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Inequality, Low-Intensity Immigration and Human Capital Formation in the Regions of Chile, 1820-1939

Abstract

This article traces inequality and numeracy development in the regions of Chile during the 19th and early 20th century. Inequality, measured with anthropometric methods, was associated with a lower speed of human capital formation. Not all talents received the necessary education to make full use of their talent for the regional economy, especially in the south. However, in its northern regions we find that Chile was relatively equal and numerate during the 19th century, and the south converged somewhat during this period. In addition, we study the correlates of low-intensity immigration in Chile. Regions with a relatively high share of North European migrants developed faster in terms of numeracy.

JEL-Codes: N360, N960, O150.

Keywords: inequality, immigration, human capital, numeracy, regions, Chile.

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Introduction

In recent decades, Chile has enjoyed one of the highest levels of average income in Latin America, together with macroeconomic and political stability. However, Chile is also a very unequal country, with a Gini coefficient (of household disposable income) as high as 0.46. The richest 10% of the population accounts for nearly 40% of the nation's income.[1]

Until October 18th 2019, the Chilean elite seemed to be either unaware of this situation (which is doubtful),[2] or they did not realize the dangers of high inequality.[3] That day, though, the most violent unrest in Chilean history erupted: many tube stations were set on fire, as well as buses, restaurants, churches, state buildings, and other iconic buildings (e.g. universities, the headquarters of the main electricity company, banks, supermarkets). Looting was widespread, and the president called the military to the street: a curfew was ordered for several days, the longest curfew during a period of democracy in the country's entire history. The Chilean oasis was quickly transformed into one of the driest deserts on earth, and the country was almost in a state of civil war. What was at the root of this unrest? Most newspapers reports and interviews with actors agree that extreme inequality, including low pensions, poor quality health care and the lack of education for the bulk of the population played the largest role in driving the conflict.[4]

Chilean inequality is not new; it has a long and dramatic history, although its long-term evolution has attracted little attention until recently (Rodríguez 2017; Llorca-Jaña et. al. 2018a; for the global comparison of Chile’s land inequality see Federico 2005, p. 155). This is

[1] https://www.oecd.org/social/income-distribution-database.htm.
[2] On 5 October 2019, a few days before the worst social unrest in Chilean recent history started (18 October 2019), a proud President Sebastián Piñera told journalists that within Latin America Chile was an oasis of political stability, with GDP, employment and wages all growing, further adding that Chile was a wonderful country to live in, which turned out to be a provocative statement for many. https://www.latercera.com/politica/noticia/pinera-asegura-medio-esta-america-latina-convulsionada-chile-verdadero-oasis-una-democracia-estable/851913/
[3] Polo Ramírez, one of the most famous and respected Chilean journalists, a few days after the October 2019 riots started, declared live on television on one of the most prestigious TV channels of the country that "we knew that there was inequality, but we [the elite] did not know that they [the poor] bothered so much". https://www.radioagricultura.cl/entretencion/2019/10/23/polo-ramirez-es-duramente-criticado-por-polemica-frase-sobre-las-manifestaciones.html
[4] See notes 2 and 3 above.

significant because today's inequality is mostly the result of past developments. To understand what is happening today we need to know what has happened during the 19th and 20th centuries.

While Chile is one of the countries with the highest income inequalities today, over the past two centuries and across regions it was markedly heterogeneous. We find that some of the northern regions were relatively equal around 1900, after several decades of declining inequality. The southern areas were more unequal especially around 1850 when numeracy was also very low. In fact, regional differences of inequality were extremely large, hence regional approach provides important value – added to understand Chilean inequality history.

We measure variance in inequality using anthropometric inequality (i.e. the variation of height, see Appendix C). We assess whether this implied also heterogeneity in numeracy development in the regions of Chile, which we trace using age-heaping methods (see Appendix B). We measured basic numerical abilities using the age heaping method, which is by now a widely accepted indicator of numeracy (A'Hearn et al 2009; Crayen and Baten 2010a; Crayen and Baten 2010b; Manzel et al 2012; Tollnek and Baten 2017). Age-heaping based numeracy estimates rely on the phenomenon that people often are rounding their ages if they do not have basic numerical skills. For example, in censuses people often report the age of 40 when they are really age 39 or 41. Earlier studies have found consistently a very high correlation between the share of people who are rounding their ages in this way and other education indicators of low education such as illiteracy. The correlation with low numeracy is particularly strong (A’Hearn et al. 2009). For the purposes of this study, we estimated inequality and numeracy for a panel of 17 regions, covering the decades of births from the 1820s to the 1930s.

The core question is whether high inequality correlated with a slower development of numeracy? Or did high inequality imply a positive income development, as Gerschenkron

(1962) famously argued for the late 19th century?[5] We find that inequality was associated with slower development of numeracy in the nineteenth century and early 20th century, suggesting that incomes could have been even higher in the following period without inequality.

Although the relationship between inequality and average income for developing countries in the 20th century is not finally settled yet, most recent studies have shown a negative relationship. This can be illustrated by the example of relatively low levels of inequality and high growth rates in Asian ‘tiger’ economies (Lindert and Williamson 2001). Many Latin American countries in contrast had high rates of income inequality, which was interpreted as hurdle to economic growth (Bértola 2016, on earnings inequality see Arroyo-Abad and Astorga Junquera 2017). Arroyo-Abad and Astorga Junquera (2017) also argue that the “Great Compression” during the mid-20th century was not really as substantial in Latin America, as it was in Europe and the U.S. (Collins and Niemesh 2019).

The theoretical underpinning of the inequality-numeracy nexus is based on three causal chains, two of them relevant for our period.[6] The first mechanism relies on the observation that in high inequality settings talents are not fully used. Of course, talents are not only allocated to the middle and higher income groups but are also abundant among the poorer income groups. But in unequal societies, children of the latter groups cannot fulfil their potential, as they do not receive the necessary education. The society as a whole suffers from this waste of talent. Demands for better education were also at the heart of the recent Chilean unrest, since better education leads to higher wages and a better future prospect (Contreras 2002). The quality of Chilean education in public primary and secondary schools, which the

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[5] Gerschenkron had agrarian countries like Russia in mind in which the government and the rich elites invested substantially in physical capital, such as railroads, mines and partially agricultural machinery.

[6] In the recent past (from the 1960s to today), a third theory can be derived from imperfect credit markets, which prevent asset-poor people from making economically profitable investments in physical and especially in human capital, but this might be less relevant for our early time period (Deininger and Squire 1998, Galor and Zeira 1993). For the 19th and early 20th century, it is an empirical question whether the positive Gerschenkronian inequality effects or the negative inequality effects of wasting talent and provoking conflict were stronger.

bulk of the population attends, is poor, in particular if compared to private schools. This poverty of education leads to low labour productivity, as well as to severe structural inequalities that impact on access to higher education, retention, output and future opportunities in the labour market (Matear 2006). A second theory is based on the idea that inequality leads to sociopolitical conflict, which in turn reduces the security of property rights, thereby discouraging the accumulation of capital (on distributional conflicts, see Alesina and Rodrik 1994; Persson and Tabellini 1994; Barro 2000). Baten and Mumme (2013) observed that the frequency of civil war is substantially higher in countries in which there are considerable health inequalities (measured by the inequality of human stature).[7] Conflicts are obviously a burden for human capital and general development (Collier and Hoeffler 2004). Perotti (1996) found that sociopolitical instability is enhanced by higher inequality, which in turn hampers economic development. As Barro (2000) argued, crime and riots deter investment and reduce the productivity of an economy.

Recent studies have found that numerical skills are among the most crucial determinants of economic growth (Hanushek and Woessmann, 2012; Baten and Juif, 2014; Baten et al 2017). Although they are closely correlated to other components of human capital, such as literacy or advanced human capital, numerical skills are vital. For example, if labourers are able to work with numerical proportions, if they can work with calendars, and plan working hours, they are far more productive. These skills were just as important for 19th century agricultural economies (Tollnek and Baten 2017; Crayen and Baten, 2010a; A'Hearn et al 2009; Manzel et al. 2012).

Chile's high inequality resulted in earlier studies that focused on its income and land inequality from the 1830s. Land inequality was studied by Llorca-Jaña et al. (2018a), who

[7] The recent riots of October 2019 in Chile have been compared to recent civil wars in Arab countries by the international press. https://www.usnews.com/news/best-countries/articles/2019-10-24/protests-across-south-america-unleash-public-anger-at-elected-leaders; http://theconversation.com/whats-going-on-in-south-america-understanding-the-wave-of-protests-126336; https://www.theguardian.com/world/2019/oct/25/protests-rage-around-the-world-hong-kong-lebanon-chile-catalonia-iraq.

found that around 85% of the population did not own any land during the 1830s, in a mostly rural agrarian society. The Gini coefficients for agricultural market income for the entire rural population were around 0.8 during the 1830s-1850s. Income inequality from the 1860s was studied by Rodríguez (2017), who used three large occupational groups and estimated their income development, finding that inequality has been high during the last 150 years, but that it has varied, and that these variations have been heavily influenced by the regional political economies. For example, income inequality decreased during the 1930s-1960s (a period of active government intervention in economic affairs), increasing during the dictatorship and remaining high but stable thereafter.

However, no study has reflected on the relationship between inequality and educational development, and numeracy in particular. Research has been hampered by the unavailability of data on both components, regional inequality over time as well as numeracy development. One exception for numeracy is the unpublished thesis by Cardemil (2015), who provided data at a national level only (rather than regional) and for a shorter period than that covered in this article.

We use a proxy indicator to measure inequality, adopting the strategy of measuring inequality in height. It is now widely accepted that, in particular for developing countries, height offers a good alternative and complement to more conventional inequality indicators such as personal income or real wages. In many respects height is a better indicator, if selectivity does not make samples unrepresentative (Salvatore, Coatsworth and Challú 2010; Cámara Hueso, Martínez-Carrión, Puche and Ramon-Muñoz 2019). In the case of Chile, labor market selectivity was not an issue because everybody was measured to do the general constriction before some were then selected for the army. Our source is based on that general constriction. The coefficient of variation of height has been consolidated as a good indicator to measure inequality [on this, see Baten 2000, Moradi and Baten 2006; Van Zanden et al. 2014a].

Inequality was substantially negatively related to the development of numeracy in 19th century Chile. The successful period of income growth could have happened earlier if inequality had not been so high in some regions of Chile during the 19th century. We also assess this in a robustness test for which we disaggregated inequality and numeracy at the city level. This is particular relevant given the recent contributions to endogenous growth theories that suggest that inequality reduces growth (for a review on this, see Crayen and Baten 2010a).

This study also takes into account the relationship between immigrants and the development of numeracy in the overall population. In earlier studies, immigration from countries with on average higher educational levels has been connected to a more positive human capital development [Droller 2018 on Argentina; Stolz, Baten and Botelho 2013; and recently Witzel de Souza 2019 on Brazil].[8]

This study will be the first in a series of studies on inequality and human capital in the developing world, providing a methodological tool kit to understand these two crucial components of development on a disaggregated, regional basis that will provide new insights for general growth economics.

Data: Regional Human Capital Trends

How can numeracy in Chile be reconstructed by region over the 19th and early 20th century? We first collected a dataset from Chilean mortality registers that local institutions recorded from the 1870s onwards, which are accessible until the early 1930s (1885-1932).[9] These

[8] However, there is also an interesting debate regarding the "quality" of the immigrants who arrived in Latin America, if compared to those going to, say, the United States, and whether or not those who arrived in Latin America were "the poor among the poor". In any case, it seems that those Europeans arriving in Latin America were not worse educated than the average population of their countries of origin, and that the poorest Europeans did not have enough resources to emigrate to Latin America (Bértola and Ocampo 2012).

[9] We thank the Church of the Latter Day Saints for providing the data on this internet site, which can also be used for scholarly research (see, for example, earlier studies by Clark, Cummins, Hao and Vidal 2015). We approached this site in November 14th, 2019. Citation: "Chile, Registro Civil, 1885-1932." Database with images. *FamilySearch*. http://FamilySearch.org : 18 December 2019. Registro Civil Archivo General (Record Office General Archives), Santiago.

records were characterized by systematic registration. In comparison with death registers collected by the churches, these registers were taken more systematically to reflect the whole population at death. Religious minorities not included in Catholic Church records were also recorded. The age of the deceased was recorded by asking the close relatives of the person who had died (A'Hearn et al. 2009). We sampled six locations in each Chilean province, beginning with the first three places according to the alphabet and continuing with the last three places (also alphabetically), in order to obtain a relatively random sampling. We took care that, among these six places, there was only a proportionate share of large cities in a single province, meaning that the urban share was representative for each province. The capital city of Santiago (a separate unit in terms of provinces) is reflected by its city quarters, such as Recoleta and others. We collected the first three hundred cases of each selected place, which allowed us to cover decades of birth from the 1820s to the 1870s relatively systematically. We calculated the level of numeracy for each province and decade of birth.[10] We dropped any province-birth-decade observation that did not contain 30 observations, but fortunately this applied to almost no cases – typically our individual units were based on more individual observations. The population in the first decades of birth in Antofagasta and Tarapacá were born before these territories were incorporated into Chile in 1883. After removing ages below 23 and above 72 and birth years before 1820 and after 1879, these resulted in a sample of 7,914 observations, spread evenly over provinces and decades of birth (Table 1).

[10] We needed to join some of the provinces which were created at a later date, such as Maule and Linares (1854: Maule), Llanquihue and Osorno (Llanquihue), Chiloé and Aysén (Chiloé) and Colchagua and Curicó (Colchagua). In order to mitigate the issue of the non-inclusion of the newly emerging provinces, we organized the provinces by birth decades and in cases where there were enough observations we included province-birth-decade units. This resulted in 19 provinces plus Magallanes, which did not have a significant number of entries in the mortality registers of inhabitants born before the 1870s. In order to make the regional structure compatible with the provincial structure in 1854, we needed to unite Cautín, Malleco, and Arauco to the 1854 province of Arauco, Biobio and Concepcion (1854: Concepcion), Tarapacá and Atacama (Atacama), which reduced the number to 16 (17 with Magallanes).

We supplemented these early mortality registers with evidence from the 1940 census for each province (in aggregated form). The census included the whole Chilean population, and statistics were published by the statistical authorities of Chile that reported single years of age, allowing us to calculate numeracy from the 1870s up to the 1910s based on the whole provincial population (Chile 1941). The overlap between the two sources, the early mortality registers and the census of 1940 indicated a substantial degree of correlation across provinces (Figure 1). This correlation allowed us to counter-check the information content and validity of the mortality–register-based numeracy estimates.

Next, we added the individual census data from “IPUMS International” on the 1960 census, in which age heaping is still visible in Chile. Hence, we calculated both the numeracy and the years of schooling by decade of birth. The 1960s census allowed for organizing the data by birth province whereas the mortality registers and the census of 1940 only included the province of death or province of residence. As basic numeracy and education is acquired in the first decades of life, we needed to rely on the assumption that migration between Chilean provinces at later ages was not both dramatically large and skill-selective.[11]

The 1960 census also allowed for calculation of the years of schooling, which helped to countercheck the information content of the age-heaping-based numeracy estimates for Chile. This process has been performed in a large number of studies using a variety of samples before, but it is reassuring that we also found a correlation between numeracy and years of schooling in Chile (for other studies and samples see, among others: A’Hearn et al. 2009, Crayen and Baten 2010a, Maravall, Baten and Fourie 2019).[12] The systematic comparison of years of schooling and ABCC index of numeracy (A'Hearn et al 2009) based

[11] There were some migratory movements to the Nitrate district during the 1880s-1920s, and from the south to Araucanía after the conquest (during the 1880s-1890s). There were also migratory movements from rural areas to urban areas, especially to Santiago. However, the close correspondence between the provincial averages from two sources that originate from different periods suggests that distortions from skill-selective migration were probably modest.

