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Inequality, low-intensity immigration and human capital formation in the regions of Chile, 1820-1939

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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 in the early period. However, Chile became slightly less unequal over time and more numerate during the late 19th century. 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.

1. Introduction

Gerschenkron (1962) famously argued that high inequality implies positive effects for income development, because it allows a high saving rate – the richer part of the population can more easily save a substantial part of his income, whereas the poorer part needs to consume almost everything.[1] On the other hand, a large recent strand of development literature argued that inequality retards growth, based theoretically on two main causal chains: The first mechanism relies on the observation that in high inequality settings talents are not fully used. As talents are not only allocated to the middle and higher income groups but are also abundant among the poorer income groups, in unequal societies, children of the latter groups cannot fulfil their potential. They do not receive the necessary education, hence the society as a whole suffers from this waste of talent (Berg et al., 2018). 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). 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.

At first view, Chile seems to be a clear case supporting Gerschenkron's view that inequality implies higher average income, as in recent decades, Chile has enjoyed one of the highest levels of average income in Latin America, together with macroeconomic and political stability (before 2019, see below). Moreover, 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 (https://www.oecd.org/social/income-distribution-database.htm).

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[1] Gerschenkron had agrarian countries like Russia before the revolution of 1917 in mind in which the government and the rich elites invested substantially in physical capital, such as railroads, mines and partially agricultural machinery.

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However, in this article we study the long-term development of Chile. We find that this view is not supported by the country's history: Chile entered its path to high income in the late 19th and first years of the 20th century, a period of declining inequality.[2] In Chile, the trend towards lower inequality during this period created an unusual rapid increase of numeracy. Moreover, exactly the low-inequality regions within Chile developed the human capital foundations for Chile's remarkable growth during the 20th century.

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 inequality 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 et al., 2010; Cámara Hueso et al., 2019). In the case of Chile, labor market selectivity was not an issue because everybody was measured to do the general conscription before some were then selected for the army. Our source is based on a general conscription system. The coefficient of variation of height has been consolidated as a good indicator to measure inequality (on this, see Baten, 2000; Moradi and Baten, 2005; Van Zanden et al., 2014a; 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). The age heaping method is by now a widely accepted strategy to proxy for numeracy (A'Hearn et al., 2009; Crayen and Baten, 2010a, 2010b, Manzel et al., 2012; Tollnek and Baten, 2017; Blum and McLaughlin, 2019). 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. Our main hypothesis is that inequality was negatively correlated with numeracy, both across regions and over time. As numeracy is potentially determined by a number of factors, we include many relevant control variables below.

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 et al., 2013, and recently Witzel de Souza, 2019 on Brazil, and Juif and Quiroga, 2019 for Spain), including a recent study for Chile, which found a robust correlation between recruited Europeans and the human capital of natives for the late nineteenth century (González, 2020).[3] There is also an interesting debate regarding the "quality" of the immigrants who arrived in Latin America (Bértola and Ocampo, 2012).

We use an instrumental variable analysis to circumvent potential endogeneity issues and to assess whether any causal effects of inequality exist. Fortunately for this part of the analysis, there was one historical event that had some characteristics of a 'natural experiment': the distribution of landed estates to the Spanish encomenderos during the early colonial period of the 16th and 17th centuries. This event created long lasting land inequality with a strong impact on 19th and early 20th century overall inequality differences. Reverse causation seems unlikely (i.e., that 19th and early 20th century regional differences of numeracy reverse-caused regional differences of this colonial-political event of the 16th century). Even temporal autocorrelation of regional differences are not a realistic concern here, because the low inequality and high numeracy regions in the north of today's Chile and its very south were not yet settled in the 16th century.

We contribute to at least three different strands of the literature. We already discussed the theoretical distribution above, which is the first contribution. Secondly, we contribute to Latin American inequality history. Many Latin American countries had high rates of income inequality, which was interpreted as a hurdle to economic growth (Bértola and Ocampo, 2016, on earnings inequality see Arroyo-Abad and Astorga Junquera, 2017). We add detailed evidence on Chile, which is a particularly relevant case for the study of Latin American inequality. Moreover, we will compare the Chilean experience with Argentina, Mexico and Peru in the last section of this study. We find that inequality trends were crucial for the numeracy development in these countries, for which evidence on both inequality and numeracy is already available for the 19th century.

Our third main contribution relates to Chilean history. Our study is partly motivated by the dramatic events of October 2019 and thereafter. On October 18th 2019, violent unrest erupted in Chile.[4] [5] 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 affected by terrible conflicts. What was at the root of this unrest? Most newspaper reports and interviews with actors agree that extreme inequality, including low pensions, poor quality health care and the lack of educational quality for the bulk of the population played the largest role in driving the conflict.

As Chilean inequality is not new, we argue that its long and dramatic history provides important insights into the implications for economic development. The long-term evolution of inequality, in particular on a regional basis, 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). Insights on this are 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 had a markedly heterogeneous development. We find that some of the northern regions (and those of the extreme south, such as Magallanes) were relatively equal around 1900, after several decades of declining inequality. The central and central-southern areas were

[2] Numerical human capital is crucial for economic growth in the 20th century (Hanushek and Woessmann, 2012; Acemoglu et al., 2014), as we will discuss below.

[3] González (2020) focussed on literacy rather than numeracy, as we do here.

[4] On 5 October 2019, a few days before the worst social unrest 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/

[5] 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

more unequal especially around 1850 when numeracy was also very low. By this stage, central and central-southern Chile remained a land of very large estates, where a few landholders concentrated most land and, by implication, social mobility also remained low (Collier, 1987; Llorca-Jaña et al., 2018a). In fact, regional differences of inequality were extremely large, hence the regional approach provides important value–added to understand Chilean inequality history. Temporal developments are also very interesting - in fact, as inequality was declining between the mid and late 19th Century and numeracy was increasing, one lesson for today is that the most successful development of Chilean human capital – in comparison to Latin American countries of the same period – took place during a phase of declining inequality (we find this for numeracy and years of schooling in the last section of this study).

Finally, our study also offers a methodological contribution. We expect that 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.

2. Data: regional human capital trends

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).

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). The age of the deceased was recorded by asking the close relatives of the person who had died (A'Hearn et al., 2009). The advantage of mortality registers is that individual persons were recorded with their age, name, and place of death. Hence, we can calculate regional numeracy for Chile for a period for which census data is not yet available at this disaggregated level.[6] An important positive feature is also that the civil registers of mortality for Chile were established for all the religions by the local government administrations, hence the lack of selectivity based on religious faith. One potential disadvantage of death registers is that it is not always clear whether the deceased was asked before his or her death by close relatives or religious persons, or whether the age was sometimes estimated. Hence, we compare the estimates based on this source with census data below for the same regions and birth decades. In general, the data quality of Chilean mortality data is quite good, and this is a tradition reaching back at least to the late 19th century (Jdanov et al., 2008).[7] We further assess the validity of this source further in Appendix A.

