the U.S. in the 17th to 19th Centuries

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Abstract
We explore pre- and early industrial inequality of numeracy using the age heaping method and anthropometric strategies. For France, we map the differential numeracy between the upper and lower segments of a sample population for 26 regions during the 17th century. For the U.S., inequality of numeracy is estimated for 25 states during the 19th century. Testing the hypothesis of a negative impact of inequality on welfare growth, we find evidence that lower inequality increased industrial development in the U.S., whereas for France such an effect was only evident in interaction with political variables such as proximity to central government.

Keywords: Human Capital, Inequality, Age Heaping, Numeracy, France, United States

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New Evidence and New Methods to Measure Human Capital Inequality before and during the Industrial Revolution: France and the U.S. in the 17th to 19th Centuries

It is very difficult to measure inequalities before and during the Industrial Revolution period. This study measures human capital inequality by employing a set of methods that developed around the phenomenon of *age heaping*, i.e. the tendency of poorly educated people to round their age erroneously.[1] For example, they answer more often '40', if they are in fact 39 or 41, compared with better educated people. In a related study, we found that the relationship between illiteracy and age heaping for Less Developed Countries (LDCs) after 1950 is relatively close.[2] The age heaping and illiteracy for not less than 270,000 individuals that were organized by 416 regions, ranging from Latin America to Oceania, produced a correlation coefficient of 0.63.[3] A number of other studies supported a close correlation between age heaping and other human capital measures for earlier periods. Data from the U.S. census manuscripts showed a very consistent and robust relationship, as well as a panel of 17 European countries for the late Medieval and Early Modern period (see below section II for a more detailed report).

The crucial advantage of those age heaping methods is that data are widely available for the early modern period, because many people were asked for their age in a more or less standardized way, when entering the military voluntarily, when they married etc. Also women who were accused of witchcraft in court were asked for their age, so one could even analyze the human capital of those accused of being witches.[4] In addition, age accuracy reflects basic numerical skills more than literacy skills, which could be important as a precondition for

[1] Mokyr, *Why Ireland starved.*
[2] A'Hearn, Baten and Crayen, 'Quantifying', Appendix (available from the authors).
[3] In this Appendix the authors compared the level of age heaping also to numerical skills as measured in the PISA survey (Programme for International Student Assessment). The data yielded a correlation coefficient of 0.80.
[4] On the relative age heaping of women see De Moor and Van Zanden, *Vrouwen.*

technical, commercial and craftsmen activities in the production process. While the ability to report an exact age is certainly not a sufficient base for those yields, it can be considered as a necessary precondition. When applying this method, we must assess the quality of the data carefully, by scrutinizing the institutional framework, and selection processes, as far as this can be reconstructed. This can be done particularly well based on data on France and on the United States. Comprehensive data sets are available for those two core countries and used in the following analysis, not only age heaping data, but also estimates on welfare trends on a low regional level. Hence we concentrate on those two countries in the present study.

One interesting sample is the data set of the French army that was originally collected by John Komlos and his French collaborators. This data set is large enough to reconstruct numeracy even in relatively small regions of France since the late seventeenth century. In section IV, we present maps of French age heaping patterns during this period that give hints about regional inequality of human capital formation. From the degree of heaping and some anecdotal evidence we can be sure that soldiers were actually directly asked for their age (no birth certificates were demanded, and no comparisons with other sources were done by the registration officers). One advantage of this data set is the inclusion of anthropometric variables, so that we can assess the relationship between net nutritional status and numeracy. For the United States, we use another informative source, namely the census records of the United States 1850-1910, which include some 650,000 cases.

Moreover, we use different units to assess inequality: We measure inequality between taller and shorter individuals (reflecting their nutritional status and social stratification), and differences between occupations of middle/upper versus lower social status. The results are multi-faceted, as the history of inequality has always been. One particularly important result is that height was a good predictor of numeracy in France: The taller half of the height distribution displayed a much lower age heaping tendency than their shorter peers, and hence higher numeracy. In the U.S., those with high-income occupations rounded less.

We use two different dependent variables for welfare growth, namely height and value added growth. How do those measures differ conceptually? The strength of value-added measures is, of course, its comprehensive account of purchasing power and its comparability over time if given in standardized monetary units (such as 1990 Geary-Khamis $). One of the disadvantages of GDP as a welfare measure is its bias against subsistence farming and production within the household. In general, non-traded goods and goods produced and consumed within households are often underreported. Moreover, other forms of informal markets, such as black markets, can often not be captured. Anthropometric techniques were developed to provide an additional welfare indicator that covers biological aspects and includes not only subsistence farmers, but also local rulers, craftsmen, and unskilled day-labourers. Moreover, it reflects the well being of children and youth, which the GDP measure does not capture well. Although the quality of nutrition is partly determined by income, heights also reflect other living standard components, such as the disease environment, hygienic behavior, and non-market nutrition factors such as proximity to the production of perishable proteins (e.g. milk or offals, which could not be transported and traded over longer distances before the mid-twentieth century).[5] Margo and Steckel found a remarkable deviation of height and income for the mid-nineteenth century United States.[6] We will use human stature as a welfare measure for French regions below. For the U.S. case, we will assess the value-added growth in industry in order to measure the productive potential of the individual states.

The present paper is organized as follows. We first review the literature on human capital

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[5] See Baten, 'Kartographische Residuenanalyse'; Baten and Murray, 'Nineteenth century Bavaria'; Komlos, 'The antebellum puzzle'; Moradi and Baten, 'Sub-Saharan Africa'.
[6] Margo and Steckel, 'The antebellum period'.

inequality and its relationship with welfare growth. We then suggest in the second section the new measurement strategy of *age heaping* that can be applied to numeracy inequality for the period before and during the industrial revolution. After discussing our data in more detail in section III, we apply the age heaping technique in section IV to 26 French provinces during the late seventeenth century, producing an estimate for human capital inequality for the first time. We also apply a modified version of this measure to 25 U.S. states in the early and later nineteenth century. Section V tests whether there is a negative impact of inequality in human capital on welfare increase in French regions between the seventeenth and nineteenth centuries. As a proxy for welfare growth, we use change in height between the late seventeenth century and the late nineteenth century. Finally, we test if inequality in numeracy in the United States, measured for birth cohorts before 1840, had a significant impact on economic growth between 1860 and 1880. Our last section concludes.

I

The new growth theory, pioneered by Romer, Lucas, Barro and Barro and Sala-i-Martin has aimed at explaining long-term growth within their models, rather than by some exogenously growing variables like unexplained technological progress.[7] Moreover, new growth economics has strongly emphasized the role of human capital formation and its persistence in nations over time. During the last decade, many scholars extended this endogenous growth theory and addressed distributional aspects of income, suggesting that inequality might reduce growth.

This idea stands in contrast to the earlier study of the inequality phenomenon, which tended to view inequality as the variable to be explained. Most prominently, Simon Kuznets analyzed the effect that economic growth had on inequality of income when he formulated the

[7] Romer, 'Increasing Returns'; Lucas, 'Economic development'; Barro and Sala-i-Martin, *Economic Growth*; Barro, 'Inequality and growth'.

well-known hypothesis that postulates an 'inverted U' relationship between income and inequality.[8] According to that hypothesis, the degree of inequality would first increase and then decrease with economic growth. During the 1990s, a fairly large body of literature has sought to test Kuznets' hypothesis of an inverted U relationship but the results were ambiguous.[9] Deininger and Squire pointed out that most of the empirical work on this topic used cross-country instead of longitudinal data to test an inter-temporal relationship.[10] According to them, the inverted U shape tends to vanish if world region dummies are included.

Williamson and Williamson and Lindert argued that the inverted U relationship holds for the historical development during the nineteenth century.[11] Van Zanden could measure inequality cycles for the pre-industrial period.[12] The studies mainly supported the notion that during growth periods, some parts of the population developed special skills and hence earned higher incomes, whereas the remaining 'traditional' sector followed after some lag. Oshima explained the phenomenon rather by considering physical capital: technology in the late nineteenth century, such as the steam engine, was characterized by large indivisibilities in production: Large factories would have been needed to achieve sufficient economies of scale.[13] These prevented all, but the richest part of the population from accumulating capital, and required a large group of unskilled workers, thus facilitating industrialization only at the cost of growing inequality over time. By contrast, it is argued, that the link between growth and inequality does not turn out as significant in recent times, as current technology is much more divisible and improved capital markets enable a much larger share of the population to make profitable investments. Barro pointed out

[8] Kuznets, 'Growth and inequality'.
[9] see for example Bourguignon and Morrison, 'Income distribution and foreign trade'; Bourguignon, 'Human resources'; Milanovic, 'Transition economies'; Polak and Williamson, 'Poverty, policy, and industrialization'.
[10] Deininger and Squire, 'Inequality and growth'.
[11] Williamson, *British Capitalism;* Williamson and Lindert, *American inequality* (but see the critical review of Feinstein, 'The Williamson curve').
[12] Van Zanden, 'Kuznets Curve'.
[13] Oshima, 'Technological transformation'.

that recent empirical work might have failed to confirm the Kuznets curve as, according to these theories, inequality would depend on the time passed since a new technological innovation was introduced into the economy, and not on per capita GDP.[14]