[12] For years of schooling, we used the threshold of the age of 25 in order to make sure that almost everybody had finished schooling by the time of the census of 1960.

on the 1960 census yielded a close correlation (Figure 2). We took into account that the numeracy index ABCC is a bounded variable and cannot go beyond 100 percent. Hence we estimated a log-linear functional form, taking the logarithm of the school years.

How did numeracy develop in Chilean regions? We first briefly discuss numeracy trends in selected regions, although the central aim of the study is the relationship between inequality and numeracy development (Figure 3). At a national level, Chilean numeracy at the beginning of our period of study, the 1820s, was extremely low. This is not surprising as there was almost no public education system in place in Chile (Cardemil 2015). In addition, the early 19th century was a period of stagnating and partially declining numeracy rates in many Latin American countries (Manzel et al. 2012). From the 1840s to the 1880s, there was an accelerated improvement in numeracy in Chile, followed by more moderate growth, and then by stagnation during the first decades of the twentieth century. Although the nineteenth-century education system was neither universal, nor good quality by international standards, it was good enough to improve the basic math skills of the bulk of the population. Primary schools' enrolment rates increased significantly between the 1850s and the 1890s, when the public elementary education system of the country was consolidated (Cardemil 2015). Among many other Latin American countries, Chile also witnessed educational campaigns during the above-mentioned period. These campaigns were funded mostly with increasing export duties during the nitrate era, along with some external borrowing. Educational investment was relatively similar in the different provinces of Chile, given that federalism was not very strong. By 1830, the conservatives, mainly based in Santiago-Valparaiso, had defeated the liberals, and with them any attempt of federalism in Chile. There was not, therefore, any conflict between Santiago and the provinces. There was a centralization of government revenues. This is quite different to what happened in Argentina, for example. Moreover, education in the family household still played a crucial role, especially in regions with less inequality where families invested in the education of their offspring, because they expected them to earn higher incomes later in life. In contrast, in more unequal regions and periods they invested much less effort, because they expected low incomes, as most of the population were unskilled labourers and had no other prospects in life.

At the beginning of the 19th century Valparaiso, which is a port city, was characterized by a relatively high numeracy rate (around 50% in 1820), reflecting the fact that Valparaiso was the main financial centre of the country, highly urbanised and dynamic, and where most Britons in Chile lived. The numeracy rate in Talca, a rural province that did not receive many immigrants by this stage, was very low: only around 15%. Both Santiago, the present capital of Chile, and Valdivia were characterized by relatively low numeracy rates in the early and middle decades of the 19th century. However, we observed a strong positive trend in the following years. All the regions improved in numeracy, which reached about 90% in the early 20th century. Since then the values in all four regions have remained relatively stable and high (compared to the early observations). Nonetheless, the numeracy skills in Talca remained lower than those in the other cities.

In Figure 3, Panel B, we show four other provinces. The Atacama region, the most northern Chilean province before the 1880s (before Tarapacá and Antofagasta were taken from Peru and Bolivia, respectively), performed well in regard to numeracy, although sparse populations in other parts of the world have often resulted in lower numeracy. Distances to the nearest school usually increased the cost of education in other countries of the world (Bouccekine et al. 2003). But in Chile, the richest copper and silver mines of the country were concentrated in the Northern region. The data for Magallanes was not available for the time period 1820-1870 (since the region was sparsely populated),[13] but we observed a high numeracy rate for this region from 1880 onwards: over 95%. We also saw an impressive rise

[13] For example, the census of 1865 reported just 165 inhabitants for Punta Arenas, the capital of the province, but by 1895 this figure had increased to over 3.000.

in the numeracy rate in Valdivia – more than 20 percentage points within a decade (1870-1880) and in Chiloé - over 40 percentage points between 1860 and 1880.

It would be tempting to conclude a strong convergence of numeracy between Chilean regions. However, all educational indicators that can be estimated for the 19th century (literacy, numeracy and enrolment) are bounded variables: they cannot move above 100 percent. Hence we would be hesitant to derive measures of convergence of human capital.

In sum, we present here for the first time a dataset that allows us to describe and analyse the regional numeracy development of a Latin American country from the 1820s to the 1930s by decade of birth, decade by decade, province by province. We will now assess whether the relatively fast development was associated with low inequality in some regions and periods, whereas high inequality hindered development in others.

Estimation of Regional Inequality Trends

How can inequality be measured in different provinces and time periods? We obviously did not have a record of income for every Chilean living in the 19^{th} and early 20^{th} century. Hence, we needed to use proxy indicators. One possibility was to measure land inequality using the share of land owned by the wealthy groups (Llorca-Jaña et al. 2018a). But this was only possible for a few points in time, and though it was a large step forward for measuring inequality, it covered primarily agricultural wealth, not overall welfare. The second approach was to use height inequality as has been suggested by Baten (2000), and further explored in Moradi and Baten (2005) as well as van Zanden et al. (2014a).

We used height inequality as a measure of inequality of consumption in Chile (see also Appendix C on this method). Clearly, food consumption accounted for the largest share of overall consumption (Baten, Crayen and Voth 2014). It is an advantage that this measure reflects the inequality of consumption of high quality foodstuffs. In the 19^{th} and early 20^{th}

century, milk and meat were scarce and important for nutrition, firstly because they were rich in high-quality protein, iron, calcium, and other essential nutrients that were crucial for the human organism itself (Baten 1999). Secondly, these nutrients were essential for creating antibodies against infectious diseases. As a consequence, individuals who consumed these high quality foodstuffs usually had a relatively high life expectancy and a healthy life (Fogel 2004).

A large number of articles have used the height inequality measure from initially local studies to studies of the whole African continent (Moradi and Baten 2006) and India (Guntupalli and Baten 2016), to global approaches (Van Zanden et al. 2014a, Van Zanden et al. 2014b). Angus Deaton (2008) has discussed this method for India and it has also recently been applied to Spanish inequality (Cámara et al. 2019).[14] Clearly, this approach needs to take into account the biological component of height variation, which results in a basic variation even if there is no inequality of food consumption. However, in addition to this basic biological variation, there is the inequality of consumption which leads the height variation to be correlated with the income inequality measures such as the income Gini coefficient (Moradi and Baten 2006, Baten and Mumme 2013, Van Zanden et al. 2014a). Moradi and Baten 2006, Baten and Mumme 2013 and Van Zanden et al. 2014a have analyzed this measure in a consistent econometric framework.

This methodology allowed us to draw on the substantial height data set collected by Llorca-Jaña et al. (2018b, 2019, 2020a and 2020b), who recorded military height, for the 18th to 20th century in large samples. The big advantage was that for most of the period this height data stemmed from general conscription, so there was no selectivity in the sample and also no significant minimum height requirement before measurement. When height inequality was compared with income inequality as estimated for the whole country by Rodriguez (2017), a

[14] See also Xu and Hang 2017, and Gausman et al 2018.

similar trend emerged (Figure 4). During the 1860s and 1870s, both indicators reached a high level, after which inequality decreased. In the 1890s and 1900s, both indicators reached the lowest values of this period. In sum both height inequality and income inequality described a similar national average trend of inequality in Chile.

As a way of counterchecking the reliability of height inequality for regional data, we compared our measure of height inequality with land inequality and observed a strong correlation for the regional cross-section of the 19th century. Land ownership is one of the sources of income inequality and subsequently also consumption inequality. However, land inequality does not reflect exactly the same inequalities as height inequality, because some population groups might have consumed different food items independently of their land endowment. For example, northern European immigrants traditionally consumed more milk than the Chilean population, who originated from Spanish immigrants and the Mapuche population. In the cuisine of the Mapuche, milk only plays a minor role and lactose intolerance is not infrequent.[15]

When height inequality was compared with land inequality – except for provinces in which northern European immigration was particularly strong, a close correlation was found between land inequality and height inequality (Figure 6).[16]

We use height inequality as a correlate of numeracy, because in high inequality settings, unusually talented people might not receive the necessary encouragement from their parents to obtain schooling or use learning devices available to other households. Moreover,

[15] Recent studies have found low dairy intake amongst the Mapuche, due to unpleasant gastrointestinal symptoms, as well as to cultural dietary habits. Likewise, lactase persistence has been found in only around 10% of the Chilean Amerindian population, as opposed to 40% of the rest of the population (Fernández and Flores, 2014, 2016).

[16] In the four provinces where northern European immigration was a factor, in contrast, the correlation was not found, which might have been because of the consumption patterns of the minority of northern European immigrants and the population who adopted their nutritional habits or created new, compromise strategies of nutrition (Appendix Figure F.1).

child labor was frequent among the poor in high inequality settings, reducing further the possibility of gaining a good education.

We need to consider that inequality might be an endogenous variable. However, we observe that differences in land inequality between provinces were established relatively early, going back to colonial roots, and there is an overall correlation between land inequality and height inequality. As numeracy differences between provinces was more variable over the 19th and early 20th century, this might suggest that the causality was in fact running from inequality to numeracy, but we cannot be sure. Hence we avoid any causal language, and rather speak of "relationships" and "correlation" between the two variables, and the same is true for the relationship between North European immigration and numeracy.

The observations on numeracy trends discussed above often corresponded with height inequality (Figure 3). We observed relatively high values in the first decade of the 19th century, which declined in the following decades (Figure 5). Chiloé was the province with the highest height inequality (and very low numeracy). What was remarkable was the high inequality rate in Santiago, which increased significantly in the first half of the 19th century, but fell continuously from 1840. Again, this trend corresponded with low numeracy in spite of Santiago being the capital city. The inequality level in Talca has stagnated since 1860.

Llorca-Jaña et al. (2018c) discussed the land inequality in Chiloé. Chiloé showed later a dramatic trend towards lower height inequality, and towards more numeracy. Interestingly, in the early 19th century, the lower income groups had a low standard of living in Chiloé, as Eduard Poeppig, a professor of Leipzig University (1835) documented, while visiting the country in the 1820s: "if Chile was badly treated by the Spanish government, it could be said that for Chiloé it had the feelings of a stepmother […] the whole archipelago was divided into just 100 *encomiendas* […] The poor indigenous people were slaves of the *encomienda*'s holders, and more badly treated than in Peru". Only later in the 19th century did land redistribution have positive effects on the lower income groups in this island region in the south of Chile. The positive effects were delayed by several decades.

The relationship of immigration and numeracy

Although the main focus of this study is the relationship between inequality and numeracy, human capital and Latin America have been related in earlier studies to immigration patterns (Droller 2018). Hence we need to take this factor into account.

Immigration in Chile during the 19th and early 20th centuries was modest, in particular if compared to nearby countries (Sánchez-Albornoz 2014; Bértola and Ocampo 2012). The labour market was already well supplied, and the cost of travelling from Europe to Chile was higher than to Atlantic countries, while the Chilean government was less interested in subsidising immigration than Argentina, Uruguay or Brazil. Furthermore, Chile was better supplied with labour, and had real wages below those of Argentina, Uruguay or Brazil (Matus 2020). Hence, immigration never exceeded 5 per cent of the population, while Buenos Aires, for example, had an immigrant share of around one third in the late 19th century (Sánchez-Alonso 2006; Bértola and Ocampo 2012), leading to the famous joke that humans descend from apes, while Argentineans descend from vessels.

Only in some provinces such as Valdivia and Llanquihue was the impact of immigration (German in particular) more important (but still limited), from the 1850s onwards. Immigration was also significant in Arauco from the late 19th century onwards, as there were German, but also Swiss, Italian and French immigrants (Blancpain 1985; Harris 2001), and Croats in Magallanes in the same period (Martinic 1999).

The question is whether there might have been external effects caused by the immigrant population, even if this population was small. Such effects might be expected if the immigrants came from countries which on average had higher or lower numeracy rates. The external effect in the former case might have resulted in learning behaviour, with native

Chileans adopting a more numeracy intensive way of educating their children, adopting similar behaviour to that which they observed in the immigrant communities from northern Europe. Moreover, even small local populations of immigrants might have demanded additional schools, which they were used to in their home countries. In 1891 a group of French and Swiss immigrants created the first *Alianza Francesa* (French school) in the country, in the remote location of Traiguén, deep into the Araucania, rather than in Santiago or Valparaiso, the most heavily populated cities in the country. Witzel de Souza (2018) recently argued that in the Brazilian province of São Paulo, the schools founded in the context of German immigration had a beneficial impact on the neighbouring population.

European immigrants were also willing to serve as teachers, which might have benefited the native Chilean population. Baeza (2019) has recently shown the key role played by Britons as educators from the early days of independence. On the other hand, one could theoretically also imagine problems with crowding-out if the immigrant population filled the human capital-intensive occupations and the native population could only obtain jobs in other sectors. This is supported by some local evidence. Most engineers employed in mining activities, for instance, were British nationals. But in spite of such local exceptional phenomena, human capital in general is an input factor, which increases average income in most countries and periods studied, in particular when equally distributed (Crayen and Baten 2010a).

One way of identifying migrants in Chile was to classify their surnames. Most people think about the meaning of their surnames and whether they can derive a sense of self-identity from them, especially if the surname differs from the other surnames in their environment. Sometimes ethnic and national stereotypes have an even stronger impact on human behaviour, if different nationalities are contrasted in societies where immigration is or has been a factor.

Immigration to Chile is particularly interesting because it emanated from many different sources, while the migrants were often clustered in clearly defined regions within

Chile: for example, many Christian Palestinian immigrants after World War I clustered in the Santiago quarter of Recoleta, and later Koreans joined in the same quarter. German immigrants often settled in the south of the country (e.g. Valdivia and Llanquihue, among other locations). Similar regional specialization was typical for Belgians and Croatians in the extreme south and extreme north of the country, and many immigrants from other nationalities. But almost everywhere the majority consisted of the descendants of Spanish (mostly Andalusian immigrants), who were the first immigrants. In addition, many Basques immigrated to Chile in the 18th century. Indigenous people often adopted Spanish names voluntarily or by force.

This unusual migration pattern in Chile meant that it was possible to study the impact of surnames and national identities or ethnic identities on human capital formation. We compared the numeracy of people with different groups of surnames such as Palestinian, German, Basque and many others, while Spanish surnames (excluding those of Basques) represented the constant (Table 2). In the regression model, the surnames of the migrants were used to identify their country of origin. We observed strong differences across immigration groups. Migrants from Northern Europe (Germany and Scandinavia) had a relatively high rate of numeracy – the coefficient was about 47% higher compared to people in Chile with Spanish surnames. The UK and the Netherlands had the second highest coefficient (33%). The mixed group including Asians (Japanese and Chinese), as well as US citizens, had 24% numeracy advantage. U.S. citizens often visited temporarily, working as technical and business managers for the mining companies. For Italy, Portugal, Poland and Croatia the coefficients were positive, but not statistically significant. There was a relatively strong negative significant coefficient of people with Mapuche surnames (the American natives), which was expected due to the difficult economic situation and discriminatory behaviour they were subjected to. In the following section, we bring together the possible effects of North

European immigration and retarding effects of inequality on the development of regional numeracy.