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

Notes: 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). Hence one big advantage of using the individual-level mortality registers was that we could aggregate them on the same regional level as census data, whereas otherwise the regions would not have been comparable (due to boundary changes of some provinces).

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.[8] 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, once the War of the Pacific (1879–1883) ended.[9] Following Chile's victory, the country annexed the provinces of Tarapacá and Antofagasta, thus becoming a near world monopolist of natural nitrate (Sabate Domingo and Peres-Cajías, 2020). 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).

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

[6] Compared to marriage registers, another advantage is that at the end digits of ages are quite uniformly represented (except for the heaping on 0 and 5). In contrast, in marriage registers in the age group 23 to 32 – for example – the end-digit 3 is strongly overrepresented, due to the fact that most people married in their late teens and early 20s in Chile during this period.

[7] By international comparisons, Chile is always defined as one of the few Latin American countries and middle income countries in general, which has a similar data quality as Europe and North America. In regards to historical periods, Chile has a very good data quality partly based on its high educational standards and especially on the high educational standards of the bureaucratic elite.

[8] On the regional aggregation, see notes to Table 1.

[9] This was an international military conflict that opposed Chile to Bolivia and Peru, over the nitrate-rich coastal regions.

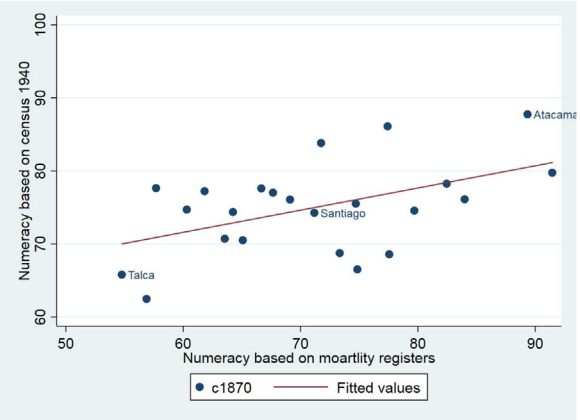


Fig. 1. Correlation between the numeracy of the age group 63-72 mostly born in the 1870s, according to the census in 1940, and the corresponding age group of the mortality register.
Note: to obtain a sufficient number of cases, we used all provinces available from both sources (not only the 1854 "super"-provinces) 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).

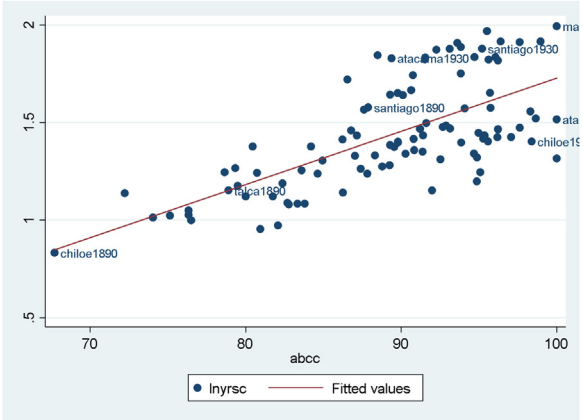


Fig. 2. Scattergram of schoolyears (in logs) and numeracy for the birth decades and provinces of the 1960 census in Chile.

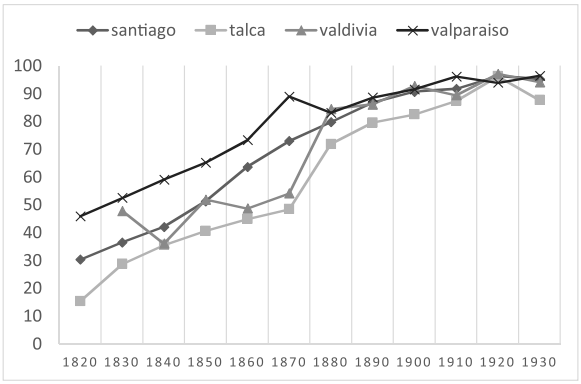
to the 1910s based on the whole provincial population (Chile, 1941). The overlap between the two sources, the early mortality registers and the census of 1940 indicated a substantial degree of correlation across provinces (Fig. 1). This correlation allowed us to counter-check the information content 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.[10]

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 et al., 2019). 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. The systematic comparison of years of schooling and the ABCC index of numeracy (A'Hearn et al., 2009) based on the 1960 census yielded a close correlation (Fig. 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

Panel A



Panel B

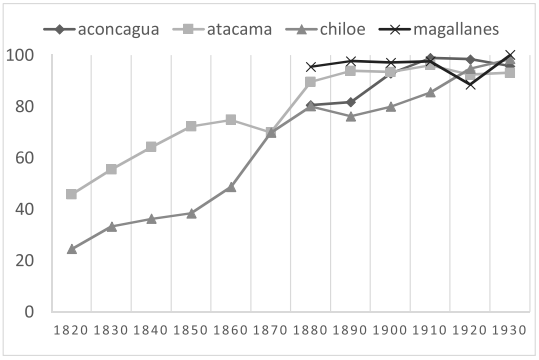


Fig. 3. Trends of numeracy in selected Chilean regions.

aim of the study is the relationship between inequality and numeracy development (Fig. 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). Political historians of the country have called the first decades after independence as the oligarchic republic, characterised by an unchallenged power of the landed, commercial and financial elites, where only a few had access to formal education, with a complete absence of social development policies in place (Larrañaga, 2010). 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,

[10] 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.

followed by more moderate growth, and then by stagnation during the first decades of the twentieth century. This coincides with rapid economic growth: real per capita GDP in the 1880s was more than twice that of the 1840s (Díaz et al., 2016). 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. We discuss below the additional impetus from European immigration. 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). The average years of schooling increased nearly four-fold between the 1830s and the 1890s (Díaz et al., 2016). 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,[11] along with some external borrowing.[12] Schooling is one of the important determinants of numeracy outcomes, the other is education in the family household. The latter 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 had to expect low incomes, as most of the population were unskilled labourers and had no other prospects in life. Moreover, another important characteristic of the household economy is the gender inequality of numeracy (Baten et al., 2017). As a stronger inequality might imply that girls received even less education, they could not provide as much education to their own children once they reached adulthood. Hence, the household schooling often relied strongly on the gender inequality of numeracy – even though gender inequality of education might not have been as high in Latin America during the 20th century compared to other low-income countries (Frankema, 2009; Fuentes-Vasquez, 2021).

Often the day-laborers were so poor that they sent their children to labour. This was the case, for example, in rural and even urban Chile during our period of study (Goicovic, 2001). Child labor reduced the possibility of children to learn at home. Typical child labor activities were dull and did not provide skills. Unfortunately, quantitative data on child labor in Chilean 19th century regions does not exist. However, the literature agrees that it was most problematic in the high-inequality regions (Goicovic, 2001).

