Short and Medium-Run Health and Literacy Impacts of the 1918 Spanish Flu Pandemic in Brazil*

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Abstract

We study the lasting repercussions of the 1918 influenza ('Spanish Flu') pandemic on health measures and literacy rates in Sao Paulo, Brazil, the most populous city in South America today, but significantly poorer a century ago. Leveraging temporal and spatial variation in district-level estimates of influenza-related deaths for the 1917-1920 time-period combined with a unique database on demographic and literacy outcomes as well as a detailed set of socio-economic, infrastructure and regional determinants newly constructed from historical data, we find that the pandemic had significant impacts. In particular, infant mortality and stillbirths rose, sex ratios at birth fell, and there was a marked improvement in male literacy rates for those 15 years and above in 1920. Further analyses reveal that these impacts are most pronounced in districts with older populations, less literate districts, and in districts where access to doctors was relatively limited. We find evidence that the male literacy effects persist in 1940. These results highlight that ramifications of the 1918 Spanish Flu pandemic were experienced for at least two decades after the event in a context where institutions were relatively weak and resources for mitigation were limited.

Key Words: 1918 Influenza Pandemic, Infant Mortality, Stillbirths, Literacy Rates, Sao Paulo, Brazil

JEL Codes: N36, O12, I15, J10

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1 Introduction

Until recently, relatively little had been written on the scarring effects of historical health shocks. Although there has been significant interest in the impact of health events since Almond (2006) studied the long-term effects of the 1918 influenza pandemic in the United States, we still are not clear how impacts may differ when we look beyond cohort controls and importantly, when we analyze effects in the context of developing countries. This is the gap we address in this paper. We study repercussions of the 1918 Spanish Flu on demographic and literacy outcomes in the state of Sao Paulo, Brazil, in the short- and medium-runs. Although today Sao Paulo is Brazil's financial center and South America's most populous city, in the early twentieth century, it was far from such. Given the lack of resources for remedial action and the relatively more primitive health care infrastructure, it is likely that the pandemic's immediate and lingering effects were more harmful in poorer nations like Brazil that were marked by social inequalities and a nascent health system. Moreover, the pandemic coincided with the ending years of the First World War. It is thus hard to disentangle the detrimental impacts of the 1918 flu from the widespread destruction caused by the War, particularly when studying main actors such as the United States. Brazil's contribution to the Allied war effort began in 1917 and was minimal, and the country did not experience the same level of destruction that those in the North endured. The First World War is thus less of a confounding factor in the historical Brazilian context.

Records reveal that in Sao Paulo (city), the disease caused 5,331 deaths in the short period between mid-October and mid-December 1918 (Massad et al., 2007), and infected up to 350,000 people, two-thirds of the population of Sao Paulo (city) (Bassanezi, 2013, Barata, 2000, Bertolli, 2003). As we demonstrate below, the pandemic's duration and intensity differed significantly across districts (the spatial unit of our analysis) in the state of Sao Paulo. We exploit this spatial variation to link the number of influenza-related deaths to a range of outcome variables over time. We accomplish this using detailed district-level historical data on vital statistics, health, and education variables. We complement this data with information drawn from official statistical reports on the pre-existing social, economic, and human capital framework that was in place at the time the disease arrived in Sao Paulo.

Our study considers two time horizons: 1920 (the short-run) and 1940 (the medium-run). We use multiple empirical methods including ordinary least squares (OLS), two stage least squares (2SLS), and coarsened exact matching (CEM). Each of these subsequent methods lends credence to the results generated from OLS which are likely to be biased especially in the early years for reasons we discuss below. Focusing on 1920 and 1940, we instrument for respiratory deaths normalized per 1000 people, our proxy for influenza-related deaths during the pandemic, with average temperature and rainfall in October 1918. The Spanish Flu arrived in Sao Paulo in late September 1918 and as we discuss in detail below, air temperature (sunlight) reduces the incidence of influenza whereas rainfall, by increasing humidity, has the opposite effect. We use temperature and rainfall in October 2018 as the peak in monthly mortality occurs in November 2018, a month later. We find that as of 1920, infant mortality and stillbirths increased whereas sex ratios at birth declined. These results are consistent with expectations as fetuses and infants are particularly susceptible to health shocks. Moreover, male fetuses are relatively more vulnerable than female fetuses, leading to excess male mortality in response to negative health shocks of this nature (Sanders and Stoecker, 2015). We consider an expanded set of instruments that includes railroad expansion as of 1920, and report bounds for our main results under assumptions that our instruments may be weak. The CEM estimator results support our 1920 findings generated by 2SLS methods.