Beside this literature on the Kuznetsian determinants of inequality, a new line of research studied the effects of the distribution of income, i.e. the opposite direction of causality. This was triggered by the contrast of relatively low levels of inequality and high growth rates in Asian ‘Tiger’ countries, at a time of high inequality and much lower growth rates in Latin American economies.[15] This research can be roughly grouped according to the specific channels through which inequality can affect growth. One idea is that by lowering the income of the median voter relative to the national average, greater inequality increases the pressure for redistribution, implying a higher tax rate. This, in turn, reduces incentives for productive investment, by inducing economic distortions.[16] Barro argues that even if no redistribution takes place, higher inequality implies higher costs for the rich to prevent redistribution.[17] The lobbying activities would consume resources and promote official corruption and tend to hamper economic performance. A second branch of theories is based on the idea that sociopolitical conflict reduces the security of property rights, thereby discouraging accumulation of capital. Perotti found that sociopolitical instability is enhanced by higher inequality, which in turn hampers economic development.[18] Besides this, as Barro argued, crime and riots deter investment and reduce the productivity of an economy.[19] In the recent past (such as the 1960s to today), a third channel might be imperfect credit markets, which prevent asset-poor people from making economically

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[14] Barro, ‘Inequality and growth’.
[15] Lindert and Williamson, ‘Globalization’.
[16] Alesina and Rodrik, ‘Distributive politics’; Persson, and Tabellini, ‘Is inequality harmful?’.
[17] Barro, ‘Inequality and growth’.
[18] Perotti, ‘Income distribution and democracy’.
[19] Barro, ‘Inequality and growth’. The conflict- and crime-related factors can be seen as secondary effects, whereas tax distortion, credit market and educational inequality effects can be regarded as primary factors, as the former are often a result of the latter.

profitable investments in physical and especially human capital.[20] For the historical period, however, Gerschenkron had argued that a rise in inequality tends to raise investment, as the rich could save more and hence invest in physical capital.[21]

Only very recently, research has focused on inequality not only of wealth or income but also explicitly on inequality of human capital. Loury studied an overlapping two-generation model: individuals have varying abilities, and those are not perfectly correlated with parental investment capabilities into children's human capital.[22] Hence, in his model, income inequality affects inequality of human capital through decreasing returns to human capital investment at the individual level – after all, richer people are not able to increase their human capital as much with higher income. Redistribution would lead to higher human capital investment among poor people, and increased aggregate human capital investment.[23] Thomas, Wang, and Fan focused on the effect of development on the inequality of education.[24] Providing a unique data base of educational Gini indices covering 85 countries for the second half of the twentieth century, they found strong evidence that an education Kuznets curve between countries over time exists. Lopez, Wang and Thomas provided a theoretical background to the detrimental effects of inequality of human capital on economic growth. Since talents are bound to individuals and not tradable like most other goods, they assume that the marginal product of human capital across individuals is not generally equalized, if inequality is substantial.[25] Hence, aggregate production depends not only on the total level of human capital but also on its distribution. They found empirical evidence that more unequal education tends to have a negative impact on per capita

[20] Ibid., Deininger and Squire, 'Inequality and growth'; Galor and Zeira, 'Income distribution and macroeconomics'.
[21] Gerschenkron, *Economic backwardness.*
[22] Loury, 'Intergenerational transfers'.
[23] Checchi, 'Access to education', analyzed the relationship between educational achievements and inequality of incomes using education Gini coefficients for 94 countries between 1960 and 1995. The results of his fixed-effects-panel regressions suggest that increased access to education reduces income inequality if, and only if, the initial level of educational attainment is sufficiently low and if average educational attainment is raised sufficiently rapidly.
[24] Thomas, Wang and Fan, 'Education inequality'.
[25] Lopez, Thomas and Wang, 'Education puzzle'.

income in most countries. The results also indicate that an equal distribution of human capital does not enhance growth by itself, but that it needs an adequate policy environment, which protects property rights.

In conclusion, there are newer theoretical approaches that focus directly on human capital inequality as a negative determinant of growth. We will put those to the test below. However, given that inequality of income and human capital might be closely correlated, we have to take interpretations into account, which see income inequality behind human capital inequality. Moreover, the reverse causality (Kuznets' view that growth causes inequality) needs to be discussed below. New evidence is clearly needed, and the seventeenth to nineteenth century histories can potentially shed light on this important debate, if we find ways to measure inequality of human capital (and income).

II

We will first discuss the general potential -- and the problems -- of the age-heaping method in this section, before discussing our measures for inequality of human capital below. The most widely used measure for age heaping is the Whipple Index, which calculates the number of observed ages that are multiples of five , relative to the number of people whom we would expect to report an age ending in a zero or a five (assuming smooth distribution of ages, which is given in most situations) multiplied by 100. The index ranges from 0 to 500. Accordingly, a Whipple Index of 500 implies that the whole population reported ages ending in multiples of five only. If everybody reports the correct age, the ages ending in 5 and 0 should account for 20% of all age statements, yielding a Whipple value of 100. Higher Whipple values reflect higher shares of people stating an age ending in a multiple of five (and thus a higher share of age misstatements). As such, a Whipple Index value of 200 means that 40% of respondents claim that their age ends in a 0 or in a five, implying that probably 20% misreport their age. Several authors emphasized that a person who cannot report her exact age, but rather reports a rounded age, normally has difficulties with numbers in general.

It is important, however, to counter-check whether census-takers or recruitment officers did explicitly ask for the age (and did not 'correct' the reported ages afterwards). In the case of the samples studied here, the soldiers were actually asked for their age, and no correction was done afterwards. Otherwise, the relatively high level of age heaping that we observe in the data would probably not have occured.[26]

How close is the relationship between age heaping and other human capital indicators such as literacy and schooling? A'Hearn, Baten, and Crayen used the large U.S. census sample to perform a very detailed analysis of this relationship.[27] They subdivided by race, gender, high and low educational status and other criteria. In each case, they obtained a statistically significant relationship. Remarkable is also the fact that the coefficients are relatively stable between 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.: In any country studied so far which had substantial age-heaping, the correlation was both statistically and economically significant.[28]

In order to assess the robustness of those U.S. census results and the similar conclusions which could be drawn from late twentieth century Less Developed Countries, as mentioned in the introduction to this study, A'Hearn, Baten, and Crayen also assessed age heaping and literacy in 17 different European countries between the Middles Ages and the early nineteenth century.[29] Again, they found a positive correlation between age heaping and literacy, although the relationship was somewhat weaker than for the nineteenth or twentieth century data. It is likely

[26] Even if the precise birthday (often related to a saint's day or a holiday) is known to the individual, it might well be that the exact amount of years since birth means little to an individual although the annual event is celebrated again and again.
[27] A'Hearn, Baten and Crayen, 'Quantifying'.
[28] On the regions of Argentina, see for example Manzel and Baten, 'Colonial and post-colonial Latin America'.
[29] A'Hearn, Baten and Crayen, 'Quantifying'.

that the unavoidable measurement error when using early modern data induced the lower statistical significance. One source of error was the heterogeneous data coverage since the regional units for literacy and age heaping did never perfectly match.

The possibly widest geographical sample studied so far has been created by Crayen and Baten, who were able to include 70 countries for which both age heaping and schooling data (as well as other explanatory variables) were available.[30] They found in a series of cross-sections between the 1880s and 1940s that primary schooling and age heaping were closely correlated, with R-squares between 0.55 and 0.76 (including other control variables, see below). Again, the coefficients were relatively stable over time. This large sample also allowed the examination of various other potential determinants of age heaping. To assess whether the degree of bureaucracy, birth registration, and government interaction with citizens is likely to influence the knowledge of one's exact age, independently of personal education, Crayen and Baten used the number of censuses performed for each individual country up to the period under study as explanatory variable for their age heaping measure. Except for countries with a very long history of census taking, all variations of this variable turned out insignificant, which would suggest that such an independent bureaucracy effect was rather weak. In other words, it is the case that societies with a high number of censuses and early introduction of birth registers had a high age-awareness. But those societies were also early to introduce schooling, and this was the variable that had clearly more explanatory power than the independent bureaucracy effect. Crayen and Baten also tested whether the general standard of living had an influence on age heaping tendencies (using height as well as GDP per capita as welfare indicators) and found a varying influence: in some decades,

[30] Crayen and Baten, 'Global trends in numeracy'.

there was a statistically significant correlation, in others there was none.[31]

In conclusion, the correlation between age heaping and other human capital indicators is quite well established, and the 'bureaucratic' factor is not invalidating 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 and twelve. Heaping of multiples of twelve might be present in some Medieval samples, although the evidence for this is quite limited.[32] Heaping on multiples of two is quite widespread among children and teenagers and to a lesser extent among young adults in their twenties. This shows that most individuals knew their age as teenagers, but only in well-educated societies they are able to remember or calculate again their exact age later in life.[33] At higher ages, this heaping pattern is mostly negligible, but interestingly somewhat stronger among populations who are numerate enough not to round on multiples of five.[34]

Duncan-Jones recommends calculating age heaping measures for the population aged 23-62 only, and we followed him, excluding those below 23 and above 62 since a number of possible distortions affect those specific age groups, leading to age reporting behaviour, different to the one featured by the adult group in between.[35] Many young males and females married in their early twenties or late teens, when they also had to register as voters, military conscripts etc.

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[31] Finally, age heaping values in East Asia were significantly lower than in other countries, suggesting that probably due to their inclination for calendars and astrology the East Asian culture increased age awareness or facilitated the calculation of the exact age by the enumerator without a similarly high level of general schooling, ibid.

[32] Thomas, 'The prothero lecture'.

[33] This might also explain why birth registers had only a limited impact on age-heaping. The problem was not the information *per se*, but in practice people did not consult the birth registers, when a census taker asked for their age.

[34] A potential measure for all sorts of heaping is the Bachi Index, which captures all deviations of the reported from the smoothed age distribution. Unfortunately, the Bachi index has several shortcomings compared to the Whipple Index. Most notably, it is statistically scale dependent. In other words, samples with identical heaping patterns but different sample size score dissimilar Bachi Index values since deviations caused by random sampling variation are not cancelled out. Its scale independence, efficiency, precision and reliability suggest that the Whipple Index should be the preferred age heaping measure. A'Hearn, Baten and Crayen, 'Quantifying' give a detailed discussion. Note that the Whipple Index reports a lower bound estimate of age misreporting. The Index does not take into account, ages that are untruthfully stated as ages other than multiples of five – if somebody reports '29' while being truly 28, this goes unnoticed. In a similar vein, age misstatements that neutralize each other are not captured. That is, if a 30 year old claims to be 35, this is counterbalanced by a 35 year old reporting himself 5 years younger.