At the beginning of the 19th century Valparaiso, which is the main 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 (Fig. 3). The numeracy rate in Talca, a rural province that did not receive many immigrants by this stage and that was characterised by very high unequal land distribution (Llorca-Jaña et al., 2018c), 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, which may be a result of a very unequal land tenure system, where agricultural workers living conditions were particularly harsh (Rodríguez, 2017).

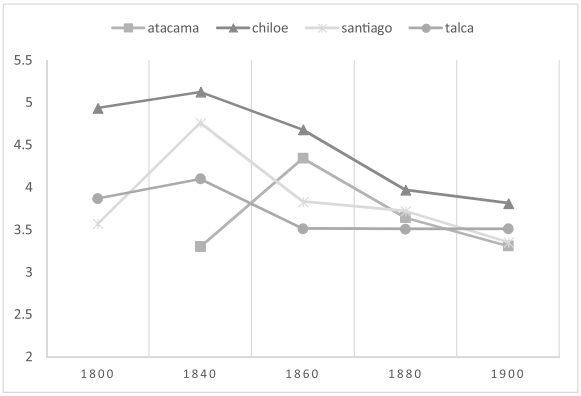


Fig. 5. Trends of height inequality.
Note: The figure shows the coefficient of variation of height.
Source: see note to Table 3 and text.

In Fig. 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, after the end of the War of the Pacific), performed well in regard to numeracy. Atacama was home of the richest copper and silver mines of the country, whose miners enjoyed the highest wages for unskilled workers in Chile.[13] The data for Magallanes was not available for the time period 1820–1870 (since the region was sparsely populated: 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), but we observed a high numeracy rate for this region from 1880 onwards: over 95 %. We also saw an impressive rise 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.[14]

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 and decreasing inequality in some regions and periods, whereas high inequality hindered development in others, especially in the early period.

3. Estimation of regional inequality trends

How can inequality be measured in different provinces and time periods? We obviously do not have a record of income for every Chilean living in the 19th and early 20th century. Hence, we

[11] During the nitrate era (*c*.1880–1930), export duties on nitrate became the most important source of revenue for the government. Next came import duties, mostly funded with nitrate exports revenues. Other sources of taxation became almost irrelevant (Sabate-Domingo and Peres-Cajías 2020).

[12] 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.

[13] It was also a region with less interpersonal violence in Chile during this period (Rivero et al., 2020).

[14] 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. Measures of convergence of human capital could be derived by combining these different bounded variables, which we plan to study in a separate article.

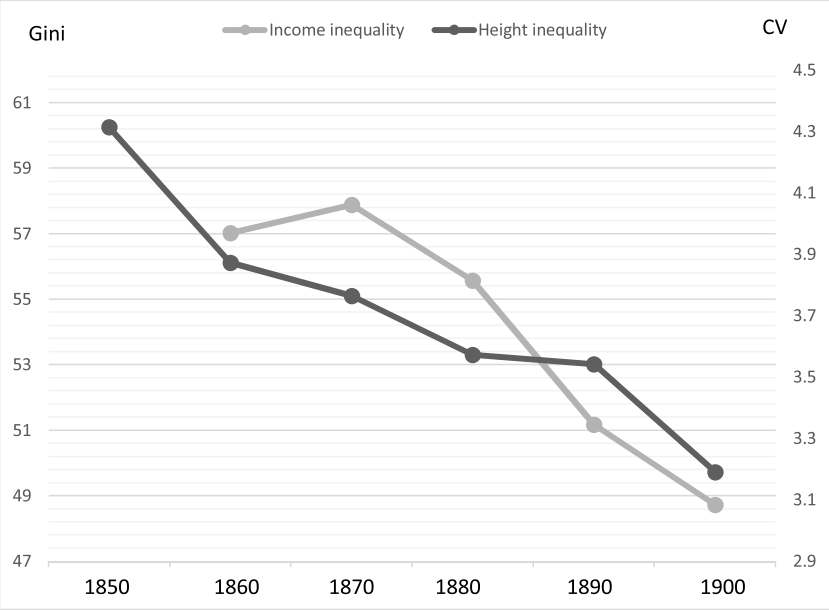


Fig. 4. Comparing Height inequality and Income inequality in Chile, 1850s-1900s.
Source: Gini coefficients of income inequality on left axis, adapted from Rodríguez (2017), coefficient of height variation ("CV") on right axis is based on our data on heights (see text).

need to use proxy indicators. A feasible approach is 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).

Height inequality can be interpreted 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 et al., 2014). It is an advantage that this measure reflects the inequality of consumption of high quality foodstuffs. In the 19th and early 20th 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; Branisa et al., 2020).

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, 2005) and India (Guntupalli and Baten, 2006), 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 Hueso et al., 2019, see also Xu and Hang, 2017, and Gausman et al., 2018). 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, 2005; Baten and Mumme, 2013; Van Zanden et al., 2014a). Moradi and Baten (2005); 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.[15] 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. Only for the first birth decades of the 19th century, the Chilean army had a small volunteer element of 5–7 percent of the total military forces. The assumption that this small part of the army could not influence our overall results seems quite plausible, but needs to be mentioned as a potential caveat. The plausibility of the assumption that this would not influence our overall results can be further assessed by comparing height inequality and income inequality as estimated for the whole country by Rodríguez (2017). A similar trend of the two inequality indicators emerges (Fig. 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 (see Appendix J on the following period). It is not possible to make the same exercise at a provincial level because Rodríguez's data is only at a national level.

The observations on numeracy trends discussed above often corresponded with height inequality (Fig. 3). We observed relatively high inequality values in the early and middle decades of the 19th century, which declined in the following decades (Fig. 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, perhaps a result of the documented poor living conditions of growing urbanization (Llorca-Jaña et al., 2019). The inequality level in Talca has stagnated since 1860, which is not surprising since there was almost no structural change in the agricultural regions of central Chile during this period.

[15] There has been an important advance to our knowledge on Latin American anthropometric history. For the latest articles, see Branisa et al. (2020); Salvatore, 2019; Borrescio-Higa et al., 2019; and Marein, 2020.

Chiloé showed later a dramatic trend towards lower height inequality, and towards more numeracy. [16] Interestingly, in the early 19th century, the lower income groups had an exceptionally low standard of living in Chiloé, as visitor Eduard Poeppig, a professor of Leipzig University (1835) documented for 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.