Turning next to the medium-run, we consider impacts on literacy rates in 1940. We begin by estimating effects on two different age groups (20-29 and 30-39 years) positing that the cohort aged 20-29 years was directly exposed to the pandemic (either *in utero* or at a very young age) while the other cohort was not. In sum, our findings indicate that the pandemic led to the deterioration of literacy rates, especially for women. This is consistent with other results that show that female educational levels are relatively more affected after natural disasters (Neumayer and Plumper, 2007, Caruso, 2015, Caruso and Miller, 2015). Concomitantly, we find an increase in male literacy rates for the cohort that was directly exposed to the pandemic which is consistent with positive selection resulting from excess male mortality. This is in accordance with existing empirical findings that the long-term effects of early-life shocks mostly involve boys' culling and girls' scarring. These results are broadly consistent with gender-disaggregated literacy results from the 1940 census that do not demarcate cohorts. Again, results from an expanded set of instruments and the CEM estimator results for literacy rates in 1940 resonate with those from the 2SLS model.

Our paper contributes to research that documents the path-dependency of human capital in response to historical epidemics and shocks (Alsan, 2015, Bleakley, 2010, Clay et al., 2018, De Souza, 2017). Our study benefits from the fact that Brazil was not a major actor in the First World War, and from the fact that given its location in the Southern Hemisphere, the 1918 Pandemic arrived in Sao Paulo in the Spring. These factors make the context of our study unique, and allow us to distill results from an environment that is cleaner in many ways from similar research that has concentrated on the developed world. To the best of our knowledge, our paper is the first study of the 1918 pandemic's impact that uses disaggregated district-level variation with novel and rich archival micro-data on the spatial and temporal distribution of respiratory deaths and historical institutions combined with contemporary controls for regional geography, immigration, health, and sanitation, to investigate the ways in which this unanticipated and intense health shock affected a range of demographic and human capital outcomes in a developing country. Our compilation of these disaggregated data from the Brazilian censuses, the Statistical Annals of

Sao Paulo, and the Sanitary Annual Statistics of Sao Paulo, among other primary sources, is an original contribution of our study. The highly disaggregated nature of our historical climate data further allows us to design strategies that help us to overcome several endogeneity concerns. Our use of information at this granular level is a strength of our paper. The results indicate impacts that are on average of the same sign but larger in magnitude than those estimated on comparable outcomes in developed countries. An important exception is our gender-disaggregated results on education which indicate an increase in male literacy in the immediate aftermath of the pandemic and in later years. We discuss how positive selection and/or segmented labor markets may be explanations for this result which is new in terms of the immediate and medium-term human capital effects of the 1918 pandemic. Taken together, our research highlights that the 1918 influenza pandemic exerted measurable influences on the human capital landscape of Brazil.

2 Literature

Considering specifically the pandemic of 1918, Almond (2006) evaluates empirically whether exposure to this health event had repercussions later in life. Using US census microdata from 1960-1980, the study finds that cohorts that were *in utero* during the pandemic have lower socioeconomic status and lower levels of education, health, and reduced employment outcomes when observed in the future. These results support the *fetal origins hypothesis*.[1] In a related paper, Almond and Mazumder (2005), using data from the Survey of Income and Program Participation (SIPP) from 1984-1996, finds that birth cohorts *in utero* during the 1918 Pandemic have poorer health outcomes almost 65-80 years after the event. Beach et al. (2018) uses linked data from WWII enlistment records and federal censuses and an individual-level panel dataset in a framework that accounts for fixed-effects, observed parental characteristics, and a wide set of controls, also finds that the evolution of human capital was impaired by the pandemic. Using data from Taiwan, Lin and Liu (2014) conclude that the 1918 birth cohorts are shorter as teenagers, have less education, and are more prone to diseases. The education results are in line with those in Chul Hong and Yun (2017) which uses data from the 1960 Korean Census to find that fetal exposure to the pandemic (the 1910 to 1920 birth cohort) resulted in lower educational attainment as measured by years of schooling and literacy, especially in provinces that suffered intensively. Basco et al. (2021) notes the heterogeneous impacts of the pandemic in Spain where low-income workers experienced the highest mortality, and hypothesizes that climatic differences may have influenced regional patterns in contagion. Richter and Robling (2013) and Cook et al. (2018) are studies that evaluate the impact of the Spanish Flu on multiple generations.