Regression results: Inequality and numeracy in a panel of regions

We created a panel of Chilean provinces and decades of birth in a regression analysis where we considered potential correlates of numeracy in the regions of Chile between 1820 and 1939. To estimate the effect of both inequality and immigration on numeracy in Chilean regions, we regressed numeracy by region and half century on inequality as measured by height inequality, immigration and the other confounding factors discussed above:

$$N_{i,c} = \alpha + ß_1 \, IE_{i,d} + ß_2 \, M_{i,d} + X'\gamma + \mu_d + \varepsilon_{i,d} \, ,$$

where $N_{i,c}$ captures numeracy (of both genders) in province *i* in decade *d*. $IE_{i,d}$ is the main variable of interest: average inequality in province *i* in decade *d*. $M_{i,d}$ is the second variable of interest, the immigration from Northern Europe. Our evidence on numeracy, migration and inequality was organized by province *i* and decade of birth *d*: μ_c are decade fixed effects, *X*' is a vector of additional potential explanatory variables such as data on conflicts and epidemic diseases, α is a constant, and ε is the error term. We treat each province-decade observation with equal weight here, not weighing by provincial population, because otherwise a few populous provinces in central Chile would drive the results. However, weighing by population would not change the results (Appendix G). The explanatory variables are also listed in Table 3: numeracy was available for 139 province-birth-decade-observations and has an average of 63.7%. Height inequality was only available for 122 province-birth-decade-definitions. The share of immigration from North-western Europeans was available for all 139 observations that were also covered by numeracy. Conflict and epidemic disease was similarly available for 122 and 130 observations, respectively. About 11% and 17% of the observations were characterized by conflicts or epidemic diseases. Cattle per capita was on average 0.66 cattle per inhabitant of Chile.

In different regression models, we distinguished different time periods, taking the whole period in column 1 and 4, focusing on the early period between 1820 and 1899 in the second and fifth column and – slightly overlapping – on the later period in the third and sixth column (period from 1860 to 1939). We included time fixed effects, using decades to control for potential trend correlation effects.

We studied the correlates of inequality – measured as height inequality – and found a relatively consistent relationship with numeracy for the whole period and for the 19th century sub-period. The primary finding was that inequality was associated with retarded numeracy formation in the Chilean regions. The third and sixth column show that this result became insignificant in the 20th century. Inequality apparently no longer had the same effect, although we have to take into account that there is only a smaller number of observations here, and the values of numeracy have less variation (they were often already between 90% and 100%).

The second variable, which was a consistent correlate, is the immigration by Northern Europeans, even though they made up only a small part of the regional population. We observed that the effect of this migration was consistently positive and mostly significant both in the earlier and the later period. This significant coefficient might have resulted from external effects as we discussed above. The other ethnicities learned from the immigrant ethnic group; if they observed a relationship between human capital investment and higher welfare, the opposite applied if the immigrant ethnic group had a lower human capital. Moreover, immigrants demanded schooling and helped to bring it into being (Witzel de Souza 2019).

We discussed above potential homogeneity of issues of the inequality variable. Similar issues could arise about the north-western European immigration variable, if immigrants went to high numeracy regions. However, that was not the case. Most North-western Europeans for the 19th century went primarily to the South of Chile, as they hoped to obtain land and farms. If we consider numeracy in the period before the immigrants arrived, these provinces had a low numeracy, for example, the provinces of Valdivia and Llanquihue. Chiloé and Colchagua which also attracted land-angry European immigrants had even the lowest numeracy. The only two exceptions were the provinces of Valparaiso (with the harbour) and Atacama (with the mines) to which immigrants went for motivations other than land.

For the epidemic disease and conflict variables we would have expected a negative impact. We observed the expected signs. But these two variables were never significant. For the cattle per capita we would also have expected a positive sign because normally cattle density is associated with a higher nutritional quality. However, this variable did not have a positive coefficient, but was rather consistently negative, though not statistically significant. In general, we observed that the explanatory share was always relatively large in these regressions.

In Figure 7 we compared the residuals of numeracy after removing the effect of all other variables and the residuals of inequality after removing the same effects. We observed that, for example Atacama in 1840 had a high value of residual numeracy and a low value of residual inequality, whereas Santiago in the same decade of birth had a relatively high level of residual inequality and a low level of numeracy. The resulting regression line was consequently negative. Interestingly, between 1840 and 1870 Atacama experienced a strong increase in relative inequality and a strong relative decrease in numeracy (not in absolute terms). The relative increases of inequality may be explained by the fact that the benefits of the export boom of this period (led by Atacama's rich silver and copper deposits), were unevenly distributed among the population, as documented by Rodríguez (2017) for the whole country. Where regions with other specializations benefited from less inequality and higher numeracy.

In Figure 8 we show the average residual inequality and the average residual numeracy for the 19^{th} century, as maps and as a scattergram. In the southern region (Chiloé and Llanquihue), inequality was high and numeracy relatively low. The opposite was true for the northern regions (Atacama and Coquimbo), while the central region was situated in between. However, even within the large central region, inequality and numeracy correlated. For example, Ñuble had a higher residual numeracy and a lower residual inequality than the other regions (Appendix Figure D.1). We also took into account spatial correlation. A detailed treatment can be found in Appendix D. As a conclusion, spatial autocorrelation does not invalidate our finding about inequality as a numeracy-retarding factor.

Robustness test: regressions of the inequality numeracy relationship at the city level

We could also disaggregate the dataset for Chile on a lower regional level, identifying the cities in which individuals entered the mortality registers (Table 5).[17] We could assign to each of these cities also a value for height inequality during the 19th century. We regress numeracy on the inequality variable only, because for the other variables we do not have consistent data at the city level. However, this robustness test at the city level is very valuable, because we can observe that in fact, height inequality correlated with lower numeracy in Chilean cities in the 19th century. This is visible in the first column in a regression without controls. In the second column, we controlled for province fixed effects, so that we controlled for any unobserved heterogeneity arising from differences across provinces. Still, the coefficient of inequality is significantly negative and large. The inequality factor played a strong role in Chilean history by having been associated with a lower level of numeracy in some cities, whereas other cities with lower inequality developed much faster. We also assessed whether the city dataset is affected by spatial autocorrelation. This is discussed in Appendix D. We can conclude from the discussion in this Appendix that spatial autocorrelation did not remove the relationship with inequality.

[17] We thank Fabian Wulfrath for collecting additional evidence on Chilean mortality registers.

Chilean inequality and numeracy in the Latin American country comparison

How did Chilean inequality and numeracy develop in comparison with other Latin American countries? Unfortunately, there are only very few estimates of inequality going back to the 1850s, but the ones that are available suggest that Chile was a highly unequal country already around mid-19th century (van Zanden et al. 2014a, Rodriguez 2017, see also Bértola et al. 2010 on the 1870 situation). The Gini coefficient of inequality in Chile was as high as 64 in 1850 (Figure 10). In contrast, Argentina, Mexico and Peru had lower inequality at mid-century.

However, during the late 19th century, there was a modest decline in inequality of Chile. This decline was shared with Peru, whereas Argentina and especially Mexico experienced dramatically rising inequality (though from a lower initial level). Argentina had a well-known history of globalization during which the owners of land obtained substantial relative income increase, relative to the unskilled agricultural workers, resulting in a strong inequality movement (Williamson 2010; for recent spotlight in fiscal preferences about inequality, see Arroyo Abad and Lindert 2017). Mexico experienced the Porfíriato development period, with fast, but with very unequally distributed progress (Andrade de Herreira 1996). If the relationship between inequality and numeracy that we observed for Chilean regions in this article would also hold for the international comparison, we would expect that Mexico's and Argentina's position in relative numeracy would worsen relative to Chile and Peru. This expected development took actually place (Figure 11). During the period when Chilean inequality was moderately declining, while Argentinean inequality increased, Chile converged substantially to Argentina's higher numeracy level (but did not reach it fully). Peru shared this convergence to Argentina, though at a lower level (Arroyo Abad 2016 finds a similar convergence of literacy). Mexico, in contrast, developed drastically worse: although Mexico had a higher numeracy level than Argentina in the late 18th century (Manzel et al. 2012), it could not keep pace with the increase of the other countries during the 19th century. Most notably, Mexico continued to stagnate during the Porfíriato period. Until the 1890s, Mexican numeracy was lagging as much as 30 percent behind Chile. In general, the Southern Cone economies participated more strongly in the first globalization boom (both in migration and trade), and had consequently higher numeracy increases than the old centres of the previous Spanish Empire, namely Mexico and Peru. But in Mexico, the relative falling back was particularly apparent and drastic. A part of this might be related to the waste of talents among the poorer social strata whose potential was not used via schooling. After the late 19th century, Chile's inequality grew again and reached its top position among Latin American countries already during the 1920s (Bértola et al. 2010). However, the period of the declining inequality between the 1850s and 1910s might have given Chile impetus for human capital formation that brought the country on a long and lasting growth path.

In conclusion, we compared national developments of inequality and numeracy in Chile, Mexico, Peru and Argentina in this section. Unfortunately, only for these countries comparable inequality estimates are available in Spanish-speaking Latin America, hence it is not possible to perform statistical analysis. But given that the observed trends at this aggregate level show similarities to Chilean regional developments, the evidence for a relationship between inequality and slower numeracy growth is strengthened.

Conclusion

Modern Chile has one of the highest levels of inequality in the world. Yet the country enjoyed a remarkable political stability since the return to democracy in 1990. In October 2019, though, what had seemed to be an oasis within Latin America erupted as the most intense and dramatic social unrest in Chilean recent history. Inequality is at the root of this social earthquake. The President and his advisors seemed to be puzzled: they thought that the negative consequences of inequality on well-being had been counterbalanced by the high average income of Chileans.

Inequality has a history and the facts of inequality need to be understood better. In this study we have traced the relationship of inequality and numeracy in the Chilean regions of the 19th and early 20th century. We found that inequality, measured by inequality of height, was associated with a lower speed of human capital formation: it seems that not everyone has received the necessary education to make full use of their talents in the regional economy.[18] We also assessed this in a robustness test for which we disaggregated inequality and numeracy at the level of 59 Chilean cities during the 19th century, controlling even for province fixed effects. Spatial autocorrelation was studied in Appendix D, and it did not invalidate the main results. Finally, we compared national developments of inequality and numeracy in Chile, Mexico, Peru and Argentina and observe similar trends even at this aggregate level. We speak only of “correlation” here, as we do not claim a causal relationship.

While our evidence on inequality confirms Rodriguez Weber’s estimates at the national level, it becomes clear in this study that inequality was a highly regional phenomenon in Chile during the 19th and early 20th century. The differences in inequality between North and South Chile were much larger than many national differences between other countries of the time. This changes our picture of Chilean development radically. It also clarifies the contribution of this article, namely, measuring inequality and the numeracy development at the regional level is crucial to understand the development in Chile.

In addition, we studied small-scale immigration in the regions of Chile. We assessed this factor by calculating the share of Northern European immigrants and their relationship with average numeracy in each province and decade of birth. Regions with a high share of North European migrants developed faster in terms of numeracy. This cannot be a mechanical effect, but was probably caused by externalities because the surrounding population adopted a similar behaviour to the small non-European immigrant group. They also benefited from the

[18] Our data on height inequality does not suffer from potential selectivity bias because we could work with general evidence constriction for most of the time.

opening of new schools in the area, led by these foreigners. We also studied the effects of persons with European names on numeracy as an indicator of belonging to a migrant family.

The nexus of inequality and numeracy is shown in the quality of Chilean public education, still poor by international standards. The two previous periods of social unrest in Chile, the Penguin Movements (nicknamed after the students' uniform) of 2006 and 2011, were protests by students demanding better education. As we have shown, this was not a new phenomenon: its roots lie in the nineteenth century. If Chile wants to continue human-capital-based development following the model of high income countries, stronger redistribution elements in the tax system are necessary to reduce inequality.

References

A'Hearn, B., Crayen, D. and Baten, J. (2009). Quantifying Quantitative Literacy: Age Heaping and the History of Human Capital. *Journal of Economic History*, Vol. 68, No. 6, pp. 783- 808.

Alesina, A. and Rodrik, D. (1994) Distributive Politics and Economic Growth. *The Quarterly Journal of Economics*, Vol. 109, No. 2, p. 479. (pp. 465-490.)

Andrade de Herrera, V., 'Education in Mexico: historical and contemporary educational systems', in J. LeBlanc Flores, ed., *Children of La Frontera: binational efforts to serve Mexican migrant and immigrant students* (Charleston, SC, 1996), pp. 25–9.

Arroyo-Abad, L. and Astorga Junquera, P. (2017). Latin American earnings inequality in the long run. *Cliometrica* 11, pp. 349–374.

Arroyo-Abad, L. (2016). The Limits Of The Estado Docente: Education And Political Participation In Peru, 1876-1940. *Revista De Historia Económica / Journal of Iberian and Latin American Economic History*, 34(1), 81-109.

Arroyo-Abad, L. and Lindert, P.H. (2017). Fiscal Redistribution in Latin America since the Nineteenth Century, In: L. Bértola, J. Williamson (eds.), *Has Latin American Inequality Changed Direction?* Springer: Heidelberg et al., pp. 243-282.

Baeza, A. (2019). *Contacts, collisions and relationships: Britons and Chileans in the Independence era, 1806-1831*. Liverpool, Liverpool University Press.

Barro, R.J. (2000) Inequality and Growth in a Panel of Countries. *Journal of Economic Growth*, Vol. 5, No. 1, pp. 5-32

Baten, J. (2000). Economic Development and the Distribution of Nutritional Resources in Bavaria, 1797-1839. *Journal of Income Distribution 9*, pp. 89-106.

Baten, J. and Blum, M. (2011). Anthropometric within-country Inequality and the Estimation of Skill Premia with Anthropometric Indicators. *Review of Economics - Jahrbuch fuer Wirtschaftswissenschaften* Vol. 62, No. 2, pp.107-138.

Baten, J., Crayen, D. and Voth, J. (2014). Numeracy and the Impact of High Food Prices in Industrializing Britain, 1780-1850, *Review of Economics and Statistics* 96:3 (July 2014), 418-430.

Baten, J. and Fraunholz, U. (2004). Did partial globalization increase inequality? The case of the Latin American periphery 1950–2000. *CESifo Economic Studies* Vol. 50 No.1, pp. 45–84.

Baten, J. and Juif, D. (2014). A story of large land-owners and math skills: inequality and human capital formation in long-run development, 1820-2000. *Journal of Comparative Economics*, 24-2, pp. 375-401.

Baten, J. and Mumme, C. (2013). Does inequality lead to civil wars? A global long-term study using anthropometric indicators (1816–1999). *European Journal of Political Economy*.

Baten, J., Szołtysek, M. and Campestrini, M. (2017). "Girl Power" in Eastern Europe? The human capital development of Central-Eastern and Eastern Europe in the seventeenth to nineteenth centuries and its determinants. *European Review of Economic History*, Vol. 21, No. 1, pp. 29-63.

Bértola. L., Castelnovo, C., Rodríguez, J. and Willebald, H. (2010). Between the colonial heritage and the first globalization boom: on income inequality in the Southern Cone. *Revista de Historia Económica / Journal of Iberian and Latin American Economic History* 28, Special Issue 02, pp 307 - 341.

Bértola, L. and Ocampo J. A. (2012). *The Economic Development of Latin America since Independence*. Oxford, Oxford University Press.

Bértola, L. and Ocampo J. A. (2016). Latin America. In: Baten, J. (ed.), *A History of the Global Economy*. Cambridge: CUP, pp. 121-157.

Blancpain, J.P. (1985). *Los alemanes en Chile: 1816-1945*. Santiago: Ediciones Pedagógicas Chilenas.