However, there was a positive trend towards less inequality between the 1840s and the 1900s. This trend was supported, if not caused, by economic and political developments. Large landowners, who were the unchallenged political and economic elite of the country at the beginning of our period of study, became less politically represented or active in the 1870s or 1890s. A recent study showed that agriculture was by far the most important economic sector of the country until the 1840s. The landed elite of the country during the 1810s–1840s (i.e. soon after independence from Spain) was to a great extent composed of the same families that were influential during colonial times. In short, this landed elite was also the political elite of the country in the early and mid-19th century (i.e. they were presidents and MPs, see Llorca-Jaña et al., 2017). However, after the 1840s the mining, commercial and industrial sectors started to become more important, and industrial elites typically promote at least a basic level of education or their workers (Galor et al., 2009, Baten and Hippe, 2018)[17] .

Rodríguez (2017) argued that the settlement in the far South and in the far North also provided new opportunities for the poorer parts of the agricultural population. The effect on inequality was even more pronounced than in other Latin American countries, such as Argentina or Brazil, because immigration to Chile was more limited. Hence, less competition between the lower income groups implied increasing wages in such a situation. Even if the Chilean agricultural workers did not migrate from the central valley in the end, many of them could use the possibility to do so as an argument in negotiations with landowners for higher salaries. This further reduced inequality in many regions of Chile. Likewise, there were important political changes taking place in the country. Political historians of the country have called the period *c*.1830s–1880s as the oligarchic republic, characterised by an unchallenged power of the landed, commercial and financial elites. From mid-nineteenth century onwards, new and more diverse political parties emerged in Chile (e.g. Radical Party), and they entered the Chilean Parliament, with wider representation of the middle-classes. Likewise, in 1874 there was a political reform that greatly expanded the number of people able to vote in Chile (Valenzuela, 1997). Subsequently, the 1890s and 1900s belong to the so-called Parliamentarian Republic, in which the president waived many of his powers to the parliament. In turn, the new parliament was composed by a more diverse political elite, that started to incorporate, albeit gradually, new and more progressive discussions within Chilean parliament. Indeed, secret ballot was introduced in the country (Valenzuela, 1997 and 1998). The evidence on inequality suggests that these economic and political developments resulted in a transformation from an extremely unequal economy dominated by traditional agriculture (with large landowners and many day-laborers) towards a less unequal society in which the workforce of industrial and commercial activities in Chile consisted of more middle-income groups.

4. The relationship of immigration and numeracy

Although the main focus of this study is the relationship between inequality and numeracy, human capital in Latin America has 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). In 1845 an immigration law was promulgated, the so called law of selective immigration. It allowed the government to provide small plots of land to immigrants, of some 13 ha if located in the center of the country between Copiapó and Bio-Bio or of 62 ha if located to the south of the Bio-Bio river. The state would also provide seeds and basic equipment to exploit the land, while immigrants would not pay taxes for twenty years.

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 (Pérez, 2021), 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).

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, once the occupation of Araucania was completed by the Chilean army around the 1860s–1870s (Ríos, 2012), 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 (and their descendants), 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. Churches and schools started to be built as soon as the first immigrants arrived to southern Chile. Between 1887 and 1915 at least 19 schools were created in the Araucania by the newly arrived immigrants or their descendants. Of these, 12 were of German background, 5 French, 1 Swiss and one British (Zavala, 2008). For example, 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, where both descendants of immigrants and other local people attended (including Mapuche) since they received some public funds: for the children, language was not a major hurdle (Zavala, 2008; Cano, 2012). Witzel de Souza (2019) 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.

[16] Llorca-Jaña et al. (2018c) discussed the land inequality in Chiloé.

[17] This and the following explains why income and consumption inequality declined in spite of a relatively high and constant level of land inequality (see also Appendix Z).

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. 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.

We compared the numeracy of people with different groups of surnames such as British, German, Basque and many others (Fig. 6). The surnames of the descendants of immigrants were used to identify the country of origin of their parents/grandparents. We observed strong differences across immigration groups. Descendants of immigrants from Northern Europe (Germany and Scandinavia) as well as those from the UK and Netherlands had a relatively high rate of numeracy, between 80 and 100 percent. For Italy, France and Belgium, we also observe a quite high raw numeracy, followed by the Chileans with Spanish sounding names. Slightly less numerate, but not significantly different were those of Basque origin (many Basques immigrated in the 18th century). There was a relatively strong negative effect of people with Mapuche surnames (the American natives), which was expected due to the difficult economic situation and discriminatory behaviour they were subjected to. We also performed a regression analysis in order to assess the numeracy by ethnic group, but controlling for decade and province fixed effects (Table 2). The ranking remains basically the same. The negative effect for the Mapuche declined during the later period between 1860 and 1909. The constant of this regression is the Chilean native population with Spanish sounding names. We could also separate out a mixed group including Asians (Japanese and Chinese) as well as US citizens that also had a strong numeracy advantage (U.S. citizens often visited temporarily, working as managers for the mining companies). In sum, a number of national immigration ethnicities had a numeracy advantage, but their number was small and could not influence the overall numeracy of the population very substantially by itself. As we described above, we could alternatively imagine that there were external effects via the formation of schools for the whole population of individual provinces, which we will also assess next. 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.

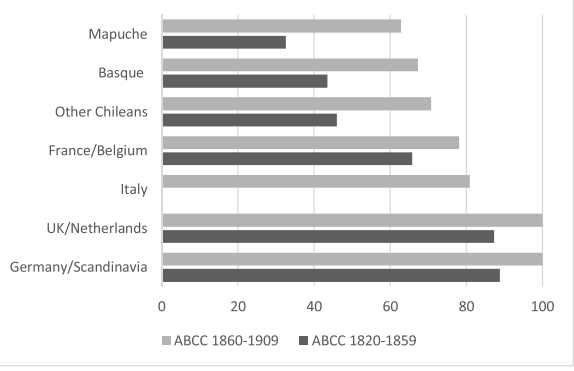


Fig. 6. Numeracy by ethnic group, for the early and late period.

5. 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:

$$N_i d = \alpha + ß_1\ IE_{i,d} + ß_2\ M_{i,d} + X'\gamma + \mu_d + \varepsilon_{i,d}, \quad (1)$$

where $N_i d$ 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, urbanization, income and epidemic diseases, α is a constant, and ε is the error term. 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 descendants of immigrants from North-western Europe 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.

Due to the potential importance of gender equality, we also added a control variable that reflects different levels of gender equality in the provinces and birth decades. In particular, we calculated the numeracy by gender and birth decade in order to assess potential effects of different gender inequalities in the different regions. The background literature reports different views about a potential impact. For the 19th century, this factor did play a role in some developing world regions (Baten et al., 2017). Frankema (2009) found that gender inequality of education was relatively low in Latin America, compared to other developing regions during the 20th century. Although Fuentes-Vasquez (2021) recently confirmed Frankema's view of low gender inequality in the later 20th century, she found substantially lower female secondary enrolment rates in Colombia during middling decades of the 20th century.

In different regression models, we distinguished different time periods, taking the whole period in column 1 and 3, focusing on the early period between 1820 and 1899 in the second and fourth column and on a late period in the fifth and sixth column (period from 1890 to 1919). We included decadal time fixed effects, using decades to control for potential trend correlation effects.