Studies that measure the aggregate effects of the pandemic on earnings, human capital accumula-

[1] The hypothesis that insults to the developing fetus, nutritional and otherwise, can have lingering effects; attributed to Barker (1995).

tion and economic growth include Karlsson et al. (2014) which finds that regions more burdened by the pandemic in Sweden had higher poverty rates in the future, and Percoco (2016) which uses mortality rates across Italian regions to find that exposure to the flu lowered educational attainments for those who were *in utero* and in early childhood. Donaldson and Keniston (2016) analyzes the impact of the event in colonial India and obtains results consistent with Malthusian growth theories. Indian districts that were heavily burdened had higher fertility rates in the aftermath of the shock, and there is also evidence of increased investments in child quality (literacy rates for men/boys rose). Bakken and Husoy (2016) match 1912-1920 data on influenza mortality and other demographic estimates to the Norwegian 1960 census and finds that exposure to prenatal influenza lead to significant declines in the years of education for men, with larger effects in the poorest municipalities. Considering Brazil specifically, Nelson (2010) examines the impact of the pandemic on later life outcomes (education, employment and wages) using labor surveys from 1986 to 1998. In keeping with previous work, those who were immediately impacted suffered in the long-run along these dimensions.

Focusing on Chul Hong and Yun (2017) and Nelson (2010), studies of the pandemic in non-US and non-European contexts, our study contributes to the literature by going further to demonstrate that the negative literacy impacts were concentrated primarily among women; male literacy rates for adolescents and above who were directly affected by the pandemic rose both in 1920 and in 1940. Further, Nelson (2010) examines effects using more recent labor force data (*Pesquisa Mensal de Emprego* from 1986 to 1998). In contrast, we are able to include a comprehensive set of demographic, economic, geographic, health, and infrastructure controls from 1920, a time period that is closer to the arrival of the pandemic in Brazil. The use of these historical data allow better controls for ground realities that existed at that time. Finally, our use of data from the 1872 census helps to set a baseline from a time-period earlier than the pandemic's arrival in Brazil. These serve as an anchor for short-run heterogeneity tests we are able to undertake, as we describe below.

3 Historical Background

Sometimes described as the "greatest medical pandemic of modern times", the 1918 Spanish Flu pandemic resulted in global mortality estimates ranging from 20 to 100 million within the span of a few months (Alonso et al., 2016). The pandemic reached Brazil in the beginning of Spring on 14th September 1918. *Demerara*, an English-flagged ship, entered the port of Recife, a northern Brazilian city, and then anchored in the harbor city of Santos, Sao Paulo (Massad et al., 2007). The sailors on board *Demerara* were sick since they had been directly exposed in Dakar, Senegal, a stop on their return from Europe (Alonso et al., 2016). A few days after the arrival of the ship in Santos, the influenza virus arrived in the interior parts of the country and many cases were reported in Rio de Janeiro and Sao Paulo, and in other cities in the northeast. The epidemic's pace and intensity were hard to contain and it spread rapidly to interior districts.

Evidence suggests that Brazilian authorities did not anticipate the deadly effects of the pandemic. The information that reached the country warning about the severity of the flu overseas did not receive due importance. Hence when it arrived, it easily overwhelmed public health systems. The few measures in place proved useless when confronted with the outbreak of a severe public health crisis as seen in newspaper extracts from the time (Figure 1 and Figure A1). Prices of foodstuff (including milk and meat) and medicines (mostly quinine, considered to be a powerful drug for any illness) surged as shortages set in (Hochman, 2016). Schools were closed (Ribeiro Zem El-Dine et al., 2021). Improvised hospitals and healthcare posts had to be established in many cities that tried to keep up with rising death rates. Sao Paulo (city) reported 116,771 cases of influenza, a prevalence rate of 22.32% (Nelson, 2010) for an estimated population of 523,194 inhabitants, and 5,331 deaths in the short period between mid-October and mid-December 1918 (Massad et al., 2007).