Boucekkine, R., de la Croix, D., Licandro, O., (2003). Early mortality declines at the dawn of modern growth. *Scandinavian Journal of Economics* 105-3, pp. 401–418.

Cámara Hueso, A.D. Martínez-Carrión, J.M., Puche, J. and Ramon-Muñoz, J.-M. (2019). Height and inequality in Spain: A long-term perspective. *Revista de História Económica*, p. 1-34.

Cameron, A. Colin, and Douglas l. Miller. 2015. A Practitioner's Guide to Cluster-Robust Inference. *The Journal of Human Resources* 50 (2): 317-371.

Cardemil, M. (2015). Numeracy and education in Chile: 1860-1940 cohorts. *MSC Dissertation. MSC Public Policy. University of Chile*.

Crayen, D. and Baten J. (2010a). 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, *Economic History Review* 53-2 (2010), pp. 452-478.

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

Chile (1885-1932). Registro Civil Database with images. *FamilySearch*. http://FamilySearch.org : last accessed 14 November 2019. Registro Civil Archivo General (Civil Registry General Archives), Santiago.

Chile (1941). *XI Censo de Población (*1940). Celade: Santiago de Chile.

Collier, P. and Hoeffler, A. (2002). Greed and Grievance in Civil War. *Centre for the Study of African Economies* Working Paper 2002-01.

Collins, W.J. and Niemesh, G.T. 2019). Unions and the Great Compression of wage inequality in the US at mid-century: evidence from local labour markets. *Economics History Review* 72-2, 691-715.

Contreras, D. (2002). Explaining Wage Inequality in Chile: Does Education Really Matter?. *Journal of Income Distribution*, Vol. 11(1-2), pp. 3-3

Deaton, A. (2008). Height, health, and inequality: the distribution of adult heights in India. *American Economic Review*, Vol. 98, No. 2, pp. 468–474.

Deininger, K., Squire, L. (1998) New Ways of Looking at Old Issues: Inequality and Growth. *Journal of Development Economics,* 57-2, pp. 259-287

Droller, F. (2018). Migration, Population Composition and Long Run Economic Development: Evidence from Settlements in the Pampas. *The Economic Journal*, Vol. 128, Issue 614.

Federico, G. (2005). *Feeding the World: An Economic History of Agriculture, 1800-2000*. Princeton: Princeton UP.

Fernández, C. I., Flores, S. V. 2014. Brief Communication: Lactase Persistence and Dairy Intake in Mapuche and Mestizo Populations from Southern Chile. *American Journal of Physical Anthropology* 155, 482-487.

Fogel, R. W. (2004). *The Escape from Hunger and Premature Death, 1799-2100*. Cambridge, Cambridge University Press.

Gausman, J. and Mejia Guevara I., Subramanian S.V., Razak F. (2018). Distributional change of women's adult height in low- and middle-income countries over the past half century: An observational study using cross-sectional survey data. *PLOS Medicine*.

Gerschenkron, A. (1962). *Economic backwardness in historical perspective*. Cambridge, Mass.

Clark, G., Cummins, N., Hao, Y., Diaz Vidal, D. (2015). Surnames: a New Source for the History of Social Mobility. *Explorations in Economic History* Vol. 55, pp. 3-24.

Galor O., O. Moav, and D. Vollrath, Inequality in Landownership, the Emergence of Human-Capital Promoting Institutions, and the Great Divergence, *Review of Economic Studies* 76 (2009), 143-179.

Galor, O., Zeira, J. (1993) Income Distribution and Macroeconomics. *The Review of Economic Studies*, Vol. 60, No. 1, p. 36. (pp. 35-52)

Guntupalli, A. and Baten, J. (2006). The Development and Inequality of Heights in North, West and East India, 1915-44. *Explorations in Economic History* Vol. 43, No. 4, pp. 578-608.

Hanushek, E.A. and Woessmann, L. (2012). Do better schools lead to more growth? Cognitive skills, economic outcomes, and causation. *Journal of Economic Growth*, Vol. 17, No. 4, pp. 267-321.

Harris, G. (2001). *Emigrantes e inmigrantes en Chile, 1810-1915: nuevos aportes y notas revisionistas*. Valparaíso, Universidad de Playa Ancha.

Instituto Geográfico Militar de Chile (2018). *Atlas Histórico de Chile*. Santiago: Instituto Geográfico Militar de Chile.

Koepke, N., and Baten, J. (2005). The Biological Standard of Living in Europe During the Last Two Millennia, *European Review of Economic History* 9-1 (2005), pp. 61-95.

Lindert, P. H. and Williamson J. G. (2003). Does Globalization Make the World More Unequal? *Globalization in Historical Perspective*, pp. 227-276.

Llorca-Jaña, M., Navarrete-Montalvo J., Araya R. (2018a). Inequality in Chile before the first globalization: an approach derived from agricultural market income, 1830s-1850s. *Historia Agraria*, Vol. 74, No. 1, pp. 103-133.

Llorca-Jaña, M., Navarrete-Montalvo J., Droller F., Araya R., (2018b). Height in eighteenth-century Chilean men: evidence from military records, 1730s-1800s. *Economics and Human Biology*, Vol. 29, pp. 168-178.

Llorca-Jaña, M., Robles C., Navarrete-Montalvo J. (2018c), Chiloé, una sociedad rural igualitaria. Distribución del ingreso agrícola y de la tierra después de la Independencia. *Magallania*, Vol. 46-2, pp. 85-105.

Llorca-Jaña, M.; Nazer, R., Navarrete-Montalvo, J., Morales, D. (2020c). Chile's milk and meat production and consumption, c.1930-2017: a history of a successful nutrition transition. *Historia Agraria*, forthcoming.

Llorca-Jaña, M., Navarrete-Montalvo, J., Droller, F., Araya, R. (2019). The physical stature of men in nineteenth century Chile: another case of stagnation during an export boom. *Revista de Historia Económica-Journal of Iberian and Latin American Economic*

History, Vol. 37, No. 1.

Llorca-Jaña, M., Clarke D., Navarrete-Montalvo, J., Araya R. (2020a). New anthropometric evidence on living standards in nineteenth-century Chile. *Economics and Human Biology*, forthcoming.

Llorca-Jaña, M.; Navarrete-Montalvo, J., Araya, R., Allende, M., Droller. F., Rivas, J. (2020b). Height in twentieth century Chilean men: growth with divergence, forthcoming.

Mace, R., Jordan, F., Holden, C., (2003). Testing Evolutionary Hypotheses about Human Biological Adaption Using Cross-Cultural Comparison. *Comparative Biochemistry and Physiology, Part A: Molecular & integrative physiology* Vol. 136, No. 1, pp. 85-94.

Manzel, K., Baten, J. and Y. Stolz (2012). Convergence and divergence of numeracy: the development of age heaping in Latin America from the seventeenth to the twentieth century. *The Economic History Review* 65, pp. 932–960.

Maravall, Baten and Fourie (2019). E*thnic patronage and education: Evidence from colonial and post-colonial Africa. Presentation on African Economic History Workshop Barcelona Oct 2019.*

Martinic, M. (1999). *La inmigración croata en Magallanes.* Punta Arenas: Hogar Croata.

Matear, A. (2006). Barriers to Equitable Access: Higher Education Policy and Practice in Chile Since 1990. *Higher Education Policy* Vol. 19: 31.

Matus, M. (2020). Posición y trayectoria de los salarios chilenos en el cono sur y sus efectos relativos en conflictividad laboral e inmigración, 1886-1928. *Historia*.

Moradi, A. and Baten, J. (2005). Inequality in sub-Saharan Africa: new data and new insights from anthropometric estimates. *World Development* Vol. 33, No. 8, pp. 1233-1265.

Perotti, R. (1996) Growth, income distribution, and democracy: What the data say. Journal of Economic Growth. Vol. 1, No. 2, pp. 149–187.

Persson, T. and Tabellini, G. (1994) Is Inequality Harmful for Growth? *American Economic Review* 84-3, pp. 600-621

Poeppig, E. (1835). *Reise in Chile, Peru und auf dem Amazonenstrome: während der Jahre 1827-1832*. Leipzig.

Rodríguez, J. (2017). *Desarrollo y desigualdad en Chile. (1850-2009) Historia de su economía política*. Santiago: Centro de Investigaciones Diego Barros Arana (Dibam).

Salvatore, R.D., Coatsworth, J.H. Challú, AE. (2010) *Living standards in Latin American history: Height, welfare, and development, 1750–2000*. Cambridge, Mass.

Sánchez-Albornoz, N. (2014). *La población de América Latina: desde los tiempos precolombinos al año 2025*. Madrid, Alianza Editorial.

Sánchez-Alonso, B. (2006). Labor and Immigration, In V. Bulmer-Thomas, J. Coatsworth y R. Cortés Conde (eds.), *The Cambridge Economic History of Latin America*, Vol. 2, Cambridge, Cambridge University Press, pp. 377-426.

Stolz, Y. and Baten, J. (2012). Brain drain in the age of mass migration: Does relative inequality explain migrant selectivity? *Explorations in Economic History*.

Thomas, V., Wang, Y. and Fan, X. (2001) Measuring Education Inequality – Gini Coefficients of Education". *World Bank Policy Research Working Paper* No. 2525.

Tollnek, F. and Baten, J. (2017). Farmers at the Heart of the "Human Capital Revolution"? Decomposing the Numeracy Increase in Early Modern Europe. *Economic History Review* 70-3, pp. 779-809.

Urrutia, Rosa; Lanza, Carlos (1993). *Catástrofes en Chile, 1541-1992*. Santiago: La Nori.

Van Zanden, J. L., Baten, J., Földvari, P., and van Leeuwen, B. (2014a). The Changing Shape of Global Inequality 1820-2000. Exploring a New Dataset. *Review of Income and Wealth* 60-2, pp. 279-297.

van Zanden, J. L. and Baten, J., Mira d'Hercole, M., Rijpma, A., Smith, C., Timmer, M. (eds.) (2014b). *How Was Life? Global Well-being since 1820.* OECD, Paris, pp. 199-211.

Williamson, J. G. (2010). Five centuries of Latin American inequality. *Revista de Historia Económica., 28*(2), 227–252.

Witzel de Souza, B.G. (2019). Immigration and the path dependence of education: the case of German-speakers in Sao Paulo, Brazil (1840–1920). *Economic History Review*, 71, 2 (2018), pp. 506–539

Xu, Y. and Hang, L. (2017). Height inequalities and their change trends in China during 1985–2010: results from 6 cross-sectional surveys on children and adolescents aged 7–18 years *BMC Public Health* vol. 17, Article number: 473.

Table 1 Number of cases: death register, by birth decade and province (structure 1854, plus Tarapacá and Antofagasta)

Province	1820	1830	1840	1850	1860	1870
Antofagasta		68	103	132	114	65
Arauco	60	134	181	219	249	163
Atacama	55	100	112	87	92	35
Chiloé	45	70	58	78	77	33
Colchagua	96	144	159	180	149	85
Concepción	69	102	106	117	156	119
Coquimbo	53	80	86	100	106	37
Llanquihue	48	101	111	125	161	107
Maule	65	131	114	129	133	73
Ñuble	34	57	61	72	63	
O`higgins	33	39	47	33	34	
Santiago	33	39	48	58	70	54
Talca	49	96	88	76	72	49
Tarapacá		72	97	112	110	67
Valdivia		55	65	71	121	48
Valparaiso		59	83	57	75	45

Table 2: Regression: Immigrant groups and their numeracy

German/Scandinavian	46.95***
	(0.000)
French/Belgian	7.22
	(0.523)
Basque	-2.79
	(0.277)
UK/Netherlands	32.57***
	(0.000)
Italian	4.43
	(0.690)
Mapuche	-10.10***
	(0.000)
Poland/Croatian	19.69
	(0.214)
Portuguese	22.52
	(0.128)
Unkn./U.S./Asian	23.66***
	(0.000)
Time FE	YES
Province FE	YES
Constant	109.62***
	(0.000)
Obs.	7,914

Note: Dependent variable is numeracy. Explanatory variables are dummy indicator variables based on typical names. Robust p-values in paretheses. ***, **, *, indicates significance at the 1, 5, and 10% level. Clustered at the province level. Unit of observation is province and birth decade, the dependent variable is numeracy. We also calculated wild bootstrapped standards errors, because we have only 16 provinces at the minimum, using the methodology by Cameron et al. (2015).

Table 3: descriptive statistics: panel of regions and birth decades

Variable	Obs	Mean	Std.Dev.	Min	Max
Numeracy	139	63.72	20.89	15.31	97.06
Inequality	122	3.84	0.61	2.27	5.17
N.Eur.Immigration (log)	139	-3.92	0.90	-4.61	-1.24
Conflict	122	0.12	0.24	0	1
Epidemics	130	0.18	0.22	0	0.6
Cattle p.c.	121	0.66	0.49	0.03	2.20

Sources: For height inequality (the coefficient of variation of height by province and decade of birth) and northern European immigration, Llorca-Jaña et al. (2019, 2020a and 2020b); for conflict, Instituto Geográfico Militar de Chile (2018); for epidemics, Urrutia and Lanza (1993); for cattle per capita, Llorca-Jaña et al. (2020c).

Table 4: regressions of numeracy in Chilean regions and birth decades

	(1)	(2)	(3)	(4)	(5)	(6)
	1820-1939	1820-1899	1860-1939	1820-1939	1820-1899	1860-1939
Inequality	-4.29**	-4.30**	-0.32	-3.80*	-3.80*	0.55
	(0.032)	(0.030)	(0.916)	(0.062)	(0.058)	(0.828)
Immigrants (North Eur.)	2.69*	2.71*	2.51	3.00**	3.02**	2.78**
	(0.072)	(0.070)	(0.144)	(0.031)	(0.030)	(0.034)
Conflict	-0.60	-0.58	2.30			
	(0.820)	(0.824)	(0.626)			
Epidemics	-6.47	-6.51	-4.64			
	(0.229)	(0.220)	(0.492)			
Cattle p.c.	-3.68	-3.59	-2.19	-3.52	-3.46	-2.04
	(0.133)	(0.155)	(0.251)	(0.142)	(0.164)	(0.249)
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Constant	60.49***	60.56***	111.85***	59.73***	59.78***	107.49***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Observations	113	109	57	113	109	57
R-squared	0.883	0.874	0.644	0.881	0.872	0.627

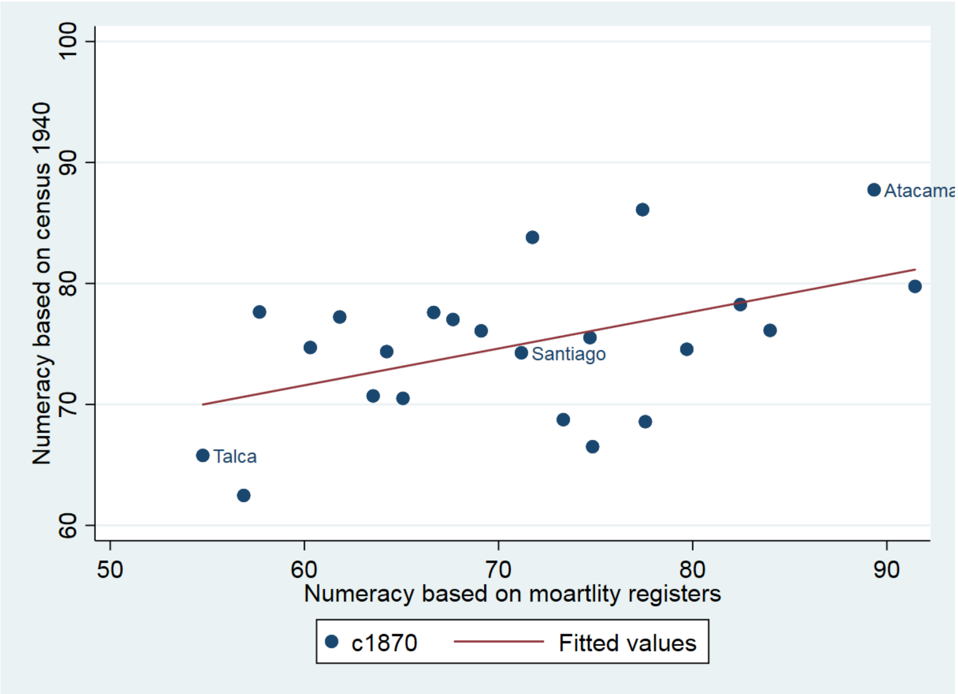
Notes: Robust p-values in paretheses. ***, **, *, indicates significance at the 1, 5, and 10% level. Clustered at the province level. Unit of observation is province and birth decade, the dependent variable is numeracy. We also calculated wild bootstrapped standards errors, because we have only 16 provinces at the minimum, using the methodology by Cameron et al. (2015). The results generally confirm the significance levels above. For example, for the inequality coefficient in column (1), the p-value is 0.0690, using 1000 replications and Rademacher weights. For column (2), the p-value is 0.0590. Finally, we do not control for regional fixed effects here, because provinces were very few. Please note, however, that the relationship between inequality and numeracy in Table 5 is robust, even if provincial fixed effects are included.