We found a relatively consistent relationship of inequality with numeracy for the whole period and the sub-periods. The primary finding was that inequality was associated with retarded numeracy formation in the Chilean regions. The second variable that correlated quite consistently with numeracy was the share of descendants of Northern European immigrants, even though they made up only a small part of the regional population. We observed that the effect of this variable was consistently positive but significant only for the whole and the early period. This significant coefficient might have resulted from external effects as we discussed above (Witzel de Souza, 2019).

We discussed above potential endogeneity issues of the inequality variable. Similar issues could arise about the Northern

Table 2
Regression: Descendants of immigrant groups and their numeracy.

	(1)	(2)	(3)	(4)	(5)
Period	1820–1909	1820–1859	1860–1909	1820–1909	1820–1909
Region	Chile	Chile	Chile	North	South
Germany/Scandinavian	41.91***	48.33***	25.02***	34.27***	48.05***
	(0.000)	(0.000)	(0.004)	(0.000)	(0.000)
French/Belgian	5.51	8.84	−0.27	−10.56	13.13
	(0.635)	(0.543)	(0.988)	(0.570)	(0.359)
Basque	−2.74	−3.39	−1.76	−10.73**	1.10
	(0.312)	(0.303)	(0.710)	(0.027)	(0.736)
UK/Netherlands	35.99***	36.06***	34.22***	35.50***	36.00***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Mapuche	−9.94***	−13.04***	−4.39		−13.14***
	(0.001)	(0.000)	(0.396)		(0.000)
Unkn./U.S./Asian	23.75***	29.89***	16.88*	18.92**	28.00***
	(0.000)	(0.002)	(0.061)	(0.028)	(0.006)
Time FE	YES	YES	YES	YES	YES
Province FE	YES	YES	YES	YES	YES
Observations	9,589	5,732	3,044	3,013	6,558
R-squared	0.11	0.07	0.04	0.09	0.10

Note: Dependent variable is reporting an age that is not a multiple of five, which is taken as a proxy for being numerate. Explanatory variables are dummy indicator variables based on typical names. Robust p-values in parentheses. ***, **, *, indicates significance at the 1, 5, and 10 % level. Unit of observation is the individual level. Time fixed effects are decadal dummies (even within the early and late period).

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 descendants of 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).

European immigration variable, if immigrants went to high numeracy regions. However, that was not the case. Most Northern Europeans of the 19th century went primarily to the South of Chile, as they hoped to obtain larger plots of 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-hungry 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.

Obviously, Chile underwent a substantial structural change towards more urbanization, especially during the late 19th and early 20th century. Hence, we assessed two models in Column 5 and 6 of Table 4, that include urbanization and income per capita. Including urbanization does not change the result substantially. The urbanization indicator is not even statistically significant. Inequality keeps its negative effect on numeracy even in the 1890s to 1910s period for which both the urbanization and the GDP per capita variable could be measured.[18] Moreover, we observe that including GDP per capita for these three decades does not change most other variables, except immigration that becomes statistically insignificant (while epidemic disease becomes statistically significant). GDP per capita has a substantial positive and statistically significant effect. However, this is a variable that could be interpreted both as an explanatory and as a dependent variable, because many studies showed that numeracy increases GDP per capita. Nevertheless, it is important to observe that the inequality-numeracy relationship is not disappearing once we control for income. Recent studies typically found that numeracy increases GDP (Hanushek and Woessmann, 2012). In contrast, the reverse natural experiments of unexpected income windfalls in other countries resulted in the finding that higher incomes did not increase schooling. A very convincing historical natural experiment consisted of the Cherokee land distribution, which took place in Georgia in the Southern US in 1832 (Bleakley and Ferrie, 2016). The authors studied the winners of this lottery for whom the previous wealth almost doubled. Bleakley and Ferrie traced their children and grandchildren over the 19th century and found that persons who received an unexpected income did not increase the schooling of their children. They used their additional income for other purposes. Similarly, studies on the recent past find not scholastic success effect among the children of lottery winners (but a health effect: Cesarini et al., 2016). As a conclusion from these results, we interpret GDP per capita in the Chilean regions rather as an outcome of numeracy, not primarily as a driving force of educational investment, although we cannot exclude any direction of causation.

For the epidemic disease and conflict variables we would have expected a negative impact. We observed the expected signs for the whole and the early period. But the conflict variable was not statistically significant, and epidemic disease only for the 1890s–1910s period. For the cattle per capita we would also have expected a positive sign because normally cattle density is associated with a higher nutritional quality (Cappelli and Baten, 2021). However, this variable did not have a positive coefficient for the whole and the early period, 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 Fig. 6 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

[18] As well as the Northern European immigrant share – this variable is unavailable after the 1910s.

Table 4
Regression: Correlates of numeracy.

	(1)	(2)	(3)	(4)	(5)	(6)
	1820–1939	1820–1899	1820–1939	1820–1899	1890–1919	1890–1919
Inequality	−4.13*	−4.14*	−3.81*	−3.81*	−3.80*	−3.80*
	(0.077)	(0.075)	(0.062)	(0.059)	(0.055)	(0.055)
Immigrants (North Eur.)	2.75*	2.78*	3.12**	3.13**	0.91	0.91
	(0.082)	(0.082)	(0.027)	(0.027)	(0.250)	(0.250)
Gender equality	0.01	0.01				
	(0.887)	(0.884)				
Conflict	−0.30	−0.30			22.53	22.53
	(0.911)	(0.913)			(0.327)	(0.327)
Epidemics	−7.05	−7.08			−8.93**	−8.93**
	(0.201)	(0.197)			(0.017)	(0.017)
Agric. Spec. (cattle)	−3.94	−3.86	−3.76	−3.70	1.25	1.25
	(0.137)	(0.162)	(0.138)	(0.159)	(0.237)	(0.237)
GDP/c					30.57***	30.57***
					(0.000)	(0.000)
Urbanization					0.43	
					(0.527)	
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Constant	61.73***	61.82***	60.36***	60.41***	77.59**	98.47***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.026)	(0.000)
Observations	106	104	113	109	31	31
R-squared	0.867	0.863	0.880	0.871	0.850	0.850

Notes: Robust p-values in parentheses. ***, **, *, 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 and Miller (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 the city level regressions of Table 5 is robust, even if provincial fixed effects are included. The time fixed effects are decadal dummies. GDP and urbanization in column 5 and 6 is based on the work of Badia-Miró (2008, 2020). 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).