[35] Duncan-Jones, *The Roman Economy*.

At such occasions, they were sometimes subject to minimum age requirements, a condition which gave rise to increased age awareness. Moreover, individuals physically grow during this age group, which makes it easier to determine their age with a relatively high accuracy.[36] All these factors tend to deflate age heaping levels for children and young adults, compared with the age reporting of the same individuals at higher ages.

The age heaping pattern of very old individuals is subject to upward as well as downward bias for the following reasons. Firstly, older people have a propensity to overstate their age, where old age is considered a sort of distinction. Secondly, selective mortality might affect the educational composition of very high age groups, while a steep gradient in the right end of the age distribution due to high mortality is misinterpreted by the Whipple Index as digit avoidance. Finally, younger household members are likely to have reported the age of the elderly if those were considered as not being able to do so anymore. To be on the safe side and to avoid the risk of measurement error from this source, we exclude the very old, as well as the very young in the present study.[37] Moreover, for military samples featuring extremely skewed age distributions centred at late teen years and early twenties, the age span should be restricted to at least 23 plus to prevent us from interpreting military-specific age distributions as digit preference.

There remains some uncertainty about whether age heaping in the sources contains information about the numeracy of the responding individual, or rather about the diligence of the reporting personnel who wrote down the statements. 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 analysing the share of signatures in marriage contracts, there might have been priests who

[36] A 17-year-old might round off to 16 or 18, but not to 15 or 20. Another reason for excluding the very young is brought forth by the fact that it is plausible that parents and other relatives returned the ages for children and for a good share of young teenagers.
[37] In principle, it might be possible to analyse the even heaping of teenagers and heaping patterns of the elderly, but given the newness of the age heaping method we opt for the most robust heaping of /adults aged 23-62 only.

were more or less interested in obtaining real signatures, as opposed to just crosses or other symbols. We find it reinforcing that we estimate generally much more age heaping (and less numeracy) for the lower social strata, and among the half of the sample population which had lower anthropometric values. Moreover, the regional differences of age-heaping are similar to regional differences in illiteracy.

We conclude that the age heaping method is now a well-established indicator for numeracy of groups, but the problem remains how upper and lower group members can be distinguished from each other for historical populations for which we typically have no individual income data. Occupations have been often used to classify upper versus lower income group individuals, and we will apply this to U.S. census data below. Of course, occupations such as ‘day-labourer’ or ‘agricultural worker’ typically yielded a low income, whereas professionals, noblemen, factory owners, and skilled craftsmen had higher incomes. Some occupations represent a wide income range.

In this study, we propose also an alternative, similarly rough proxy to distinguish social groups, based on human stature: We contrast those above and below mean height, and aggregate human capital characteristics by sample half. Almost all anthropometric studies that considered occupational or income groupings found that the well-off strata of society were taller, as long as regional differences are held constant (such as proximity to protein production).[38] A second very interesting aspect to this strategy is that tall individuals are much less likely than short individuals to have suffered from infant protein deficiency syndrome (IPDS) that reduces learning abilities to a certain extent. The syndrome was wide-spread during the seventeenth to nineteenth centuries, when malnutrition was so grave that most populations were severely stunted (with adult males being shorter than 170 cm on average). Support for this claim comes from biologists and

[38] For recent collections of anthropometric studies, see , see Steckel and Floud, *Health and Welfare*; Komlos, ‘Anthropometric History’.

psychologists who have conducted experiments on the influence of protein malnutrition in childhood and the intellectual ability later in life. While the ethical backgrounds of those experiments are debatable, the results cannot be ignored. For example, Lucas finds that children who had received less nutrient-rich diets showed markedly lower neurodevelopment during the first two years of life, compared to a control group.[39] Even as late as age 7.5 the IQ scores are significantly lower. A randomized experiment in Guatemala suggests that protein supplements can produce marked improvements in cognitive ability.[40] Especially numerical abilities could be affected. Similar findings are brought forward by Paxson and Schady.[41] They use a sample of over 3,000 preschool age children from Ecuador to identify determinants of children's language ability. The authors find that household socio-economic characteristics have a significant effect, and that its importance increases with the child's age. Most relevant for the present paper is the report by Grantham-McGregor since it points to a link between heights and cognitive ability even on the individual level.[42] Her study on stunted children showed that nutritional supplements can produce important gains in intellectual development. Several other studies indicate that the persistent exposure to undernourishment and poverty produce a cumulative effect on cognitive ability.[43] The longer a child's nutritional and educational needs go unmet, the greater the overall cognitive deficits. This applies not only to severe but also to mild undernourishment. Magnusson, Rasmussen, and Gyllensten reason that genetic influences cannot fully explain the correlation between heights and cognitive ability from observing stature and intelligence of Swedish siblings. One caveat to the proposed anthropometric method is clearly that genetic height variation remains on individual level.[44] Nonetheless, we are confident that most individual variation can be

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[39] Lucas, 'Programming by early nutrition'.
[40] Brown and Pollitt, 'Malnutrition and intellectual development'.
[41] Paxson and Schady, 'Cognitive development'.
[42] Grantham-McGregor, 'Growth retardation and cognition'.
[43] e.g., Gorman, 'Cognitive development in children'; Strupp and Levitsky, 'Early malnutrition'.
[44] Magnusson, Rasmussen and Gyllensten, 'Swedish men'.

averaged out by means of sufficiently large sample sizes.[45] Hence, we apply the age heaping method (our non-numeracy indicator) to the taller half and the shorter half of sample populations, as well as to the upper and lower occupational strata. Firstly, we can compare the numeracy of those from higher versus lower income occupations in the U.S. (Table 1, U.S. census data). We exclude immigrants as their numeracy might have been determined in the countries of origin before they migrated. In general, age heaping was modest among the Northern United States population that was born between the 1800s and 1870s. The Whipple Index was between 116 and 127 (see Table 1). Given the calculation mentioned above, a Whipple Index of 127 means that an estimated 5.4 percent of the population reported an uncorrect age. Inequality was very low in the Northern U.S., whereas it was much higher in the South. Secondly, we have a very large sample of French army soldiers that was created by Komlos and co-operators, described in detail in Komlos' study and in our section III.[46] Judging from his description of recruitment practices, this sample has a certain overrepresentation of lower income groups. Analysing more than 20,000 recruits, we found that short soldiers of the Southwest had very strong heaping (low numeracy), whereas it was low among tall Frenchmen in the North (see also Table 1).[47] In addition, inequality in the province of Ile de France (Paris) was higher than in any of the other samples.

One important result from these samples is that the half of the population which was taller or had higher-status occupations (and came probably from more advantaged family backgrounds) had always lower or equal heaping values, whereas numeracy tended to be lower among the shorter half of the population, and those with lower-status occupations.[48] Moreover, it is interesting that great inequality of numerical human capital was evident in the Southern U.S. and

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[45] Please note that we calculate the inequality within regions, hence possible genetic differences between regions should not play a decisive role.

[46] Komlos, 'Anthropometric History'.

[47] We excluded those younger than 23 years and those of unknown province.

[48] In Appendix 3 (available from the authors), we show that the taller half is consistently more educated in 38 Developing Countries born 1950-1980, and that the inequality of literacy between the taller and shorter half correlates with the inequality of numeracy, measured in the same way.

Southwest of France, which developed poorly in the later nineteenth century industrialization waves.[49] In contrast, Northeastern France and the Northern United States was characterised by only modest inequality. According to recent theoretical models, as described in more detail in section I, low inequality might impact favourably on economic growth. If the low inequality – growth relationship postulated in section I held, we would expect the earliest industrial development in the Northern U.S. and the Northeast of France – and that is where it took place.[50] Paris is somewhat of an outlier to this relationship. Perhaps its positive development in spite of high inequality was stimulated by the proximity of the central government, or because it was economically specialized in a different way. In the following, we will study a number of regions of France and the U.S., as this relationship would otherwise be based on too few cases.

III

As in all inequality studies, we have to consider which social strata are actually covered by a given sample: In many types of source, lower classes are over-represented; hence inequality might look smaller, compared with samples of broader coverage. It is vital to assess the representativeness of each type of sample. The French soldiers were recruited between the 1690s and 1780s.[51] We draw on Komlos' description in the following. Most of the soldiers enlisted under the reign of Louis XV and XVI. The information reported in the sources includes age, height (in French *pied*, *pouce*, and *ligne*), place of birth, the company into which the soldier enlisted, and for a smaller share the own previous occupation and the one of the father. With regard to place of birth, Komlos reports an overrepresentation of urban places, and argues that

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[49] The black slaves were excluded from the Southern U.S. sample.

[50] Admittedly the direction of causation cannot be fully clarified yet, as it might have been the regnios of low inequality were richer also in the preceding period.

[51] Komlos, 'Anthropometric History'. The sources were preserved in the French military archive in Chateau de Vincennes. We dropped some 1,000 foreigners enlisted in the army since we study birth cohorts born in French provinces only. The anthropometric measurement quality appears relatively high, as 42 percent of heights were not reported as a (rounded) integer.

recruits tended to report the nearest urban locality.[52] Given that we study the provincial averages here, those inaccuracies can be neglected.