Table 5: regressions of numeracy in a cross-section of Chilean cities

	(1)	(2)
Inequality	-6.923***	-5.320***
	(2.474)	(1.855)
Constant	101.3***	95.80***
	(9.308)	(7.956)
Province FE	No	Yes
Observations	59	59
R-squared	0.108	0.740

Note: Dependent variable is numeracy in the 19th century. Robust p-values in paretheses. ***, **, *, indicates significance at the 1, 5, and 10% level. Clustered at the province level. Unit of observation is province and birth decade, the dependent variable is numeracy. We also calculated wild bootstrapped standards errors, because we have only 16 provinces at the minimum, using the methodology by Cameron et al. (2015). Model1 includes no province Fixed effects, whereas Model 2 does.

Figure 1: Correlation between the numeracy of the age group 63-72 mostly born in the 1870s, according to the census in 1940, and the corresponding age group of the mortality register



Note: to obtain a sufficient number of cases, we used all provinces available from both sources (not only the 1854 "super"-provinces) for the mortality register, the birth decades of the 1860s and the 1870s are averaged (after adding the average increase between the 1860s and the 1870s to the birth decade of the 1860s).

Figure 2: Scattergram of schoolyears (in logs) and numeracy for the birth decades and provinces of the 1960 census in Chile

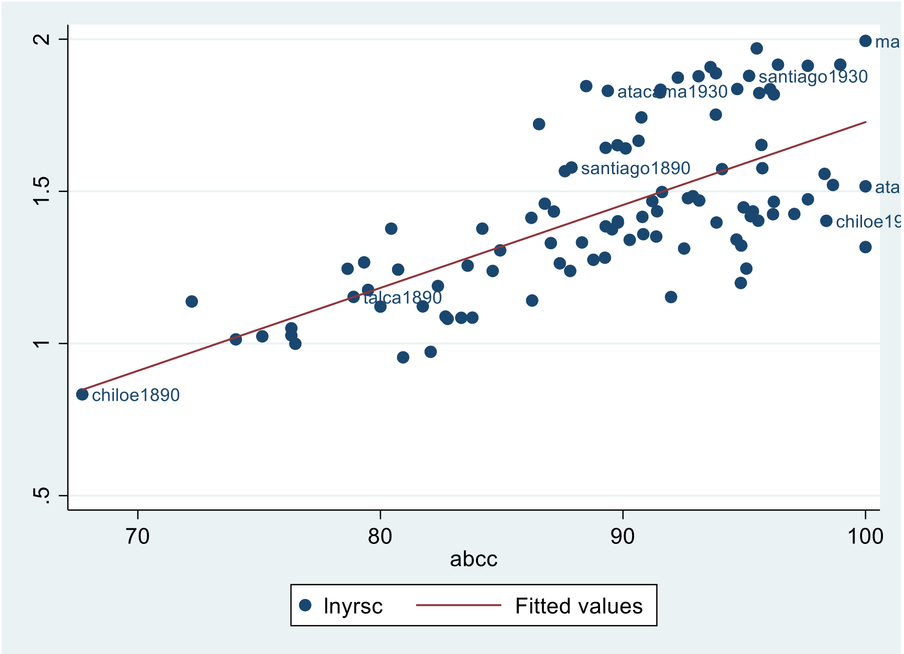
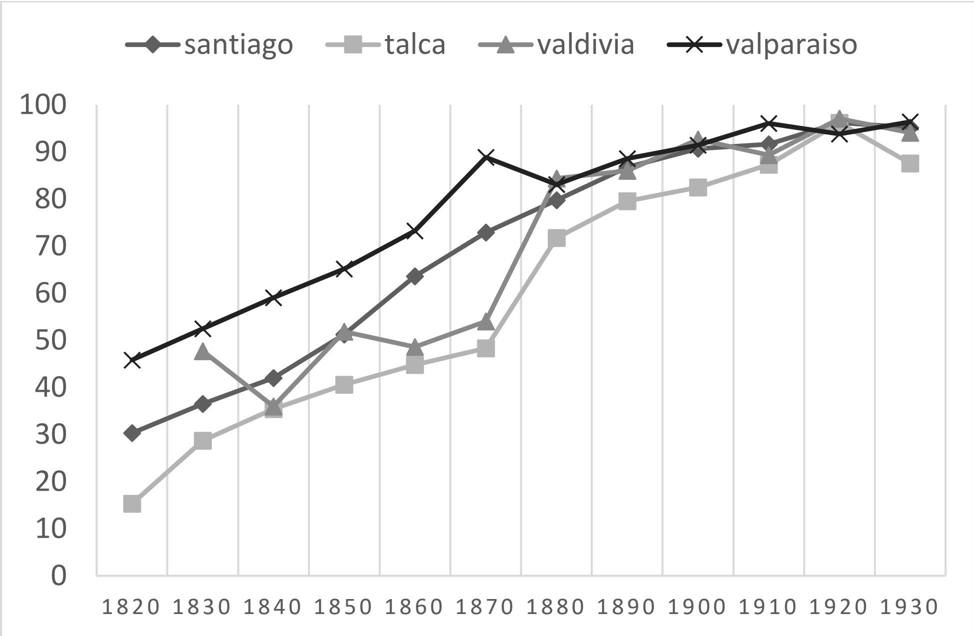


Figure 3: Trends of numeracy in selected Chilean regions

Panel A



Panel B

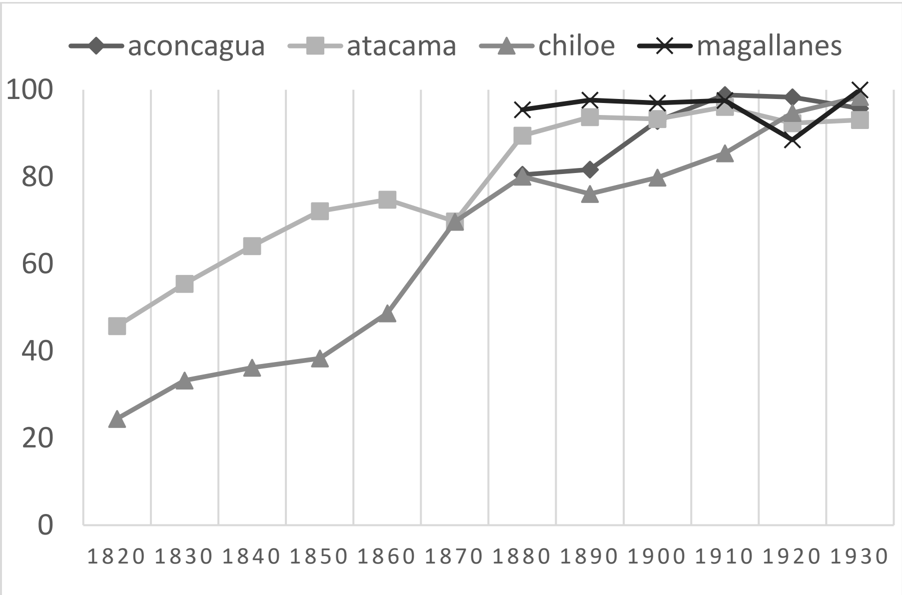
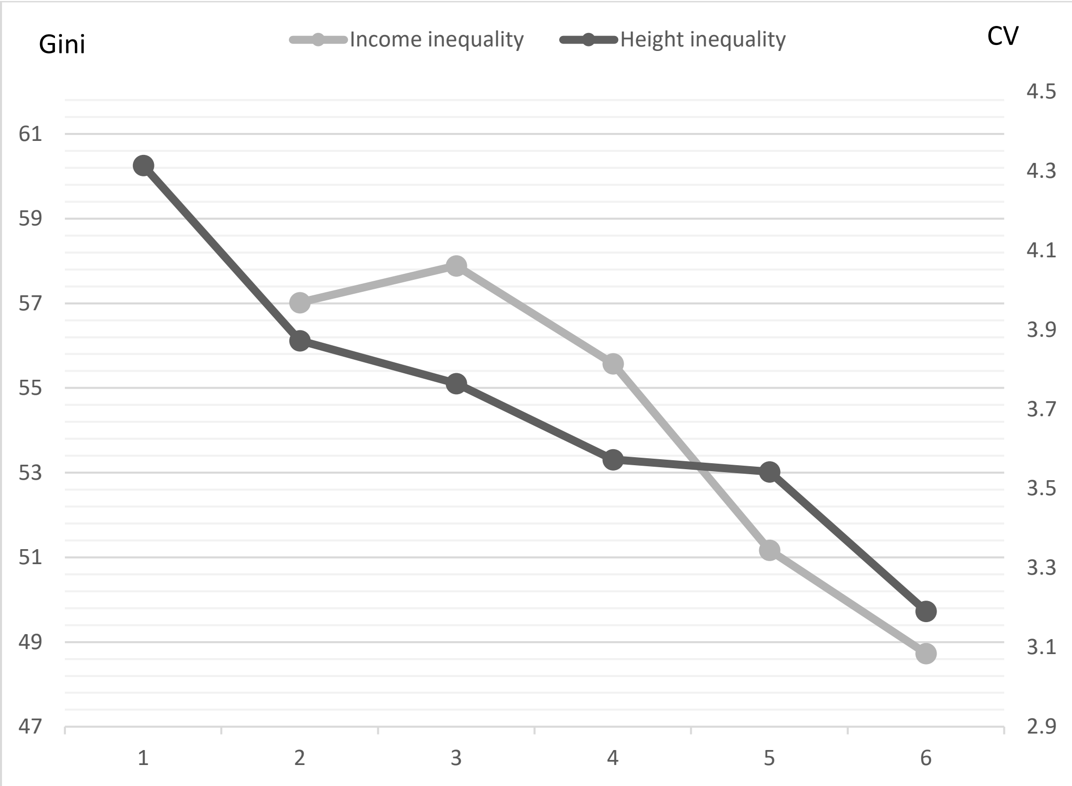
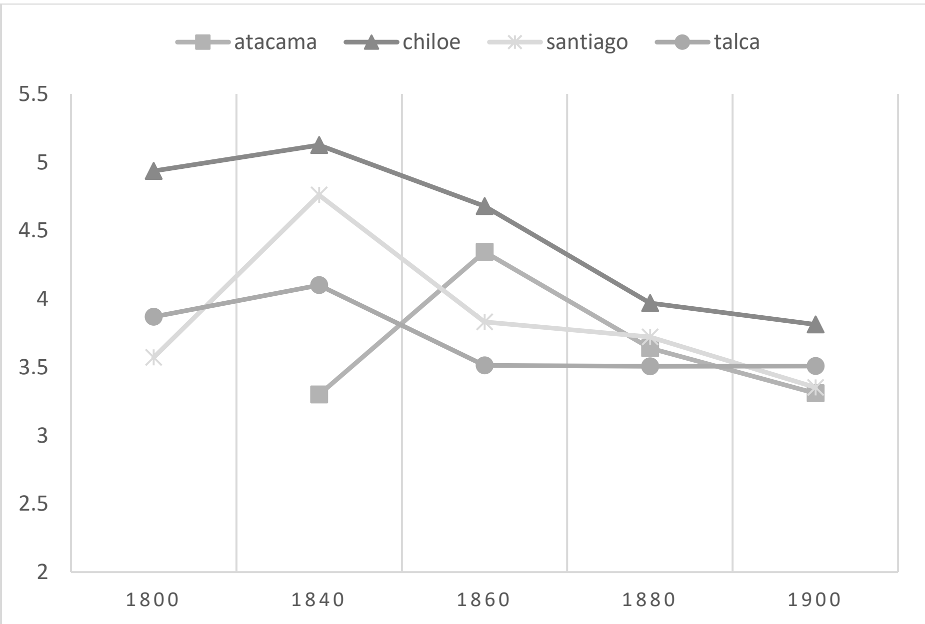


Figure 4. Comparing Height inequality and Income inequality in Chile, 1850s-1900s



Source: Gini coefficients of income inequality on left axis, adapted from Rodriguez-Weber (2017) on, coefficient of height variation ("CV") on right axis is based on our data on heights (see text).

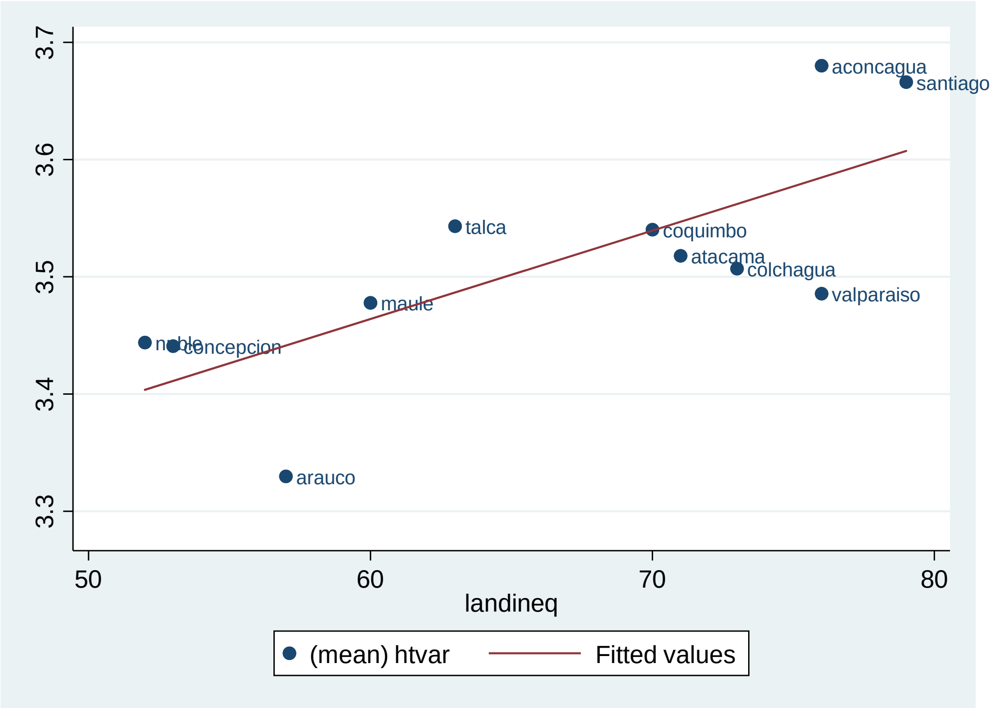
Figure 5: Trends of height inequality



Note: The figure shows the coefficient of variation of height.