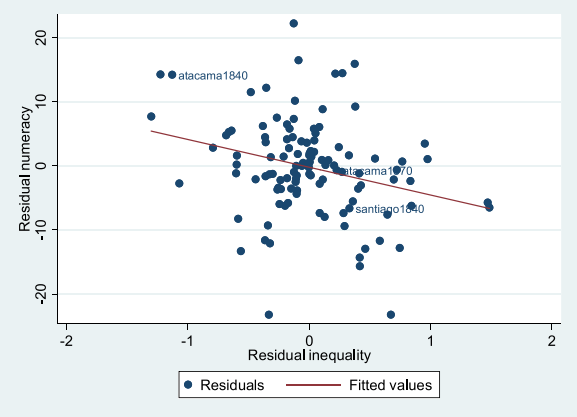


Fig. 7. Comparison of residual numeracy and residual inequality.
Note: this figure shows the residual inequality which is the height inequality after regressing on all the other explanatory variables. Residual numeracy which is the numeracy regressed on other variables and saving the predicted residuals.

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, but that nonetheless benefited all.

In Fig. 7 we map the average residual inequality and the average residual numeracy for the 19th century. In the central-southern region (Chiloé and Llanquihue), inequality was high and numeracy relatively low. The extreme South (Magallanes) is not shown here, as it was settled only during the late 19th century. 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.

6. 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). We could assign to each of these cities 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,

Table 5
Regressions of numeracy in a cross-section of 59 Chilean cities during the 19th century.

	(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 parentheses. ***, **, *, indicates significance at the 1, 5, and 10 % level. Unit of observation is city, the dependent variable is numeracy. Model1 includes no province Fixed effects, whereas Model 2 does.

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.

7. Instrumental variable regressions

Although regressions with decadal fixed effects and city level regressions provide a robust assessment of the conditional correlations between height inequality and numeracy, endogeneity in the form of simultaneity could still exist. Accordingly, we use an instrumental variable analysis to circumvent this endogeneity issue and assess whether any causal effects exist. Clearly, finding suitable instruments for Chile during this early period is a substantial challenge, but there was one historical event that had some characteristics of a 'natural experiment': the distribution of landed estates to the Spanish encomenderos during the early colonial period of the 16th and 17th centuries. This event created long lasting land inequality with a strong impact on 19th and early 20th centuries overall inequality. We cannot imagine reverse causation (i.e., that 19th and early 20th century regional differences of numeracy reverse-caused regional differences of this colonial-political event of the 16th century. Even temporal autocorrelation of regional differences is quite unlikely, because the low inequality and high numeracy regions in the north of today's Chile and its very south were not yet settled in the 16th century.[19] We use land inequality and the distribution of large estates to encomenderos that was finished by the 17th century as an instrument. This was frequently described in the historical literature: Pedro de "Valdivia gave all the land and Indians from the Valley of Choapa to the valley of Copiapó to only eight vecinos [wealthy neighbour] . . . the northern encomienda grants often remained in the same family for many generations. No better example of this could be found than the Aguirre family whose descendants retained the encomiendas of Copiapó and Coquimbo until the abolition of all encomiendas . . . and remained important landowners in the region into the twentieth century" (Loveman, 1979, p.84). "Extreme concentration of land in the large estates condemned the mestizo rural laborers to generations of exploitation" (Loveman, 1979, p.104).

The region with the most unequal land distribution stretched between Aconcagua and Valdivia (with the Mapuche Araucaria region in between). The centre of this region is close to the border between Maule, Talca and Ñuble. Distance measures are often used as instruments (Becker and Woessmann, 2009). One advantage here is that such a distance measure can take into account migration possibilities and cultural factors of land-owner behavior: (1) The psychological and monetary migration cost for an unskilled day-laborer to migrate from this core region of early land inequality to the far north or very far south (were land inequality and income inequality in the 19th century was lower) might have been higher than, say, in Santiago, which was closer to the Northern "border" between the area of extreme land inequality and lower land inequality. Moreover, the hacienda owners of the core region had hacienda owners as neighbors even going 400 km north or south, hence the culture of land inequality (for example, the legitimacy to pay low wages to unskilled day laborers) was less debated in this region. This resulted in a landowner behavior during the 19th century that was more extreme than in regions further north or south.

Before we execute our IV regressions, we need to consider other potential factors that could prevent our instrument from meeting the exclusion restriction. Specifically, our instrument becomes invalid if any characteristics of the early land distribution to encomenderos affected numeracy via other causal channels. Such characteristics are not immediately apparent, but, for example, the selection of more fertile lands by the encomenderos could be such a factor. However, if other variables such as population density and inequality would have been equal, more fertile land might have been actually beneficial for education. This is because fertile land requires less labour input and hence most likely also less child labour, but other variables were of course not equal – especially the urbanization (a proxy for population density) and inequality variable, via which this process was mediated. Nevertheless, we include two proxies for population density, namely urbanization and cattle specialization of agriculture, in order to control for this potential other factor that might have influenced numeracy differences. We perform the following instrumental variable

Table 6
Instrumental variable estimation: Instrumenting the inequality-numeracy relationship with 16th century colonial land assignments.

	(1)	(2)
Second stage		
Inequality	−10.94***	−10.49**
	(0.009)	(0.024)
Immigrants (North Eur.)	2.74***	2.98***
	(0.006)	(0.005)
Gender equality	0.01	0.01
	(0.908)	(0.816)
Conflicts	−3.11	−2.82
	(0.264)	(0.371)
Epidemics	−9.36**	−8.22*
	(0.038)	(0.073)
Agric. Specializ. (Cattle)	−3.62**	
	(0.021)	
Urbanization		0.45
		(0.889)
Time FE	Yes	Yes
Constant	143.13***	119.06
	(0.000)	(0.381)
First stage		
Distance to land ineq. centre	−0.30**	−0.30***
	(0.002)	(0.002)
F-Stat	12.30	11.62
Observations	77	77
R-squared	0.820	0.812

Notes: *** indicates significance at the 1% level (robust standard errors); ** at the 5% level; and * at the 10 % level. The dependent variable is numeracy in the province and birth decades after the 1830s. The instrument for height inequality is the distance to the centre of the land inequality region. We include the controls specialization on cattle agriculture (typical for low population density regions), urbanization, and the other controls of Table 4. Time fixed effects are decadal. Sources: see text.

[19] Interestingly, a recent literature argued that inequality in Latin America during the colonial period was actually relatively modest compared to Europe. This focuses on income inequality, not on land inequality. Land inequality in turn was already high, but food and housing was cheap in Latin America – especially, high quality food such as meat. Hence, even day-laborers had relatively high purchasing power compared to Europe, were food was much more expensive (Milanovich et al., 2011). Only during the 19th century, when Latin American food became tradable and the age of mass migration began (though with limited effect on Chile), land inequality turned fully into income inequality. This finding is important for the quality of our instrumental variable, because it reduces the potential issue of temporal autocorrelation of regional differences, which otherwise could have limited the usability of early land inequality as an instrument for later height and income inequality.