How representative was the French army of the underlying French population? Unfortunately, only fourteen percent of the archival entries contained the father's occupation, and eleven percent of the soldier's own occupation before recruitment. Among the recorded soldiers´ occupations, 'craftsmen' was the most frequent category (44%).[53] Given that the largest part of the French population was agricultural, the proportion of occupations belonging to 'agriculture' (7%) and 'worker/labourer' (jointly 17%, referring mostly to agricultural but also to industrial labour) was probably less than the corresponding share in the French society. However, second sons of farmers or of agricultural labourers were less likely than craftsmen recruits to report an occupation when enlisted and the true share of those with rural backgrounds is underestimated on the basis of the available occupational information. It is thus difficult to obtain a reliable evaluation of the representativeness of the data based on occupational structure. To obtain a rough impression we compare the average age heaping values for both the military sample and other sources of the French population. From Paris death registers we know the level of age heaping in the families of Parisians who died in 1740 was 123 for the 23-32 year-olds and 151 for the 33-42 year-olds.[54] Age accuracy in the death registers is thus slightly worse than among Parisian soldiers aged 23-42 born during the corresponding birth decades (90 percent of Parisian soldiers were aged 23-42) who featured a Whipple Index of 122. In other words, in terms of numeracy the soldier sample might be modestly biased towards more numerate persons, at least

[52] One possible reason for this could have been to facilitate the enlistment procedure for the recruitment officer for whom the names of larger places were more familiar and thus easier to spell correctly.
[53] It is likely that some of those listed under 'textiles' (13%), 'food processing' (7%), and 'middle class' (7%) also belonged to this group (the distribution of father's occupations was similar).
[54] A'Hearn, Baten and Crayen, 'Quantifying', based on Mols, *Démographie Historique.*

in the case of Paris.[55] We conclude that the existing evidence does not speak for a negative selectivity of soldiers, as one might have expected. Given the positive relationship between height and numeracy, the minimum height requirement might have had a positive impact on the selection process.[56]

We also studied the very large U.S. census database provided by the Integrated Public Use Microdata Series (IPUMS) of the Minnesota Population Centre (MPC).[57] Records for nearly 650,000 men and women with data on race, age, literacy, and birthplace were extracted from 1% samples of the decennial population censuses 1850 - 1870 and 1900. The instructions for the census enumerators concerning the variables relevant for the present study were broadly consistent for the 1850, 1860 and 1870 enumerations. The 1900 census questionnaire included an additional question on year of birth in order to increase the accuracy in age reporting. The attempts seem to have been in vain, however, since age accuracy had not increased markedly in the 1900 enumeration, which led to the renewed omission of the very same question in the 1910 census questionnaire.[58] Since the U.S. data are based on a census (and it was relatively skilfully done), it can be assumed to be representative of the underlying population.

IV

Is the differential numeracy between the taller and shorter half of the population even observable on a low level of regional disaggregation? We examine this issue on the basis of French provinces in the late seventeenth and early eighteenth century, and for the nineteenth century US

[55] Note that age accuracy might be reduced by the fact that age is not stated by the individual himself but by a family member or other person, as it is obviously the case for death registers.
[56] Are there sufficient numbers of cases for the regional units under study? The highest numbers of cases are available for Guyenne and Ile-de-France (which included Paris). Guyenne comprised a large area, including the populous city of Bordeaux, so the high number of soldiers indicates a certain representativeness.
[57] The IPUMS data are available online from the Minnesota Population Centre at the University of Minnesota. Steven Ruggles, Matthew Sobek, Trent Alexander, Catherine A. Fitch, Ronald Goeken, Patricia Kelly Hall, Miriam King, and Chad Ronnander. *Integrated Public Use Microdata Series: Version 3.0* [Machine-readable database]. Minneapolis, MN: Minnesota Population Centre [producer and distributor], 2004.
[58] Bailey and Parmelee, ‘Age returns’.

States. Especially French regional human capital formation in the early modern period has been a white area on the map so far, hence we report the data in somewhat greater detail.[59]

From Figure 1, it can be inferred how human capital, measured in terms of numeracy, was distributed regionally among French soldiers born in the seventeenth century. The darker the shaded areas, the lower the level of numeracy (i.e. higher Whipple indices of 'non-numeracy'). We find the lowest level of numeracy in a belt stretching from Brittany southeast to Auvergne. The low level of numeracy there stands in sharp contrast to the high levels in the provinces Picardie/Hainaut, Anjou, Orléans, Bourbonnais, and the Rhone valley.

In order to assess not only the level of numeracy, but also its inequality, we apply the technique described in section II. We thus group the birth cohorts in tall and short soldiers on provincial level. That is, the recruit is considered being tall if his body height is above the mean height in the province where he was born. We then divided the resulting 'non-numeracy' of the shorter half by the one of the upper half, hence a value of 1.5 indicates that the shorter half displays a heaping behaviour that is 50 per cent stronger than in the taller half, whereas a value of 1.0 or even below indicates little difference (=low numeracy inequality, see Figure 2). A low value of inequality might be expected in regions that required few skills for those that were active, for example, in cattle herding, and hence had non-market access to protein (in mountainous parts of Franche-Comté or the Basque mountains, for example). We argue that 'access to protein' meant that there was a much weaker relationship between human capital (and

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[59] The Appendix 1 (available from the authors) reports regression results using 25-year birth cohorts, i.e. 1660-1684, 1685-1709, 1710-1734 and 1735-1759. The effects discussed here proved to be robust to this alternative birth cohort specification.
For the French regional level, we have to make sure that our regional units contain sufficient observations to calculate differential numeracy values for the lower and upper half. Some French provinces of the *ancien régime* were rather small and provided only a small number of soldiers; hence we aggregated them with neighbouring provinces. We reduced the number of French regions from 36 to 26 to obtain more similar unit sizes. Since the merged provinces were either very small provinces adjacent to a large neighboring province or two small provinces next to each other, we consider the loss of information as small. Aggregation had to be made not only spatially but also over time, i.e. birth decades. The resulting 50-year birth cohorts comprise about 200-1300 soldiers each, which give good estimation results with the age heaping method.

implicitly income) and nutritional status. The highest levels of inequality in the late seventeenth century were prevalent in North-Central France between Ile de France, Saint-Onge, Bourbonnais on the one hand, and the Rhone valley on the other hand, i.e. the large regions south of Paris and along the large rivers that include much of the grain and wine belt that produced surpluses for the urban development of Paris and the big cities (Figure 2). In contrast, we find low inequality around Franche-Comté in Eastern France, and in the southwestern area of Gascony/Bearn/Foix. It is quite interesting that these are all peripheral mountain regions. Low inequality is also detected in Limousin and Marche where both tall and short soldiers had exceptionally low levels of numeracy. These are actually two of the poorest regions of France today. Moreover, this area was characterized by a particularly adverse environment (swamps etc.), so the height-education relationship might have been distorted by heterogeneous disease environments.

What might determine the size of numeracy inequality? Are more dynamic regions more equal? It seems as if in late seventeenth Century France, higher inequality of numeracy was more often apparent in urbanized, more densely populated regions which tended to industrialize more strongly in the subsequent period. This would not support Lopez, Thomas and Wang's hypothesis, which predicts that inequality hampers economic development. In contrast, the evidence is consistent with a Kuznetsian view that the direction of causality was reverse: The more urbanized and industrially developed parts of France generated higher inequality. For the British case, Sanderson argued that there was a decline of literacy between the 1780s and 1800s especially among the industrial workers of Lancashire.[60] He argues that during this period, investment in schooling was not sufficient in the rapidly growing cities of this most industrial county, and the demand for workers' literacy skills was also not given. At the same time, he emphasizes that clerks, entrepreneurs, and the richer parts of society probably kept or expanded

[60] Sanderson, 'Literacy and social mobility'.

their education, which would be an alternative explanation of initial Kuznetsian patterns in the rapidly growing industrial cores. From an alternative perspective, one could also argue that those central and river regions of France were relatively market-integrated and concentrated on wheat growing. The high degree of market integration might have led to a stronger division between the upper and lower income groups. In summary, on the basis of the underlying data, it does appear as if more dynamic regions in France are initially characterized by higher inequality. As industrial development was strongest in the North and Northeast, we cannot confirm Lopez, Thomas and Wang's hypothesis for early industrial France that high inequality of human capital adversely affects economic growth.

Turning to the U.S. case, we distinguish the inequality of numeracy by occupational groups. All occupations have been classified by the IPUMS team according to the median total income (in hundreds of 1950 dollars) of all persons with that particular occupation in 1950, which is certainly not unproblematic for our purposes, but it can provide a first guidance.[61] We excluded all immigrants from our analysis, as a large share of them migrated when they were already young adults. Therefore, migrants can be considered as having received their education in greater part in their country of origin unless they migrated with their family when they were young.[62]

In order to group the population into two groups of different social status, we

[61] We omitted those individuals with occupations that were classified as zero income. The zero income group was very heterogeneous, since many of these people were in the labour force, but, because they did not report an occupation, they received an income score of zero. This group also includes some persons of typically high education (such as retired businessmen as well as gentlemen and ladies with inherited wealth) and some persons with typically quite low education (e.g. unemployed people, Native Americans living on reservations). We also omitted all women in this step, as a very large share of them were housewives or were at least recorded in the census as having no occupation (although they might have been active in the family business).
[62] Family migration was wide-spread until the mid-19th century, but in the later 19th century the single (or couple) migrant became quite frequent.

distinguished the upper from the lower part of the occupational hierarchy.[63] Having excluded all states where either the upper or the lower segment was based on fewer than 100 observations, we computed the Whipple Index for both social groups and the ratio of both index values (lower to upper class), which we used to measure inequality. The ratio thus gives the relationship between the lower and upper part of the occupational scores, and the higher this ratio, the larger inequality of numeracy.[64]

We hypothesize that the highest inequality of numeracy may be found in the southern plantation belt of the U.S., where a relatively small group of whites benefited strongly from the export-oriented plantation system, whereas the majority of smaller farmers and other occupations might have had much lower income and financial means to invest in children's education (Table 1). We actually observe this pattern for those cohorts born before 1840 (i.e. before large-scale industrialization in the U.S. started, see Figure 3). States like Alabama, Louisiana, Georgia, and Mississippi clearly had the highest inequality of numeracy, produced by a particularly low numeracy among individuals who belonged to the lower segment of the occupational hierarchy.