Source: see note to Table 3 and text.

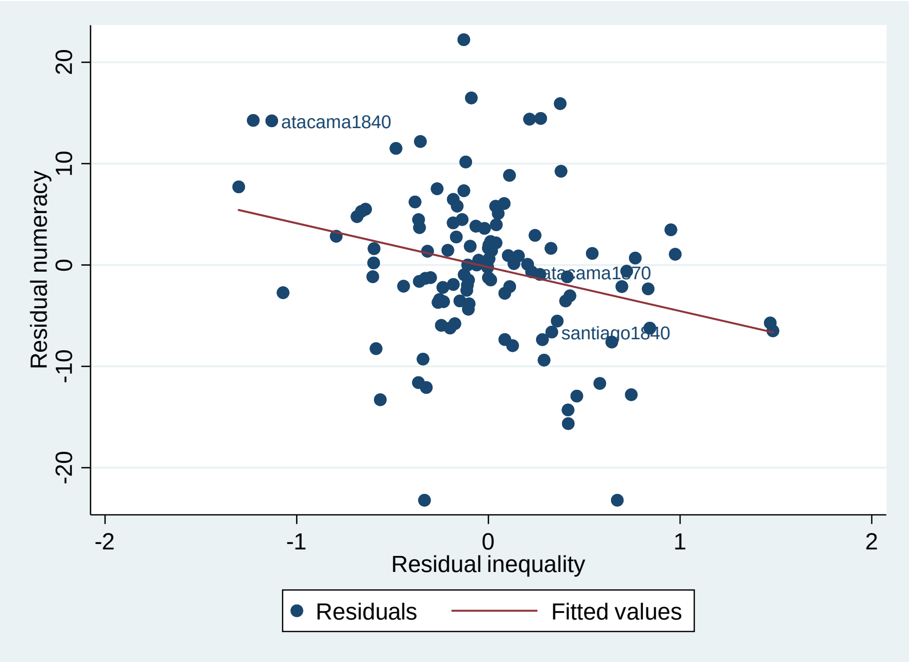
Figure 6: Comparison of land and height inequality in C/N Chile



Note: This includes the „non—North-European-immigrant" South. Land inequality is the share of the land owned by the richest. The coefficient of variation of height is on the horizontal axis.

Source: See text

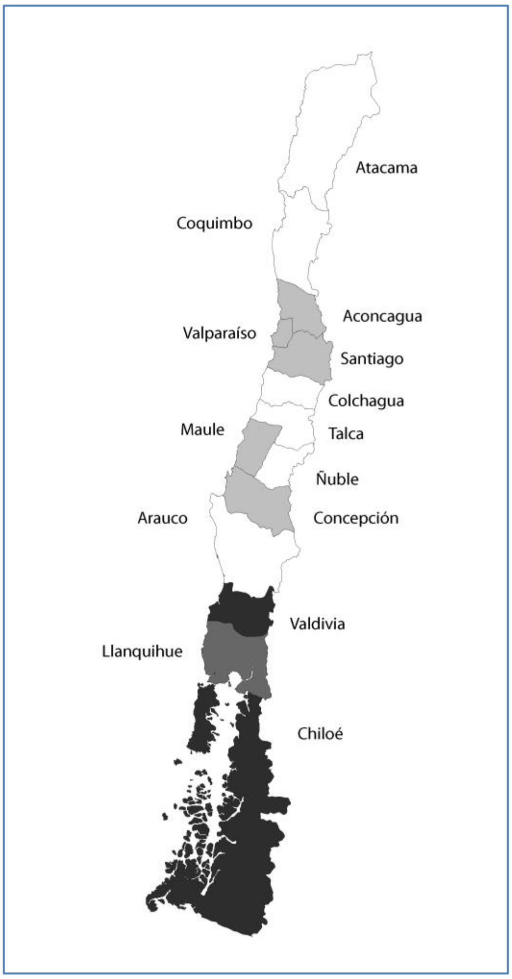
Figure 7: Comparison of residual numeracy and residual inequality



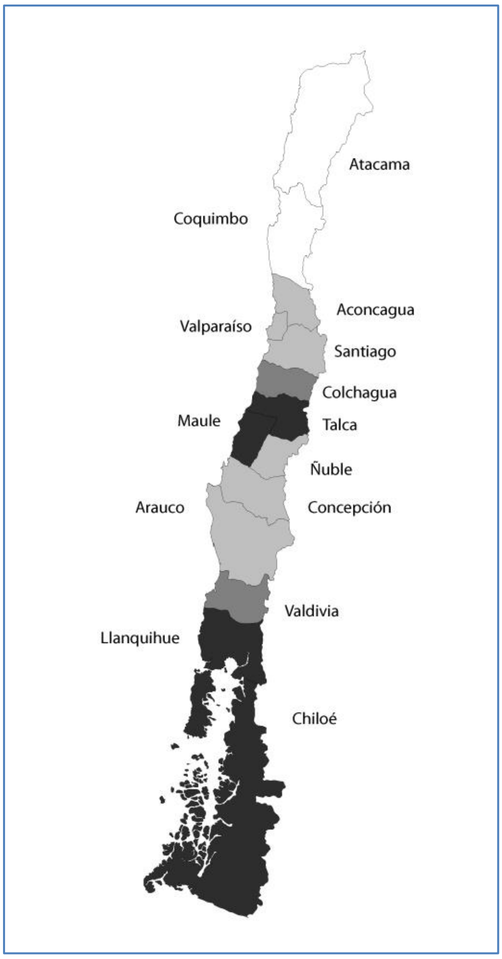
Note: this figure shows the residual inequality which is the height inequality after regressing on all the other explanatory variables. Residual numeracy which is the numeracy regressed on other variables and saving the predicted residuals.

Figure 8: Mapping the residual numeracy and residual inequality, 1820s-1900s

Residual Inequality



Residual Numeracy



Note: We used light grey-shades for low values.		
Category 1	-0.332	-0.107
Category 2	-0.106	0.119
Category 3	0.120	0.346
Category 4	0.347	0.572

Note: We used dark grey-shades for low values.		
Category 1	-8.661	-3.915
Category 2	-3.914	0.831
Category 3	0.832	5.578
Category 4	5.579	10.325

Note: These maps show residual inequality and numeracy for the whole 19th century. For the method of calculation see notes to Table7.

Appendix. Figure D.1: Residual numeracy and residual inequality of Chilean provinces, 1820s-1900

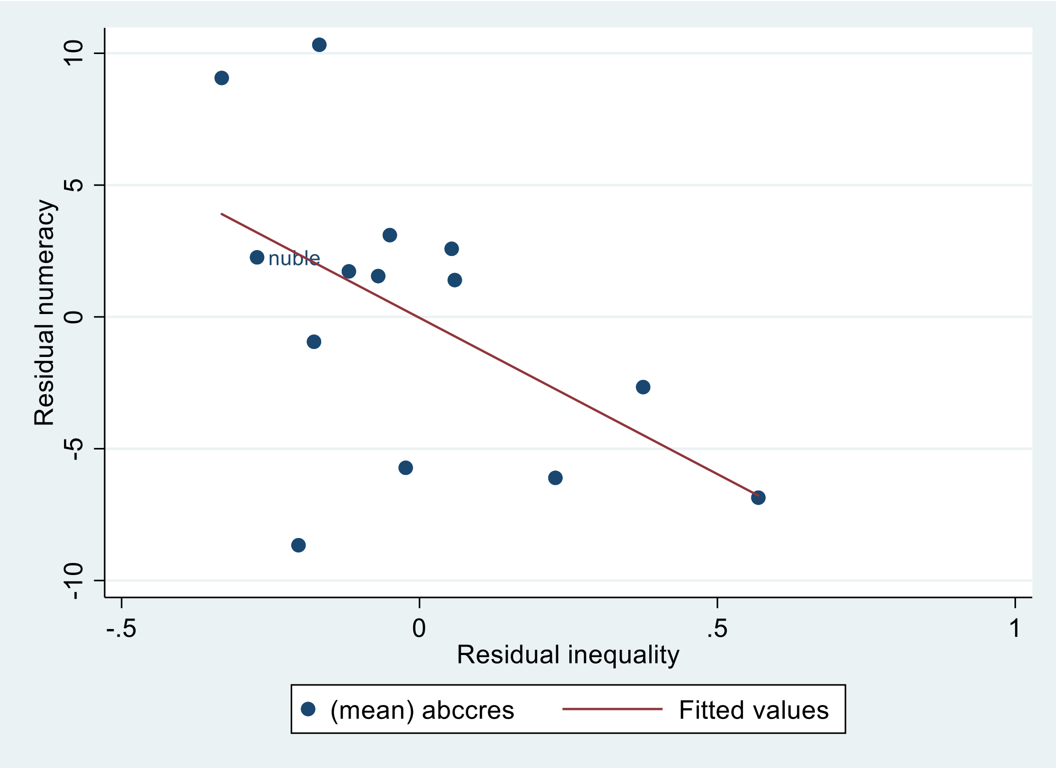
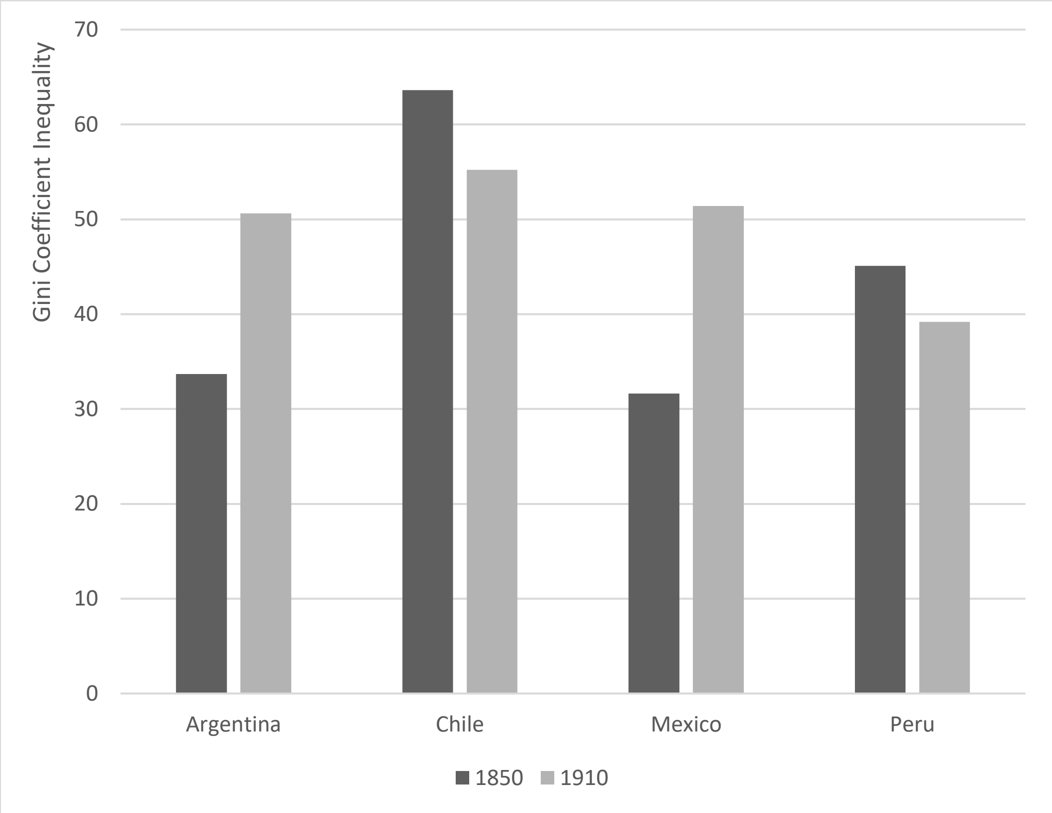
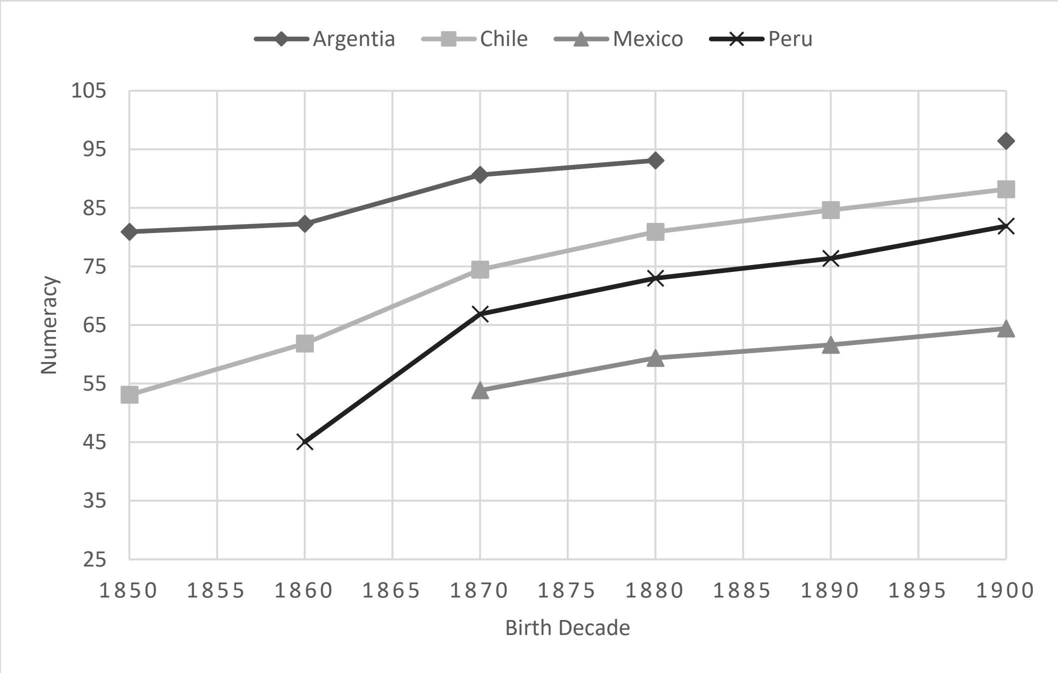


Figure 9: Placing Chile's inequality in international comparison: 1850 and 1910 levels of inequality in Argentina, Chile, Mexico and Peru



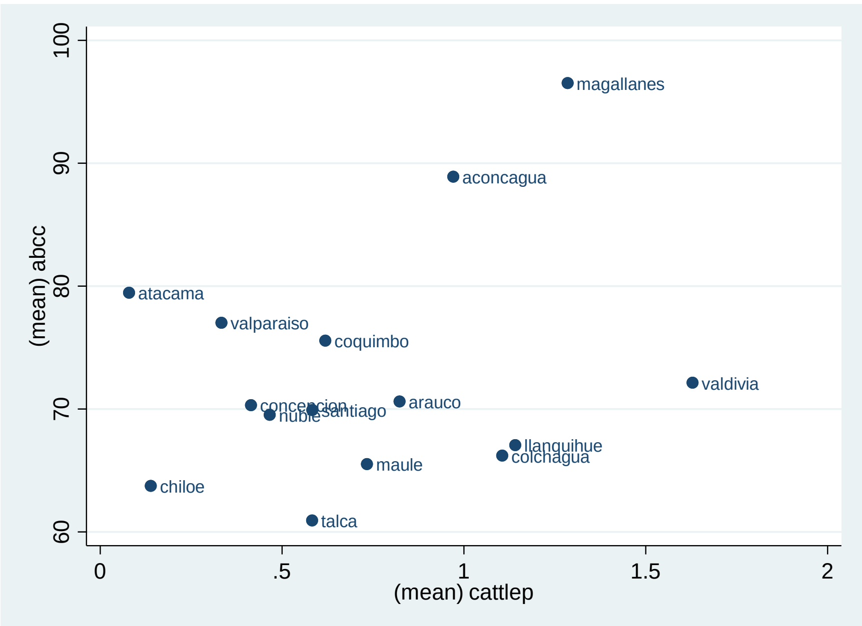
Source: van Zanden et al. (2014a), clio-infra.eu.