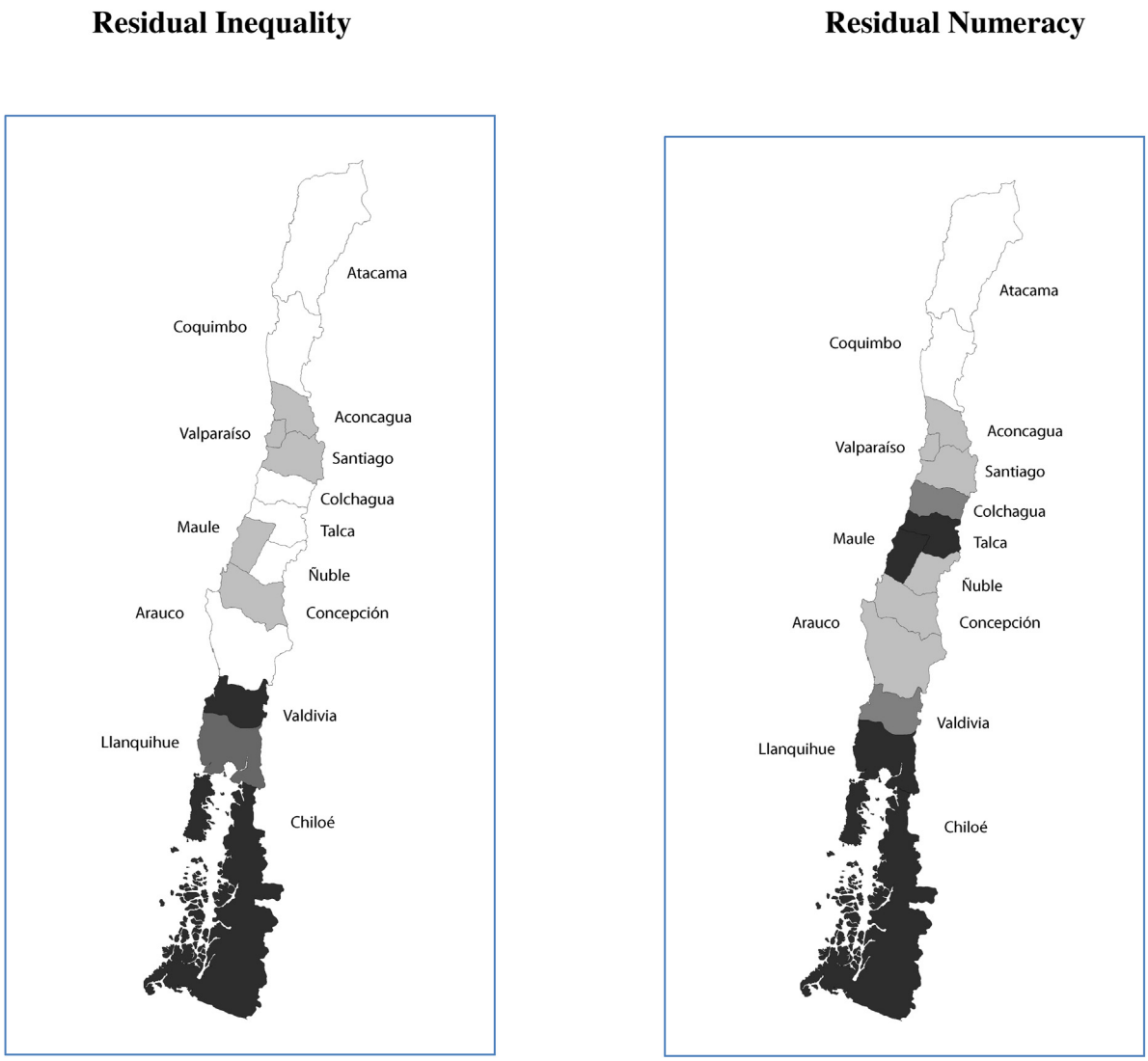
specification for the first and second stage:

$$height\ inequality_{id} = \alpha + \beta_1 distance\ to\ land\ ineq\ centre_i + \varepsilon_{id} \quad (2)$$

$$numeracy_{id} = \alpha + \beta_1 height\ \hat{inequality}_{id} + \beta_k \psi_{id} + \varepsilon_{id} \quad (3)$$

where *distance to land ineq centre* i is the distance to the centre of the land inequality region (near the border of Ñuble, Maule, and Talca in 1000 km units, ψ_{id} is a vector of other control variables for provinces i and decades d, α is a constant and ε_{id} is an error term.

In Table 6, we present the instrumental variable estimation, including all explanatory variables that have been identified before, finding negative and significant coefficients for height inequality. We again find a positive and significant coefficient for low density immigration. A specialization on cattle agriculture (typical for low population density regions) had actually a negative



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

Fig. 8. Mapping the residual numeracy and residual inequality, 1820s-1900s.
Note: These maps show residual inequality and numeracy for the whole 19th century. For the method of calculation, see notes to Table 4. Please note that the far south (Magallanes) cannot be shown, as it was only settled in the later 19th century.

effect, whereas urbanization was insignificant. In the first stage, we see that a large distance to the center of 16th century land assignments resulted in lower height inequality, such as in Atacama. The F-statistic above 10 indicates that our instrument is far from being weak.

8. 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; Rodríguez, 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 (Fig. 9). In contrast, Argentina, Mexico and Peru had lower inequality at mid-century.

However, during the late 19th century, there was a 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 Herrera, 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 actually took place (Fig. 9). 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). This higher speed of numeracy increase was substantial, as Chile grew by 28 %, whereas Argentina only grew 12 % (1850–1880). 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. Peru with its declining inequality grew 37 % (1860–1900), while Mexico with its tremendous inequality story only increased 11 % in numeracy (1870–1900). 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 centers 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 declining inequality between the 1850s and 1910s gave Chile impetus for human capital formation that brought the country on a long and lasting growth path (Fig. 10).