It is intriguing that inequality was very low in the Northeast. These differences would support the interpretation of Lopez, Thomas and Wang that lower inequality of human capital stimulates economic growth, as the strongest economic growth took place in the Northeast. We

[63] We opted for a 'top 40 vs. bottom 60' distinction, assigning a lower social standing to the large (14% of the underlying population) and indivisible occupational group with an income score of 20, which consists mainly of labourers. Given the gradient in numeracy and literacy from this group to the adjacent class with higher income scores, this cut-off point appears reasonable, see Appendix 2 (available from the authors). The upper class of occupations is led by physicians and other academic jobs, which had an occupational income score of 8,000 Dollars (in 1950). In the lower segments of those 'top 40' per cent of the male population, the occupational groups featuring an income score of 22 and 21 mainly comprise skilled workers such as bookkeepers and secretaries. As a caveat we have to note that there were also some groups that had a relatively high income around 1950, but their social and economic status in the nineteenth century might have been lower (workers in textile factories, for example). While all farmers were classified by the IPUMS research team as being in the 'bottom 60%' segment, we have to keep in mind that some farmers might have been relatively wealthy and skilled.

[64] The question of endogeneity naturally arises: did they achieve a good position in the upper half of the occupational hierarchy, because they had good numeracy? Or was social mobility still relatively low, and hence most sons took over the occupations of their parents? Probably both patterns existed. However, for our purposes, the question is not as relevant, since we simply want to measure the distance of numeracy between the more and the less successful half of the population within as many states as possible.

can roughly summarize the situation before 1840: numeracy was low and unequally distributed in the South. In contrast, the North, and especially the Northeast, had higher numeracy and a relatively egalitarian distribution. For the post-1840 birth cohorts, the economic environment in the U.S. changed dramatically. Large parts of the country industrialized rapidly and attracted workers from other parts of the world. Kuznets hypothesized that inequality rises in the first stages of industrial development, which might not only apply to income inequality, but also to educational inequality. Hence we would expect this effect in the newly emerging centres of industrial expansion. Moreover, the arrival of more and more immigrants at the East coast (which tended to be less skilled than previous immigration waves) might have increased inequality in the industrial centres, as lower skilled Native-born Americans had to compete with the newly arriving immigrants. We observe that the inequality of numeracy in industrial states such as Connecticut and New Jersey moved into the top ten of American inequality in this period (Figure 4). New Jersey's inequality increased substantially from a value of 1.03 to 1.19. Even more extreme, in Connecticut inequality increased to the Northern maximum value of 1.32 for the later birth cohorts (from a value near 1 for the 1800-39 birth cohort). The richer part of the 1840-79 population of Connecticut had a Whipple Index of 111, the poorer part a Whipple Index of 146. The higher inequality in north eastern states such as Connecticut and New Jersey can be attributed to the fact that numeracy levels of the less skilled occupational groups worsened or did not improve as fast as the numeracy levels of the better skilled 40 percent of the population.[65]

In summary, we conclude for the early period: inequality of numeracy was in fact low for the Northeastern U.S. where industrialization was strongest later-on. For the birth cohorts after 1840 we find that industrialization in the U.S. led to increased inequality in the centres of

[65] The Northern US was a pioneer in the development of public education, which explains the low levels of age heaping found among the population in the earlier period. However, after the subsequent expansion of the US population, the provision of educational services was sometimes outstripped, which was typically leading to a decline in the numeracy skills of the poorer half of the population.

industrial development, which supports Kuznets' hypothesis.

V

In the modern world, the inequality of human capital has a strong negative influence on welfare growth, as the studies cited above demonstrated.[66] However, growth in today's world might be much more driven by human capital intensive processes that require schooling and numeracy of a large share of the society, compared with the pre-twentieth century period. Gerschenkron argued that inequality of income might actually have been more conducive to nineteenth century growth.[67] Economic development during the high time of the industrial revolution was strongly focused on physical capital formation: it mattered much more whether the investments could be undertaken during the nineteenth century, whereas in the late twentieth century, the skills of the workforce are likely to have been a stronger determinant. To the extent that income inequality is correlated with human capital inequality we have opposing views for different centuries, but rigorous empirical tests are scarce for the later period, and non-existent for the early period. Hence it remains an open issue which theoretical concept applies to the real world situation in the long run.

In the following section, we test the effect of human capital inequality on growth, using the inequality of numeracy measures that we presented in the previous section for seventeenth and eighteenth century French regions. Is Gerschenkron's positive or Lopez, Thomas and Wang's negative view of inequality visible in the history of French regions? Or possibly, opposing forces were at work, leaving the empirical picture inconclusive, because both mechanisms were important.

Which other variables should be taken into account? Thinking of French regional development, the focus on centralism immediately comes to mind. France has a reputation for

[66] Lopez, Thomas and Wang, 'Education puzzle'.
[67] Gerschenkron, *Economic backwardness.*

centralizing many important institutions and gathering decision-makers and the most talented people in Paris, since at least the Napoleonic period.[68] Paris was a strong attractor of French elites, and of taxes: public goods were centred disproportionately on Paris, partially financed by the provincial tax-payers. Paris was gradually transformed in the nineteenth century from an overcrowded and unhealthy Moloch into the cultural capital of the world. It is not a rare phenomenon that the capital region is favoured by spending on public goods: In today's Less Developed Countries, for example, recent studies argue that the government spends much more on the capital region in order to satisfy its nearby citizens, as they pose a direct threat in times of crisis and unrest. For the French case, this would imply that centralization might have been strongly reinforced by the events of the French revolution, which demonstrated the peril dissatisfied nearby citizens posed to the ruling classes.

In sum, we need to control for *centralité*, and its potential interactions with the inequality of numeracy, the variable of main interest in this study. We measure *centralité* by the distance from Paris, assigning different categories, from Ile de France coded as zero and the Provence coded as eight. We interact the distance variable with the inequality index values as we measured them for the late seventeenth and eighteenth century's French provinces.[69] Since standard indicators of economic development such as industrial value added, real wages, income per capita, or life expectancies are unavailable for seventeenth century French regions, we use the change in height as a proxy of the biological standard of living as dependent variable. Besides its availability, this proxy indicator has some other, more conceptual advantages for our purposes. One advantage compared with income is that the biological standard of living is an outcome indicator that takes into account the health effects of public goods: it has been frequently argued that centres of economic development were unhealthy places generating an overall much lower

[68] Page, *Localism and Centralism*.
[69] To obtain sufficient observation numbers, we opted for the broad birth cohorts 1660-1709 and 1710-1759.

standard of living than unadjusted incomes would suggest.[70] Height in contrast also reflects the amount of public goods that might improve hygienic and health conditions, such as waste removal or isolation of infectious disease carriers. The regional height levels for the 17th and 18th centuries can be estimated with a method suggested by Komlos, who first calculated truncated means of the sample, and then adjusted using a regression formula derived from a simulation.[71] With this method it is possible to obtain estimates of unadjusted population mean heights. The height data for the 19th century comes from recruitment statistics.[72]

The increase of human stature between the seventeenth and the nineteenth century was quite different across French regions (Figure 5). In the central regions, between Anjou, Ile de France (incl. Paris), Bourgogne, and Poitou, heights increased substantially. In contrast, the periphery did not improve much compared with the catastrophic seventeenth century minimum of height: Languedoc/Roussillon, Provence/Venaisson, Lorraine, and Alsace were clearly unsuccessful compared to the average French development. The Lyonnais developed also quite badly.

We are particularly interested in the potential interaction effects between the French *centralité* and the inequality of numeracy, approximated by our age heaping method. The adverse provinciality effect could have been much more detrimental in an unequal region, compared with more egalitarian ones, if we follow Lopez, Thomas and Wang's view of human capital inequality effects.[73] As can be deduced from Table 2, this interaction term 'dis * ineq of numeracy' had a significant negative effect as large as the French *centralité* for the whole period of the seventeenth to nineteenth centuries as well as the later sub period of the eighteenth to nineteenth centuries. Adding a square term of distance from government '(distance to government)^2', we can

[70] Szreter and Mooney, 'Urbanization'
[71] Komlos, ‚Anthropometric History', p. 164.
[72] Baten, ‚Kartographische'
[73] Ibid.

conclude that the detrimental effect of the French *centralité* on the periphery was non-linear and decreasing with distance. The regressions yield robust results after the inclusion of other control variables such as level of height, level of age heaping, and inequality in age heaping. We find that the level of age heaping does not matter for the biological welfare, while we can observe some convergence in height.

In column 4-7, we used a separate inequality estimate for the eighteenth century (whereas columns 1-3 referred to our seventeenth century estimates). Given the similarity of results, we are confident that those results are robust in spite of the obvious measurement error that should bias significance downwards (see also notes to Table 2). Please note that in the French case, only the interaction of inequality with distance from the government was significant, whereas inequality of numeracy never had a significant influence (col. 3). This can be interpreted on the basis of Gerschenkronian effects. One could imagine that higher inequality of education in the centre led to higher inequality of wealth, which caused in turn higher average saving rates and hence Gerschenkronian investments. We could also imagine reverse causality -- Kuznetsian forces might have increased inequality. These results confirm our hypothesis that centralism in France was crucial to regional development. This could be explained by selective migration to the capital as well as by the central allocation of state funds.