It is useful to provide further details on the historiography and political economy of Brazil around the time the pandemic arrived. Since the early 1900s, Brazil experienced public health reforms that were often unpopular. Some authors believe that the unpopularity arose from general religious resistance to vaccinations that originated among groups with alternative practices and cultures (Hochman, 2009). For instance, in order to eradicate smallpox, a law was passed in 1904 in Rio de Janeiro (then capital of Brazil) that authorized mandatory vaccinations against this disease. As a consequence of this law, sanitary brigade workers accompanied by police entered homes to vaccinate people often by force. This resulted in the 'Vaccine Revolt' of 1904 which was a public uprising against this law (Goulart, 2005, Hochman, 2009). Goulart (2005) notes that the same individuals who attempted to improve public health leveraged the pandemic and used it as a 'tool for political engineering' such that it legitimized a group of 'sanitarians' as 'intelligentsia', and invested them with political authority to further the process of modernization in Brazil. Goulart (2005) further elaborates how a group of hygienists came to be perceived as the only individuals with sufficient political and social capital to counter the state's incompetence. Bertucci-Martins (2005) explains that measures implemented by the official health services were questioned by the population that was doubtful of the government's ability to tackle the epidemic. These were the socio-political circumstances and popular sentiments at the time the pandemic arrived. Hence while the authorities did not anticipate how deadly the pandemic could be, the widespread popular response to news warning of its severity may also have been received with apathy, with resulting consequences on the outcomes we study here. However, the challenges of every day life posed by increases in the prices of essentials as well as the rising death toll from the pandemic would have served to quickly focus attention. This would have been even more the case when the Brazilian president Francisco de Paula Rodrigues Alves, newly elected for a second term, succumbed in

January 1919. Some studies estimate that approximately 350,000 (two-thirds of Sao Paulo's population) might have been infected (Bassanezi, 2013, Barata, 2000, Bertolli, 2003). Our data suggest that in 1918 and 1919, when the pandemic was at its peak, the percentage of deaths attributed to influenza-related causes stood at 52.6% and 53.8%, respectively.

Comparing these estimates to the United States, Pennsylvania, Maryland and Colorado, with influenza deaths of 883.1, 803.6 and 776.5 per 100,000 of the population, respectively, had some of the highest mortality rates in 1918.[2] Garrett (2007) explains that the first wave in the United States occurred in March 1918 and lasted through summer of 1918. The second wave in Fall of 1918 was worse. Unlike in the United States, there was only one wave of the pandemic in Brazil. In Figure 2, we show the scale of respiratory deaths per thousand people for the state of Sao Paulo relative to that of cities in the United States in 1918.[3]

The municipality capital (in Sao Paulo) for which monthly data is available from 1917-1920 from Annual Statistical Reports provides a snapshot of the situation[4]. Figure A2 shows mortality patterns in this region. Compared to the same months in 1917, there were 514 and 5,274 more deaths in October and November 1918, respectively. This represents a 87.3% rise in total number of deaths in this municipality. Figure 3 shows the monthly total deaths per 100,000 of the population from January 1917 to December 1919. The mortality shock due to the pandemic is clearly evident. Figure A3 demonstrates that both neo-natal and post-natal mortality (measured as deaths per 1000 live births) also peaked in this region during October-November 1918. We aggregate the district-level data to the municipality level for the period 1917-1920 in Figure A4, and report the spatial variation in influenza-related death rates using the 1920 boundaries for the state of Sao Paulo.

The pandemic resulted in a higher mortality rate among prime-age adults creating a 'W'-shaped age-profile distribution for affected groups.[5] A reason proposed for this pattern is that young male adults in particular might have been more vulnerable given their relatively higher participation rates in the labor force, and their disproportionate exposure to other diseases such as tuberculosis. Another explanation from the medical literature is that the 'cytokine storm' that causes an excess

[2]Mortality rates reported in (Garrett, 2007) are drawn from *Mortality Statistics in 1920* and include influenza and mortality estimates.

[3]Crosby (1989) indicates that the highest mortality rate in the United States (US) was in New York city. Our data indicates that in Sao Paulo, the comparable estimate is almost 10 out of 1000 people (when deaths due to unknown causes are also considered). The average for US cities stood at 5.8 out of 1000. Clay et al. (2019) notes that variation in mortality across U.S. cities was related to several factors including pre-pandemic levels of infant mortality, illiteracy and air-pollution.

[4]The capital area differs from the state of Sao Paulo in having a somewhat larger economic sector, higher population density, and greater presence of healthcare infrastructure. It includes the following sub-regions: Se, Mooca, Consolacao, Bom Retiro, Cambuci, Santa Cecilia, Perdizes, Bela Vista, Vila Mariana, Bras, Penha de Franca, Ipiranga, Santana, Lapa, Nossa Senhora do O, Sao Miguel, Butanta, Osasco, Liberdade, Belenzinho, Santa Efigenia.

[5]The 1918 Flu killed relatively younger men and women aged 15-44 years unlike other influenza epidemics that typically killed mostly young children and older cohorts resulting in a U-shaped mortality distribution.

production of immune cells and their related compounds, cytokines, is more evident in healthy young adults aged 20-40 years old during a flu infection. This strong immune reaction can result in premature death (Loo and Gale, 2007, Kobasa et al., 2004). Children and seniors with weaker immune systems are less affected as the likelihood that their immune systems will overreact is lower.[6] Given its sudden unanticipated arrival in Spring in the Southern Hemisphere, and with its short duration of about ten weeks, existing studies posit random assignment of the infection in Brazil (Nelson, 2010).