Figure 10: Numeracy in selected Latin American countries, 1850s-1900s



Source: Crayen and Baten 2010, clio-infra.eu

Internet Appendix A: Cattle p.c. and numeracy by region is positive, but the other factors are making the cattle factor insignificant



Internet Appendix B: The age-heaping method

In both industrial and agricultural economies, numeracy was clearly a core component of human capital. In agricultural societies, individuals making decisions about the timing of activities had to take a number of issues into account, such as the weather, the status of plants and animals, and other similar variables (Baten 2016; the following is also based on the discussion Baten, Szoltysek and Campestrini 2017).

Measuring the production factor "human capital" has never been simple, as advanced forms of skills are difficult to compare. Economists have therefore resorted to using proxy indicators, such as the share of people signing a marriage register. A comparison of different proxy indicators might be the best option for obtaining reliable insights. This is the rationale for using the age-heaping methodology, which is based on the tendency of poorly educated people to round their age erroneously. For example, less-educated people are more likely than people with greater levels of human capital to state their age as "30," even if they are in fact 29 or 31 years old.

The calculation of the ABCC Index of numeracy is shown here as a derivation of the Whipple Index (Wh):[19]

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

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

The correlation of numeracy and literacy illustrates that the numeracy indicator is informative. Crayen and Baten (2008) found that the relationship between illiteracy and age-

[19] "ABCC" comes from the authors' names A'Hearn, Baten and Crayen (2009), plus Greg Clarks, who inspired this simple linear transformation of the Whipple index with a comment. The underlying Whipple Index is the only one that fulfills the desired properties of scale independence and that ranks samples with different degrees of heaping reliably.

heaping for less developed countries after 1950 is very close. They calculated age-heaping and illiteracy rates for no less than 270,000 individuals who were organized into 416 regions, ranging from Latin America to Oceania. Their findings indicated that the correlation coefficient with illiteracy was as high as 0.7 and that the correlation with modern student test results for numerical skills was as high as 0.85. They therefore concluded that the age-heaping measure “Whipple Index” is more strongly correlated with numerical skills. This correlation was reported in many studies (Appendix B has more examples). Crayen and Baten (2010b) also examined a variety of other potential determinants of age-heaping, such as the degree of bureaucracy (proxied by the number of censuses performed for each individual country up to the period under study), birth registration practices, and government interaction with citizens that potentially influenced the likelihood that an individual would know his or her exact age, independent of personal education. Crayen and Baten found that bureaucracy indicators were mostly insignificant, which would suggest that an independent bureaucracy effect was rather weak. In other words, it appears that societies in which a large number of censuses were conducted and where birth registers were introduced early on had a high degree of age awareness. However, those societies also introduced early schooling, and this was the variable that clearly had more explanatory power than the independent bureaucracy effect. They 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 there was a statistically significant correlation, while in others there was none.

We should clarify that the time costs incurred by those parents who let their children acquire basic numeracy are not extremely high. Some amount of explanation of numbers when playing children’s games requiring number processing is often enough. Still, the costs were and are too high for many families. Families sometimes sent their children to work instead if it was necessary for family survival, with severe consequences for the children

In conclusion, the correlation between age-heaping and other human capital indicators is well established, and the “bureaucratic” factor does not invalidate this relationship. One caveat relates to other forms of heaping (apart from the heaping on multiples of five), such as heaping on multiples of two, which was quite widespread among children and teenagers and, to a lesser extent, among young adults in their twenties. However, excluding ages younger than 23 is an easy remedy for this. It also shows that most individuals knew their age as teenagers, but only those in well-educated societies were able to remember or calculate their exact age later in life. We will also exclude those above 72 because a number of distortions could affect groups composed of elderly individuals.

Many young males and females married in their early twenties or late teens, when they also had to register as voters, military conscripts, etc. On such occasions, they were sometimes subject to minimum age requirements, a condition that gave rise to increased age awareness. Moreover, individuals in this age group were physically growing, which made it easier to determine their age with a relatively high degree of accuracy. All these factors contributed to a reduction in age-heaping among children and young adults relative to levels observed among older adults. Because the age-heaping patterns of very old individuals were subject to upward as well as downward bias for the reasons mentioned above, the very old should also be excluded.

A question that needs careful study is whether the age-heaping found in the sources reflects the numeracy of the responding individual or, rather, the diligence of the reporting personnel who wrote down the statements (e.g., Szołtysek 2011, 2014). The age data of the relevant age groups of 23-72 were normally derived from statements from the person himself or herself. However, it is possible that a second party, especially the household head, the father, or the husband, may have made or influenced the age statement. It is even possible that the enumerator estimated the age without asking the individual (especially for lodgers, inmates, or other temporary household members such as unrelated servants). In such cases, we would not be able to measure the numeracy of the person interviewed. By contrast, if the enumerator asked the person for his or her age and obtained no response, a round age estimated by the enumerator would still measure basic numeracy correctly. A large body of literature has investigated the issue of how to handle cases in which individuals did not report their own information, especially whether women's ages were reported by their husbands. Friesen et al. (2011) recently systematically compared the evidence of a gender gap in numeracy and in literacy for the late nineteenth and early twentieth centuries and found a strong correlation. They argued that there is no reason why the misreporting of literacy and age should have yielded exactly the same gap between genders. A more likely explanation is that the well-known correlation between numeracy and literacy also applies to gender differences.

Moreover, there is sometimes direct evidence in the sources that the wives themselves were asked. Manzel et al. (2011) reported finding sources on Latin American Indio women in which statements such as the following were included: "She says that she is 30, but she looks more like 40." Even for black female (and male) slaves in the Cape Colony in South Africa who were accused of crimes, the legal personnel created a separate column that indicated whether the person was guessing her age or whether she actually knew it. We can speculate that if these Indio and African women—who probably were not shown much respect by colonial officers—were asked to report their age, then women of mostly European origin — who were likely treated with a greater level of respect — might also have been asked to report their age. For our study, the question of whether the women answered themselves is slightly less important because we only seek to estimate average numeracy.

The problem of different enumerators influencing the quality of age statements has also been studied in a twentieth century context. While a large part of age misreporting indeed arises because the respondents do not know their exact age, this problem is likely to be exacerbated by differences in the quality of the performance of the enumerators, as some of them may have taken their duties more seriously than others (United Nations 1952, 59). Referring to the notorious hardships encountered in the surveying processes in contemporary developing countries, Ewbank observed: “In particular, the training of interviewers, their level of education, and their ability to understand and pursue the interests of the researcher will significantly affect the quality of data [on age]” (Ewbank 1981, 15). However, the difference between the behavior of twentieth century enumerators and the officials of the late nineteenth centuries is that the former had much easier access to sources that would enable them to cross-check age statements. Officials of the nineteenth century could have looked up birth years in birth registers, but because the registers were usually chronologically sorted, the cross-checking of ages would have required a substantial investment of time.

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

A’Hearn, Baten, and Crayen (2009) used a large U.S. census sample to perform a very detailed analysis, and they confirmed a significant relationship. It is also remarkable that the coefficients were found to be relatively stable between samples; i.e., a unit change in age-heaping was associated with similar changes in literacy across the various tests.

To assess the robustness of those U.S. census results and the similar conclusions that could be drawn from the less-developed countries of the late twentieth century, A'Hearn et al. (2009) also assessed age-heaping and literacy in 16 different European countries between the middle ages and the early nineteenth century. Again, they found a positive correlation between age-heaping and literacy.

The widest geographical sample studied so far was created by Crayen and Baten (2010b). This sample included 70 countries for which both age-heaping and schooling data (as well as other explanatory variables) were available. 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 shown to be relatively stable over time.

Internet Appendix C: The method of estimating inequality using the coefficient of variation of height

We assess relative deprivation measured by the coefficient of height variation. This variable measures how unequal the access to good nutrition and healthcare is for different groups in the society. We therefore will describe the idea, its origin and the measurement process in detail below (the following discussion is based on Baten and Mumme 2013, and Baten and Blum 2011).

We begin with a short discussion of average height, before we turn to height inequality below. Mean adult height is by now a well-established indicator of biological welfare (Fogel 1982; 1986, Steckel 2009, Komlos 1985). Environmental conditions prevailing during a cohort's first three years of life have a strong influence on adult height, because the growth rate in human stature is highest during this age (Eveleth and Tanner 1990, Baten 2000a).[20]

[20] Admittedly, the environmental influence on growth during later ages, especially during the adolescent growth spurt, remains – theoretically speaking – a potential void. However, Baten (2000b) finds in a multi-country

Hence, stature measurements of adults that were recorded decades later can be used to shed light on the period of the first years after birth (cf. Moradi and Baten 2005). There is comprehensive anthropometric theory documented in the literature that cannot be reported here in detail (Komlos 1985, Steckel 1995, Baten 2000b; and on height inequality especially Baten 2000a). These studies provide proof that genetic factors matter strongly at the individual level, while population averages are mostly determined by nutrition and health conditions. If a person's parents were tall, she is also tall for genetic reasons, but, at a population level, the Dutch were very short during a period of severe protein malnutrition during the mid-19th century. Many patterns that earlier anthropologists considered to be attributable to genetics (such as tall Masai and Tutsi) turned out to be the results of special nutritional and health environment features.[21] The nutrition and health impact on height is confirmed by studies such as the one by J.P. Habicht et al. (1974), who found that upper class groups of African countries were of similar height as the average U.S. citizen, whereas the middle and lower class in their countries were severely stunted.[22] Graitcer and Gentry (1981) confirm this finding for Egypt, Togo, and Haiti. Correspondingly, educated young Chinese in Beijing today are only marginally shorter than the U.S. standard would predict. There may be exceptions with very isolated populations, such as the Pygmies, for whom genetic height potential may play a limiting role at the population level. In other words, for those populations even optimal diet and health conditions would not produce height levels similar to Western averages. But those exceptional populations have never accounted for a substantial share of the world population during the past two centuries.

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empirical study that this effect is negligible compared with the impact of the first three years, as long as individuals have reached their final height.

[21] In late 20th century, there may be a modest effect of intergenerational height transmission at a population level in wealthy populations due to nutritional customs (for example, in Japan; Baten 2006).

[22] The following discussion is based on Moradi and Baten (2005).

Occasionally, purchasing power and the biological components of welfare (life expectancy, health, quality of nutritional intake) diverge from each other. In such situations, heights and real incomes also diverge. For example, it has been observed that heights fell, even though real incomes grew, when the U.S. economy switched from being characterized by farmers living in remote frontier areas to a highly urbanized industrial society. These deviations are, of course, interesting by themselves: they allowed important anthropometric contributions to crucially influence debates in economic development, as, for example, the standard of living discussion or the resolution of fundamental research puzzles (such as the "early industrial growth puzzle").[23] We therefore use a data set of adult male height from 165 countries since 1810 that has been compiled only recently (cf. Baten and Blum 2012).[24] The dataset is more closely documented in this study.

After these general remarks about height as an indicator of average nutritional quality and a healthy environment during children, we discuss now height inequality. We use the coefficient of height variation (CV from here) to estimate height inequality – and thereby the inequality of living standards – of a population within a certain birth decade. Baten (2000a) showed that the coefficient of height variation is a good proxy for overall inequality within societies, as the two measures are correlated (see also Moradi and Baten 2005, Van Zanden et al. 2014a). However, human height is influenced by factors that are not traded, but rather provided by public goods, such as the healthcare system within the society. Therefore, the correlation between income inequality and height inequality is not a perfect one. But we argue that anthropometric inequality measures might be even advantageous compared to income-based inequality indicators in civil war studies as height captures important aspects of living standards, in particular nutrition and health (Komlos 1985, Steckel 1995). More specifically, although income inequality is an important factor for dissatisfaction, people might be even

[23] The 'antebellum puzzle' or the early 'industrial growth puzzle' (see Komlos 1985, 1998, Margo and Steckel 1989) count among them.
[24] The dataset will be available via the Clio Infra-internet site soon.

more inclined to rebel if they feel deprived of very basic factors of well-being while other groups of the society have access to these.

The effects of inequality on heights are best understood by comparing the likely outcomes of a hypothetical situation, in which a population is exposed to two alternative allocations of resources A and B after birth:

(A) All individuals receive the same quantity and quality of resources (nutritional and health inputs). This case refers to a situation of perfect equality.

(B) Available resources are allocated unequally (but independently of the genetic height potential of the individuals).

In the case of A, the height distribution should only reflect genetic factors. Despite perfect equality, we observe a *biological variance* of (normally distributed) heights in this case. Yet how does the height distribution respond to an increase in inequality (B)? The unequal allocation of nutritional, medical and shelter resources allows some individuals to gain and grow taller, while others lose and suffer from decreasing nutritional status. In comparison with the situation of perfect equality, the individual heights of the rich strata shift therefore to the right, the poor strata shift to the left. Thus rising inequality should lead to higher height inequality, although this effect is weakened by the fact that the genetic height variation accounts for the largest share of height variation. Even a bimodal height distribution could result if the resource endowment differed extremely between groups. In practice, since the biological variance continues to contribute a large share to the total variance, most height distributions are normally distributed or very close to normal, but with a much higher standard deviation than A (but see A'Hearn (2004), Jacobs, Katzur and Tassenaar (2008) on late teenagers).

The standard deviation is not a satisfactory measure of inequality, since anthropologists argue that the *biological v*ariance increases with average height (Schmitt and Harrison 1988). The coefficient of variation (CV) takes this effect into account and is a consistent and robust estimate of inequality. For a country i and a five-year-age birth decade t, the CV is defined as:

(1) $$CV_{it} = \frac{\sigma_{it}}{\mu_{it}} \cdot 100$$

Thus, the standard deviation σ is expressed as a percentage of the mean μ. Baten (2000) compared height differences between social groups using the CV for early 19th century Bavaria, since an ideal data set was available for this region and time period, with nearly the entire male population measured at a homogeneous age and the economic status of all parents recorded. The measures turned out to be highly correlated. Therefore, high CVs sufficiently reflect social and occupational differences without relying on classifications. The CV of a totally equal society is yet unknown and can only be empirically approximated. For decomposing world health inequality, Pradhan et al. (2003) tried to standardise height inequality by assuming that the height distributions in OECD countries reflect the genetic growth potential of individuals only. However, this would mean that no nutritional and health inequality exists in OECD countries, which seems highly implausible. In Germany during the 1990s, for example, height differences between social groups were as large as two centimeters (Baten and Boehm 2009; Komlos and Kriwy 2003). Even in egalitarian Scandinavia, some height inequality remains between regions (Sunder 2003).