For the U.S. case, we also test the theories brought forward by Lopez, Thomas and Wang vs. Gerschenkron in a regression framework, using our inequality measures for the United States from section IV of our paper as an explanatory variable.[74] More specifically, we examine if inequality of numeracy had a statistically significant effect on subsequent industrial growth in the U.S.[75] To address this question, we use samples from the manuscripts of the decennial federal

[74] Ibid.; Gerschenkron, *Economic backwardness.*
[75] Note that we considered inequality before 1840 and economic growth for the period of 1850-1880 only, so that endogeneity is not a problem.

census of manufacturing for 1860 and 1880 collected by Atack, Bateman and Weiss.[76] The authors drew random samples of each state and territory that included between 6,000 and 10,000 firms in each census and cover 22 of the 25 states that we used in our descriptive analysis above.[77] Economic growth was low in 'high inequality' regions such as Alabama, Mississippi, and Missouri, and it was high in 'low inequality' regions (i.e. Indiana, New Hampshire, Pennsylvania and Illinois, see Figure 6). However, in two regions of low inequality (Massachusetts and Maine), growth was also low. This might have been caused by convergence effects, as Massachusetts had industrialized early – hence we will need to control for convergence effects in the following regressions.

In our regression analysis, inequality of numeracy (measured for the birth cohorts 1800s-1830s) has a significant and negative impact on economic growth during 1860-1880 (Table 3, Column 1). Embedded in a multivariate regression with additional variables, the variable remains significant (Column 2). Moreover, the level of age heaping (non-numeracy) also had a negative influence – in other words, both the level and equality of numeracy mattered positively for subsequent industrial growth. This is important, as one could imagine that the incidence of age-heaping in the lower half is exclusively responsible for the growth-constraining effect. However, we find here that in a joint regression, both the level and inquality of numeracy matter for growth. We also included a dummy variable that takes the value 1 for the 11 southern states and 0 otherwise.[78] The dummy variable was designed to capture effects caused by the different industrial structure between North and South as well as the consequences of the civil war. The differences between the U.S. South and the North are certainly manifold, and were very much so during the nineteenth century. Not only did the South suffer severe destruction of its

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[76] See Atack and Bateman, 'U.S. industrial development' for a description of the data set.

[77] For Rhode Island, all census years are missing, while for Georgia and Louisiana, only 1880 is available.

[78] The southern states include Alabama, Delaware, Georgia, Kentucky, Louisiana, Maryland, Mississippi, North Carolina, South Carolina, Tennessee and Virginia.

infrastructure and population during the Civil War in the early 1860s, but its general economic structure was also very different from the North. Rather surprisingly, the dummy variable for the South turns out statistically insignificant. All in all, the model can explain as much as 55 per cent of the variance of value-added growth. We can thus conclude that our empirical analysis of nineteenth century United States shows mild support for a negative impact of inequality on economic development, as predicted by Lopez, Thomas and Wang.[79]

VI

Age heaping provides an exciting new way to measure the numeracy of populations before the Industrial Revolution, if a number of institutional factors can be taken into consideration. Moreover, if there are proxies available for the lower versus middle/upper class origin of individuals in a sample (such as occupational group or anthropometric percentiles), we can even study the inequality of numeracy for pre-industrial economies. We have assessed this methodology for France and the U.S. during the seventeenth to nineteenth centuries and produced maps of numeracy inequality for France in the late seventeenth century, and the U.S. in the nineteenth century. Next we studied whether recent theories, which suggest a negative influence of human capital inequality on subsequent welfare growth, can be confirmed for this period. We find that this was indeed the case for the United States. Through regression analysis we find that inequality of numeracy exerts a significant negative relationship on subsequent economic development in the United States. In France, the relationship was less clear. Taking also political factors into account, the proximity of a region to the central government in Paris turned out to be an influential variable for nineteenth century France. Interestingly, this factor in interaction with numeracy inequality also had explanatory power: Peripheral regions with high inequality experienced especially low welfare growth. The U.S. case allowed to trace the path of inequality

[79] Lopez, Thomas and Wang, 'Education puzzle'.

into the industrial period. We find that the industrial (and immigration) centres in the Northeast actually had strong surges in inequality in the spirit of Kuznets' inverse U hypothesis.

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Tables

Table 1: Difference in non-numeracy by tall versus short individuals in France, and lower versus middle/upper income occupations in the U.S.

Country/Region	Institution	Birth Decades	WI* Low	WI* high	Ratio
US (North)	US census	1800s-1830s	127	125	1.01
US (South)	US census	1800s-1830s	180	138	1.37
US (North)	US census	1840s-1870s	126	116	1.08
US (South)	US census	1840s-1870s	165	129	1.38
Paris	French Army	1650s-1760s	141	102	1.38
France (Northeast)	French Army	1650s-1760s	125	117	1.07
France (Southwest)	French Army	1650s-1760s	142	125	1.14
France (Total)	French Army	1650s-1760s	135	123	1.10

Notes: * WI is the Whipple Index, which stands for low numeracy, and higher values of the 'ratio' indicate higher numeracy advantages of the taller half of the population, compared with the shorter half in France, and higher numeracy advantages of the middle/upper income occupations in the U.S. Source: see text.

Table 2: Determinants of height change in France: distance, distance interacted with inequality, and other variables

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Dependent Variable:	17th-19th C	17th-19th C	17th-19th C	18th-19th C	18th-19th C	18th-19th C	18th-19th C
Dis * ineq of numeracy 1660-1709		-0.15 (0.00)					
Dis * ineq of numeracy 1710-1759					-0.16 (0.00)		-0.11 (0.01)
Distance to government	-0.16 (0.00)		-0.41 (0.00)	-0.17 (0.00)		-0.38 (0.01)	
(Distance to government)^2			0.03 (0.04)			0.04 (0.06)	
Level of age heaping 1660-1709			0.01 (0.23)				
Inequality of age heaping 1660-1709			0.43 (0.25)				
Level of height 17th C			-0.19 (0.00)				
Level of age heaping 1710-1759						-0.01 (0.11)	-0.00 (0.31)
Inequality of age heaping 1710-1759						-0.52 (0.38)	-0.07 (0.91)
Level of height 18th C						-0.22 (0.00)	-0.21 (0.00)
Constant	2.77 (0.00)	2.74 (0.00)	328.40 (0.00)	1.54 (0.00)	1.51 (0.00)	373.1 (0.00)	356.60 (0.00)
Observations	83	83	83	83	83	83	83
R-squared	0.10	0.10	0.43	0.09	0.10	0.52	0.50

Robust p values in parentheses. Note: We calculated the dependent variable as the height change between adjusted Komlos & Kim estimates (adjusted with the method proposed by Komlos, 'Anthropometric History', p. 64) on the basis of the provinces, and heights in French departments from the Annuaire statistique (cited from Baten, 'Kartographische'). This means that sometimes two or three department heights are compared with the joint province height estimate, introducing some randomly distributed measurement error. Due to space constraints, we excluded the insignificant results for the sub period 17th-18th centuries. Source: see text.

Table 3: Inequality as a determinant of industrial growth in the 19th Century U.S.?

Dependent Var.: Real Growth 1860-1880	(1)	(2)
Inequality of numeracy before 1840	-1.76	-0.77
	(0.00)	(0.05)
Value added 1860	-0.82	-0.79
	(0.00)	(0.00)
Level of age heaping before 1840 (Whipple Index)		-0.61
		(0.05)
Dummy for Southern states		-0.24
		(0.27)
Constant	2.56	2.39
	(0.00)	(0.00)
Observations	22	22
R-squared	0.39	0.55

Robust P-values in parentheses. Notes: For demonstration purpose, value added 1860 and level of age heaping before 1840 are divided by 100. Since input and output values were reported in nominal Dollar amounts, we adjusted for changes in prices using 's the price deflators of Atack, Bateman and Margo, 'Amercian Manufacturing'.
Dummy for Southern States: We grouped the data on the basis of the Census divisions used by the US Census Bureau. Accordingly, we created the group 'North' (including the divisions East North Central, Middle Atlantic and New England) and 'South' (West South Central, East South Central and South Atlantic). Source: see text.