Is the relatively good progress of Chile in terms of numeracy confirmed if we consider years of schooling instead? We find that in terms of the initial level of years of schooling, Chile was only on rank four compared to the other larger continental economies (Table 7). In other words, before 1870 Chile had only average years of schooling, which corresponds well with our results that inequality was high in Chile during the early and mid-19th century. Not only Uruguay and Argentina, but even Venezuela had a higher schooling level in 1870 compared to Chile. However, around 1900 Chile had the fastest progress, both in the decades before 1900 and during the first years of the 20th century: In 1870–1900 Chile reached position number one with 0.79 school years

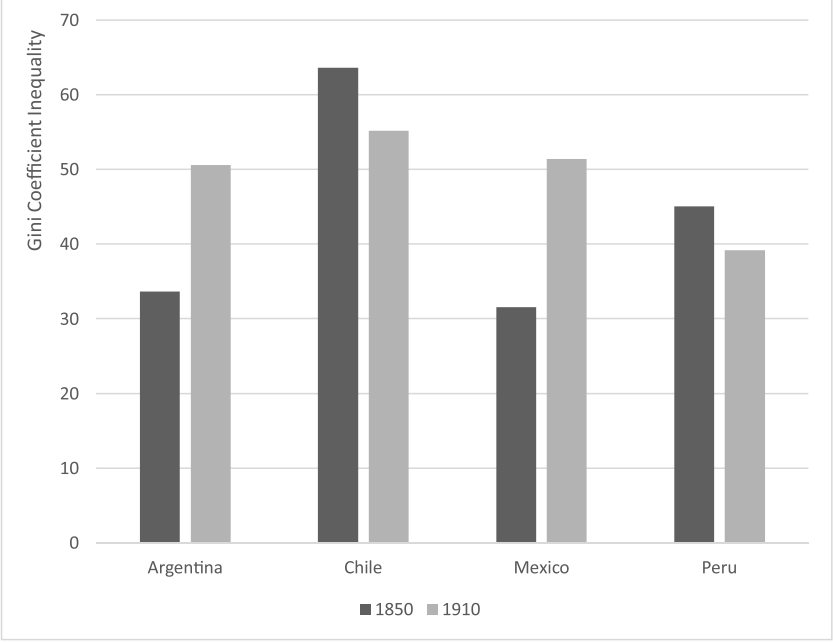


Fig. 9. Placing Chile's inequality in international comparison: 1850 and 1910 levels of inequality in Argentina, Chile, Mexico and Peru. Source: van Zanden et al. (2014a), clio-infra.eu.

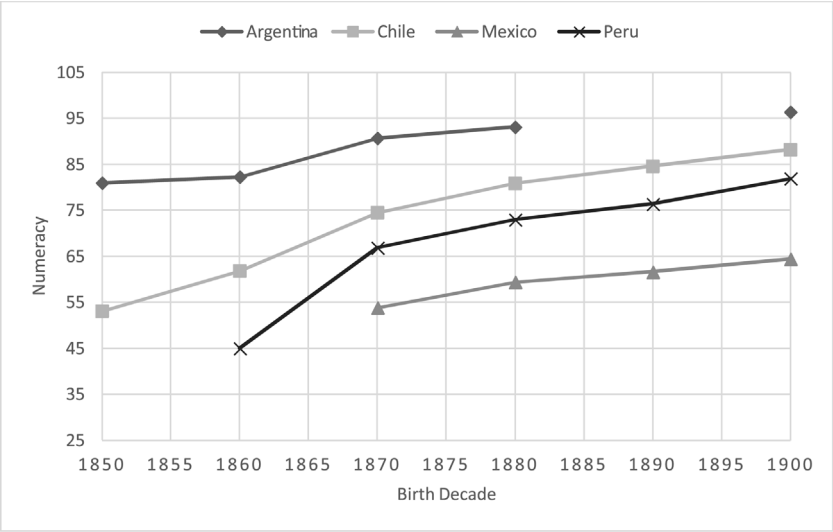


Fig. 10. Numeracy in selected Latin American countries, 1850s-1900s.
Source: Crayen and Baten, 2010a, 2010b, clio-infra.eu.

Table 7
Comparison of years of schooling 1870-2010 of selected Latin American countries.

Country	Initial level 1870	Change 1870–1900	Change 1900–1930	Change 1930–1960	Change 1960–1990	Change 1990–2010
Argentina	1.5	0.62	1.58	**2.48**	1.61	0.98
Brazil	0.46	0.28	0.53	1.81	3.56	1.50
Chile	0.94	**0.79**	**2.16**	1.86	3.21	1.40
Mexiko	0.56	0.53	0.43	1.90	3.50	1.56
Peru	0.63	0.20	1.22	1.42	**4.10**	**1.65**
Paraguay	0.28	0.47	1.34	1.67	1.97	0.99
Uruguay	**1.61**	0.62	1.14	2.13	2.23	0.98
Venezuela	1.1	0.28	0.28	1.91	1.88	1.18
Chile's position	**4**	**1**	**1**	**4**	**3**	**4**

Note: Bold are the most successful countries of this group. Bolivia is not included as data on the 1870s is lacking. A very similar ranking is observable if the percentage changes of years of schooling are considered. See Appendix Y.1.
The changes refer to the absolute change of years of schooling between two years.Source: Clio-Infra.

growth; and in the period 1900–1930 Chilean human capital was increasing by 2.16 school years. This again resulted in position number one among the larger continental Latin American states.

In contrast, even though the total number of school years gained was more substantial during the 1960–90 period, Chile never reached position one again, but the country situated in the middle of the comparable Latin American states. In 1930–1960 Argentina was growing fastest with 2.48 additional school years. In 1960–1990 and 1990–2010 Peru made the strongest progress with 4.10 years and 1.65 years (see Table 7).

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 a 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.

9. Conclusions

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 was 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. Our results are related to those recent events, as we find that one crucial period of Chile's history was characterized by declining inequality: the 1840s to the 1900s period, during which Chile developed into an economy relatively rich in numeracy skills.

In sum, 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 centuries. 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. 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. In order to deal with endogeneity issues, we could obtain exogenous variation from the assignment of encomiendas to large Spanish land owners in the 16th and 17th centuries. We find in an instrumental variable estimation that inequality was causally influencing numeracy. Finally, we compared national developments of inequality and numeracy in Chile, Mexico, Peru and Argentina and observe similar trends even at this aggregate level.

While our evidence on inequality confirms Rodríguez (2017)'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 (Fig. 8). The differences in inequality between north and central-south Chile for example, 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 descendants of Northern European immigrants and their relationship with average numeracy in each province and decade of birth. Regions with a high share of descendants of North European immigrants 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 immigrants' descendants group. They also benefited from the opening of new schools in the area, led by these foreigners and supported by the state.

The nexus of inequality and numeracy is shown in the quality of Chilean public education, currently modest by international standards. As we have shown, lessons of the nineteenth century suggest that less inequality will promote numeracy growth. In fact, the overall increase of numeracy in Chile during the period of declining inequality between the 1840s and 1900s was 43 %. To put this into comparison, the difference between the poorest and wealthiest economies in the world during the early twentieth century was around 50 % (Crayen and Baten, 2010a, 2010b). Similarly, the increase of Western European economies between the 16th and the 19th century was around 45 % numeracy increase – this development is also known as "the European numeracy revolution" (A'Hearn et al., 2009; Tollnek and Baten, 2017). In other words, we can at least speculate that without the dramatic inequality-reduction of the late 19th century, and the resulting numeracy increase, Chile would have ended up in a much poorer group of countries later-on. Moreover, we would conclude that if Chile wants to continue its human-capital-based development in the future, stronger redistribution elements in the public finance system are necessary to reduce inequality.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.ehb.2021.101030.

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