Moradi and Baten (2005) have estimated the relationship between income inequality and height CV for 14 African countries and 29 five-year periods. They controlled for the differences in income definition and population coverage by including dummy variables. In addition, country fixed-effects were included (**Fehler! Verweisquelle konnte nicht gefunden werden.**2, model 1 and 3) which implies that their analysis focused mainly on intertemporal effects.

They found that height CV was significant and positively correlated with the gini coefficients of income (Table 1). An increase in the CV by one unit corresponded with a rise in the gini coefficient by 13.2 points in the fixed-effects specification. It is noteworthy that the relationship between the CV and the gini coefficient is not sensitive to country fixed-effects in general. In another regression without country fixed effects (2), they obtained a coefficient between nutritional and income inequality of 20.9. Both coefficients were very close to Baten and Fraunholz's (2004) estimate for Latin America, which reported a significant coefficient of 15.5 based on gini coefficients whose underlying data are of the highest possible quality. Additional robustness tests including weighting for sample quality confirmed the relationship. Moradi and Baten (2005) argued that an excellent case for comparing the development of both income and height-based inequality measures is Kenya, for which the estimates by Bigsten (1985) offer a consistent source with a sufficient number of data points. The development of both inequality measures is nearly identical, except for the sudden fall of the gini coefficient in 1955 with which the CV does not correspond. It is actually not clear which of the two inequality measures describes the development better, but at least it seems that the CV's movement is somewhat smoother and less volatile (the CV might moreover be less volatile due to some consumption smoothing, as people reduce their savings in harder times to smooth their consumption). However, both the strong rise of inequality in Kenya during the early 1950s and the more gradual rise of the late 1960s are clearly visible in both series. Similarly, the decline in inequality thereafter is confirmed by both measures. Summing up, the development of CVs over time serves as a promising measure of inequality, even more so because in periods and countries in which other data on inequality are either non-existent or unreliable.

Actually, most estimates between height CV and income gini have been performed for the period after 1950s when real incomes started to increase and a smaller part of that budget was allocated to food and shelter. This might bias the correlation between height CV and gini coefficient of income downwards because in many regions a lower portion of income was spend on food and shelter in the later period. Our main interest is the period prior to 1950, and especially the poorer countries. In that period budgets were relatively small, and the proportion spent on food and shelter high, so height CV and income ginis should be closer correlated than in the post-1950 period. In sum, the relationship between gini coefficient of income and height CV seems quite well-established.

Additional references

Baten, J. and Blum, M. (2011). “Anthropometric within-country Inequality and the Estimation of Skill Premia with Anthropometric Indicators”, *Review of Economics -- Jahrbuch fuer Wirtschaftswissenschaften* 62-2 (2011), pp.107-138.

Baten, J. and Blum, M. (2012). “Growing Taller, but Unequal: Biological Well-Being in World Regions and Its Determinants, 1810-1989, *Economic History of Developing Regions* 27 (2012), pp.S66-S85. V.

Online Appendix D: Checking whether spatial autocorrelation invalidates the results?

Does spatial autocorrelation invalidate the results that inequality reduced inequality? Kelly (2019) recently argued that many results in the persistence literature could have arisen from random spatial patterns and that the likelihood of this problem is higher if spatial autocorrelation is not controlled for (the following internet appendix is based on one section in Keywood and Baten (2019). Our study is less affected by this issue because our explanatory and dependent variables are coded for contemporaneous time units, but we still need to control for spatial autocorrelation. Spurious relationships may form due to numeracy spillovers rather than as a result of truly economic interactions. Here, we make use of spatial econometric techniques, first formalised by Paelinck and Klaasen (1979). For recent surveys, see Lee and Yu (2010) and LeSageand Pace (2009).

We first constructed an inverse distance weighting matrix based on the coordinates of the geographic centroids of our geographical units. In this way, our models control for spatial effects in a linear manner – with neighbouring regions having a greater weight than those further away – as opposed to only capturing the effects of immediate neighbours or using an alternative system with an unequal weighting mechanism that reflects historical characteristics, for example.

Because spatial methods require a weighting matrix to link each observation of the dependent variable to every contemporaneous observation from a different geographical unit's dependent and independent variables, they require strongly balanced panels. We fitted a fixed-effects spatial model for balanced panel data. In order to obtain a balanced panel data set, we had to limit our evidence to the 1900s to 1930s, and we could only include epidemic disease as additional control variable, as the other variables had a least one missing value. We used clustered sandwich estimator to cluster for regions, and Both if we include time fixed effects (Table D.1 below, we took the birth decade of the 1900s as omitted category for the constant) or if we do not (results available from the authors), height inequality significantly reduces numeracy.

Our spatial analysis utilises one of the most commonly used spatial econometric models, the Spatial Autoregressive Model (SAR Model):

$$y_{it} = \rho \boldsymbol{W} y_{it} + \boldsymbol{X_{it}} \beta + a_i + \varepsilon_{it}$$

where y_{it} is a vector for the numeracy variable in time period t; $\boldsymbol{X_{it}}$ is a matrix of all time-varying regressors for time period t that we can mobilise; a_i is a vector of region fixed effects; ε_{it} is a vector of spatially lagged errors; $\boldsymbol{W}$ is an inverse distance weighting matrix constructed using the coordinates of region centroids; β is a vector of ordinary regression coefficients; and ρ *is* a coefficient of the spatial characteristics described below.

The SAR Model controls for the direct effect that variation in the dependent variable of other regions may have on region i (measured by ρ) i.e. the effect of numeracy spillovers from neighbours.

Our results show similar coefficients for inequality, although these are surprisingly somewhat larger (in absolute terms) than those from our main specification in the text.

In sum, the results of this spatial regression is similar to the ones without controlling for spatial autocorrelation. The ρ *pa*rameter is significant only at the 5% level. This leads us to believe that despite limited evidence of dependent variable and error term spillovers across regions, spatial autocorrelation is not a notable source of endogeneity in this study.

Robustness test: regressions at the city level

In addition, we assessed spatial autocorrelation for the cross-sectional dataset of fifty-nine cities in Chile, which we also discussed in the main text. We find that although rho is substantial and significant, this does not invalidate the coefficient of height inequality. This coefficient is in a similar range as the coefficient without controlling for spatial autocorrelation. Moreover, the inequality coefficient is still substantial. Hence, we can conclude that inequality mattered strongly by retarding human capital formation, because a lot of talented Chileans during the 19th century did not get the opportunity to develop their cognitive basic abilities.

Table D.1: Checking spatial autocorrelation in a balanced sample

```
SAR with spatial fixed-effects                      Number of obs =         60
Group variable: prnum                            Number of groups =         15
Time variable: bdec                                  Panel length =          4
R-sq: 0.3437
                                 (Std. Err. adjusted for 15 clusters in prnum)
------------------------------------------------------------------------------
             |               Robust
        abcc |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
Main         |
       htvar |  -10.38297   1.454673    -7.14   0.000    -13.23407   -7.531862
      epidem |    8.43285   6.040634     1.40   0.163    -3.406575    20.27227
Time FE: included
-------------+----------------------------------------------------------------
Spatial      |
         rho |  -.5176539   .2589665    -2.00   0.046    -1.025219   -.0100888
```

```
-------------+----------------------------------------------------------------
Variance     |
    sigma2_e |   4.658556   1.133163     4.11   0.000     2.437597    6.879515
```

Notes: We performed these tests using the stata commands:

spmat idistance AK lati longi, id(prnum) normalize(row)

xsmle abcc htvar epidem bdec1910-bdec1940, wmat(AK) model(sar) fe type(ind) robust

Table D.2: Checking spatial autocorrelation for the cross-section of cities

	(1)	(2)	(3)
	spatial		
VARIABLES	abcc	rho	sigma
htvar	-6.160***		
	(2.352)		
Constant	54.41***	0.594***	10.31***
	(16.17)	(0.170)	(0.977)
Observations	59	59	59

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Additional References

Kelly, M. 2019. The Standard Errors of Persistence. Available at SSRN: https://ssrn.com/abstract=3398303 or http://dx.doi.org/10.2139/ssrn.3398303 [Accessed 29 Jun. 2019].

Keywood, T. and Baten, J. (2019). “Elite Violence and Elite Numeracy in European Regions from 500 CE to 1900 CE: A Co-Evolution?” with Thomas Keywood. CEPR Working Paper 14013.

Lee, L.-F., and J. Yu. 2010. Estimation of spatial autoregressive panel data models with fixed effects. Journal of Econometrics 154: 165-185.

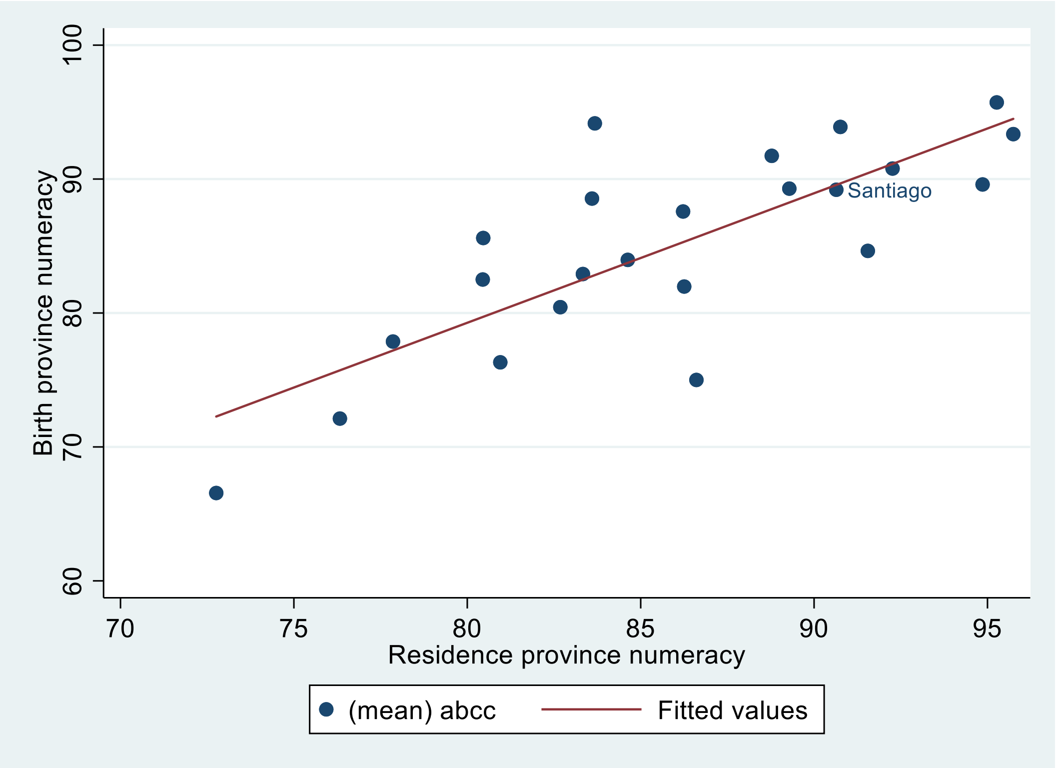
LeSage, J., and R. K. Pace. 2009. Introduction to Spatial Econometrics. Boca Raton, FL: Chapman & Hall/CRC.

Paelinck, J. and Klaassen, L. 1979. *Spatial econometrics*. London: Gower Publishing.

Online Appendix E: IS numeracy by province of birth and province of residence strongly correlated?

We also assessed the degree to which the numeracy of the province of birth and province of residence is correlated in Chile. For this, we could use the census of 1960 that reported both. For example, did numerate persons migrate systematically from a variety of provinces to the capital of Santiago? We find, using the example of the age group of 53-62 (i.e. those Chileans born mostly in the 1900s), that the correlation coefficient of numeracy in the province of birth and the province of residence is in fact as high as 0.79 (0.000). The deviations from the regression line were unsystematic, for example, we do not observe that the residence population of Santiago was much more numerate than the birth population.

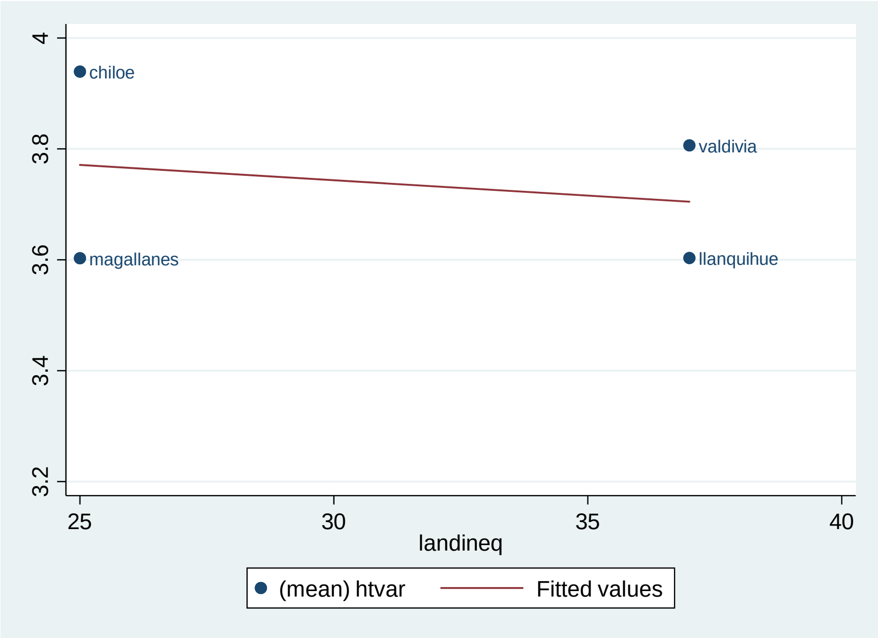
Figure E.1: Comparing the numeracy by province of birth and by province of residence for the birth decade of the 1900s (census 1960)



Note: For the method of calculation see Figure 7.

Online Appendix F:

Appendix Figure F.1: Comparison of land and height inequality in Southern Chile



Online Appendix G: Weighted regressions, by population size

In the main text, we treated each province-decade observation with equal weight here, not weighing by provincial population, because otherwise a few populous provinces in central Chile would drive the results. However, weighing by population does not change the results (Table G1.).

Table G.1 Regressions of numeracy, using weighting by population size

	(1)	(2)	(3)	(4)	(5)	(6)
	1820-1939	1820-1899	1860-1939	1820-1939	1820-1899	1860-1939
Inequality	-3.85*	-3.85*	-0.26	-3.38*	-3.38*	0.81
	(0.056)	(0.054)	(0.934)	(0.088)	(0.084)	(0.764)
Immigrants (North Eur.)	3.01**	3.02**	2.98*	3.34***	3.34***	3.31**
	(0.020)	(0.021)	(0.062)	(0.009)	(0.009)	(0.010)
Conflict	-2.01	-2.01	1.01			
	(0.402)	(0.400)	(0.819)			
Epidemics	-6.71	-6.73	-5.50			
	(0.214)	(0.207)	(0.400)			
Cattle p.c.	-4.93**	-4.89**	-3.43*	-4.71**	-4.69*	-3.19*
	(0.039)	(0.049)	(0.077)	(0.047)	(0.059)	(0.071)
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Constant	61.22***	61.25***	112.09***	60.09***	60.10***	109.86***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Observations	113	109	57	113	109	57
R-squared	0.889	0.881	0.676	0.886	0.879	0.659

Note: The same specifications as in Table 4, but using population weights (square root of population size in 1909). Source: Anuario Estadístico, Censo 1907.