Figures

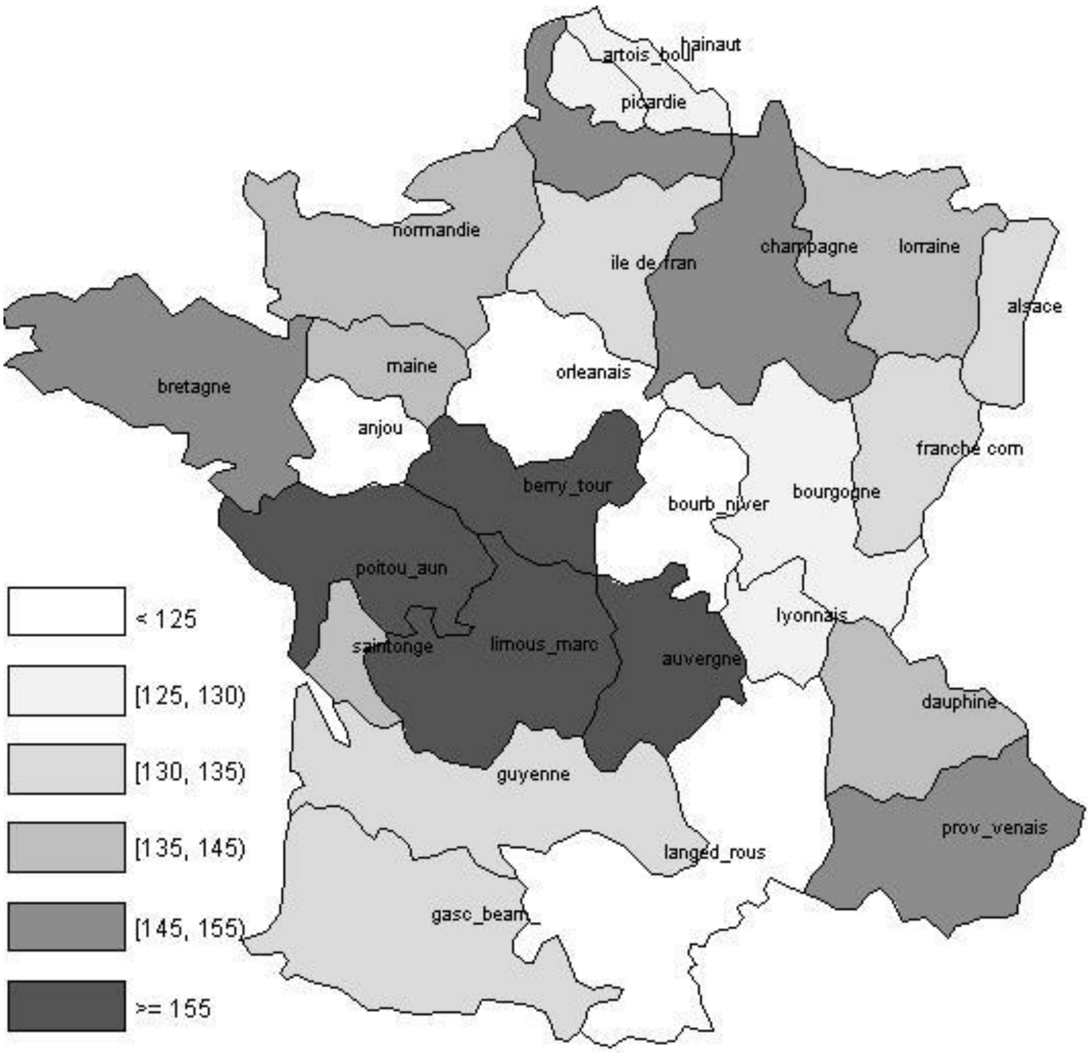

Figure 1: Non-numeracy in seventeenth century France (Whipple Index values of 1660-1709).
Source: see text.

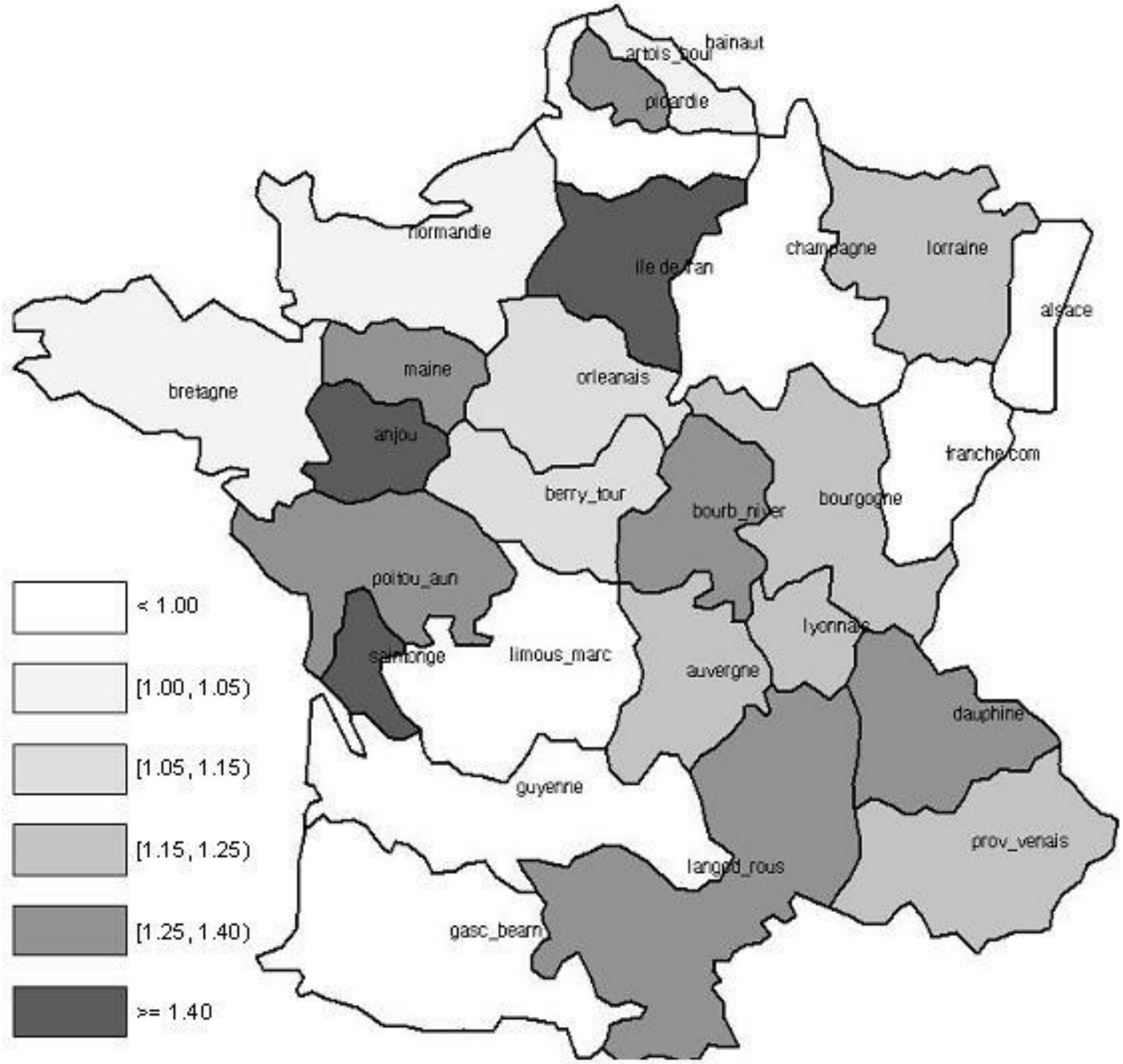

Figure 2: Inequality of Numeracy in seventeenth century France (Inequality of Whipple Index values of 1660-1709).
Source: see text.

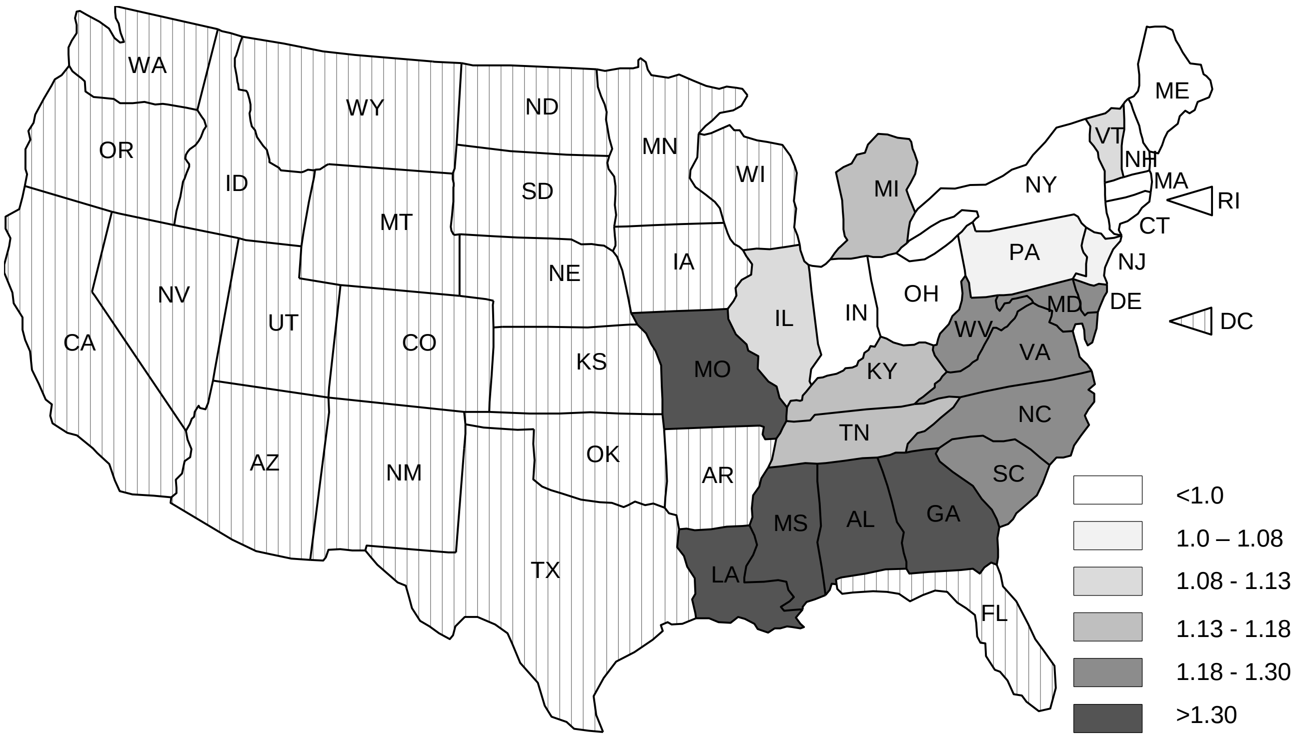

Figure 3: Inequality of Numeracy in the U.S. birth cohorts before 1840
Source: see text.

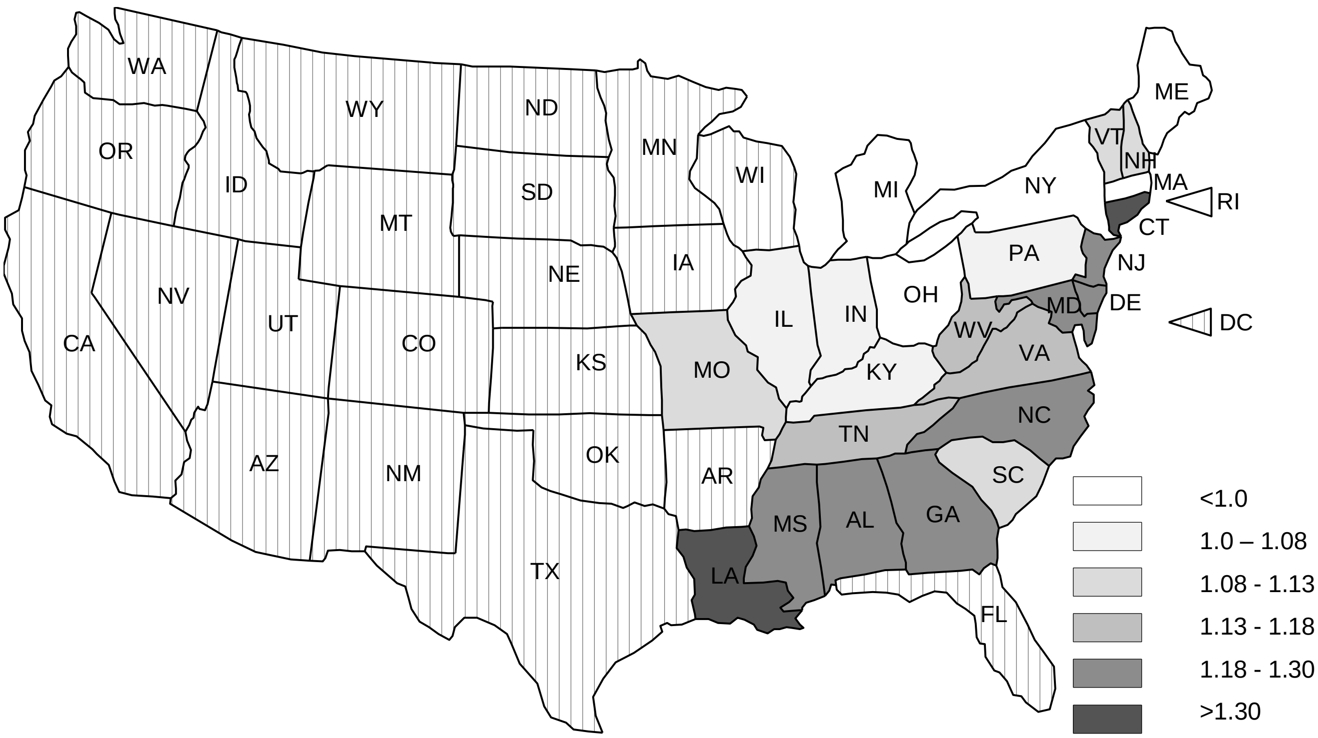

Figure 4: Inequality of Numeracy in the U.S. birth cohorts after 1840
Source: see text.

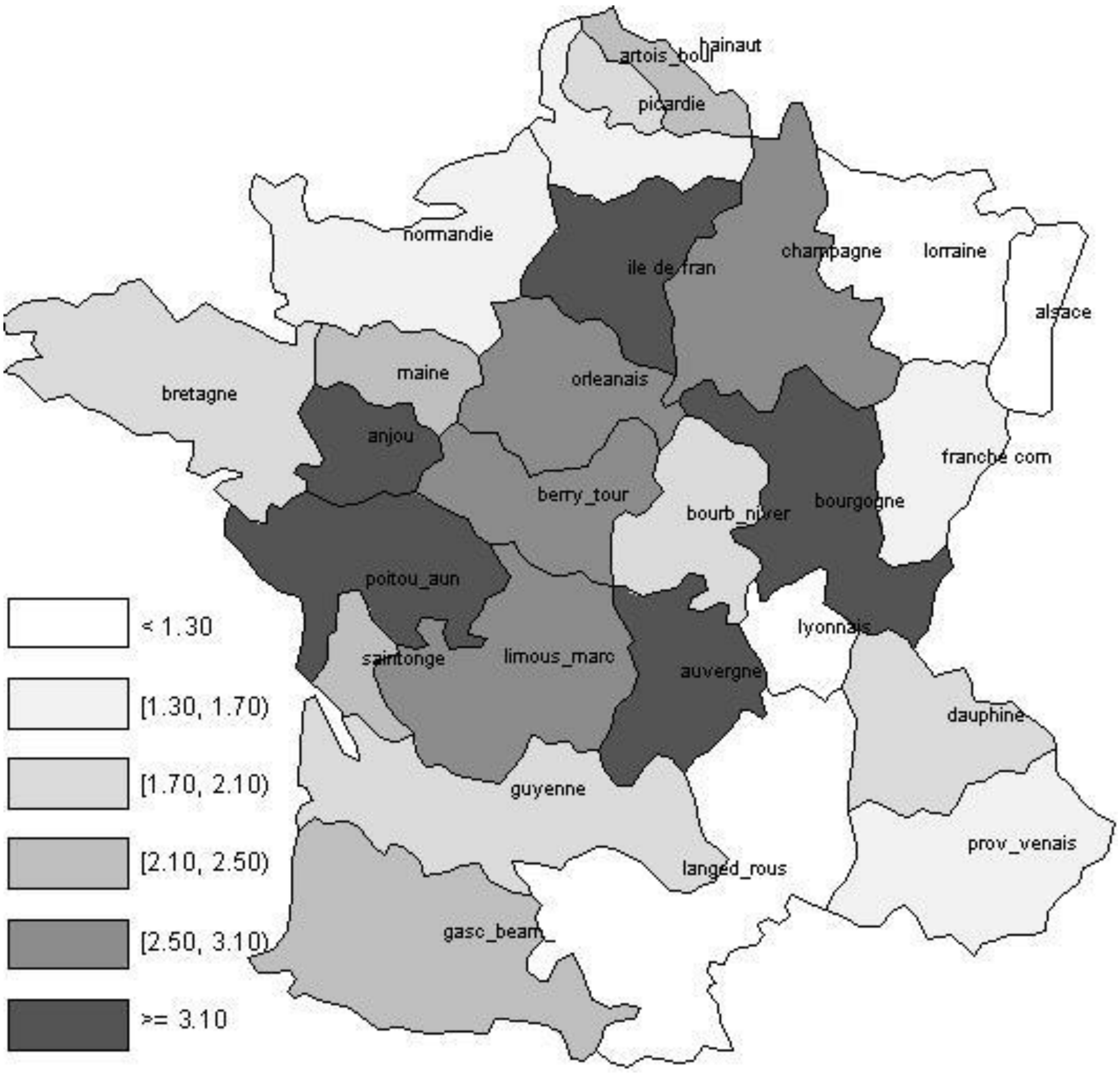

Figure 5: Change in height (in cm), seventeenth to nineteenth century.
Source: see text.

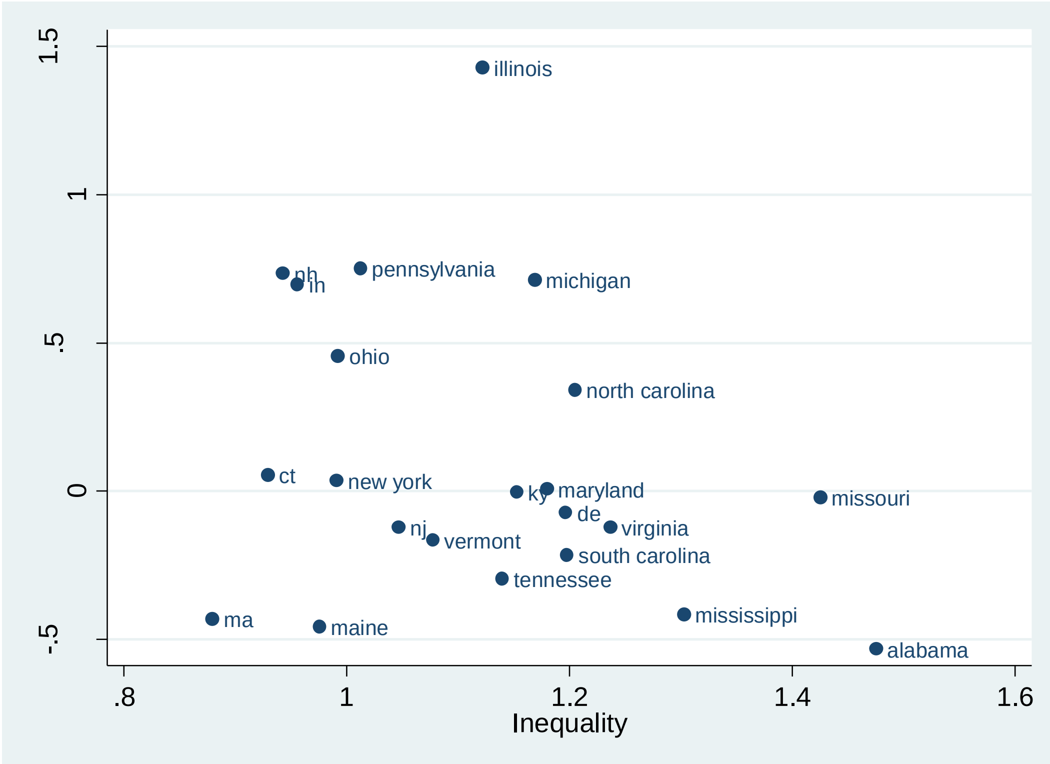

Figure 6: Inequality's impact on economic growth in nineteenth century United States.

Notes: "Inequality" is the inequality of age heaping of the birth decades 1800s-1840s.

"Economic Growth" is the real growth of industrial value added between 1860 and 1880. Source: see text.

Abbreviations:
CT- Connecticut
DE- Delaware
IN- Indiana
KY- Kentucky
MA- Massachusetts
NH- New Hampshire
NJ- New Jersey