In response to the onset of the pandemic, public health authorities designed campaigns to disseminate information on preventive and curative measures.[7] These included isolation, good personal hygiene, no extra work that could result in fatigue, and quarantine measures in several areas. Furthermore, there was overall confusion as statements released by medical establishments that conveyed that the epidemic was mostly benign was in dissonance with published data that indicated an exponential growth in the number of victims. Hospitals ran short of medicines and a full-blown public health crisis ensued in Sao Paulo as Brazilian authorities struggled to keep pace.

4 Data and Summary Statistics

Using historical and archival records, we construct a unique database on health outcomes related to major disease categories and socioeconomic indicators for districts in the state of Sao Paulo in the early decades of the twentieth century. We complement the data on district-level deaths by cause with measures of infrastructure, demographic information, and regional variables. We accomplish this by digitizing statistical reports and by matching these to Brazilian regional census data from 1920 onwards. Our spatial unit of analysis is the district, a disaggregated territorial stratification of the state of Sao Paulo.[8] Use of districts gives us over 300 unique regional observations for the period 1912-1921, which we combine with other historical and contemporary data from 1872, 1912-1921, and 1940.

An important consideration while creating our dataset is ensuring that standardized boundaries are tracked over time. The boundaries of many districts and municipalities changed considerably

[6]We are unable to compare prevalence rates across different age groups due to data limitations.

[7]Failure to comply with these measures may explain why different areas in Sao Paulo were impacted differently by the virus. For instance, Bertucci-Martins (2005) and Bassanezi (2013) reveal that two municipalities, Campinas and Riberao Preto, that had suffered from yellow fever in the late nineteenth and early twentieth century, acted on these measures propitiously. Meanwhile Sorocaba, relatively smaller than Campinas and Riberao Preto, and with less experience in epidemics, struggled relatively more as they failed to adopt the right initiatives on time.

[8]A district in Brazil is an administrative unit within a municipality. We choose to use district-level data rather than municipality-level data as the data on vital statistics for 1917-1921 are available at the district-level which allows for a larger sample size. Further, municipalities in the west of the state were extremely large in size (for example, Bauru); therefore we use districts to reduce measurement error.

over the time-period of our analysis.[9] We use official territorial and administrative maps that provide information on the evolution of districts over time to match the data in a consistent manner.

We begin by describing the deaths by cause and vital statistics information used in our analysis, and the source(s) from which they are obtained. Details on our climate data, sanitary and health infrastructure, geography and railroads, and the Census data from 1872, 1920 and 1940, as well as their sources, are provided in the Appendix and in Table A1.

4.1 Deaths by Cause and Vital Statistics

The Sanitary Authority, created in 1892, was responsible for ensuring the collection of reliable health statistics in Sao Paulo. These statistics are publicly available from 1901-1928 (Bassanezi, 2013). The Annual Statistical Reports of Sao Paulo contain the vital statistics required for our analysis. More specifically, we obtain deaths by cause for 14 major disease categories, allowing us to construct our key variable of interest: deaths rates from respiratory infections from 1912-1921, our best proxy for influenza-related deaths.[10] The Annual Statistical Report also provides information on economic and financial statistics including municipalities' receipts and expenditures, which we use as controls. We obtain the initial shares of influenza-related deaths for 1915 in the *Annual Statistical Report of Sao Paulo (1915)* for which deaths by cause are available for 180 municipalities. Further, we use the *Demographic Studies: The Population of Sao Paulo in the last decade: 1907-1916* to obtain pre-pandemic population statistics for most municipalities. We use per capita municipality expenditures on hospitals and health in 1940 from the *Annual Statistical Report of 1940*.

4.2 Summary Statistics

The mean value for the infant mortality rate in 1920 is 22.57 (per 1000 live births) and that for stillbirths per total births is 0.05.[11] As expected, male literacy is higher than female literacy in

[9] The first census of 1872 contains data on 88 municipalities; by the 1940 census reports, the number of municipalities was 350.

[10] For reasons explained in the next section, we also collect data on other vital statistics. These data are further complemented with information from a special official Sanitary Report in 1918.

[11] These data are from the Census that was collected on September 1, 1920. The timing of the pandemic in Brazil is September 1918 to mid-late 1919 approximately, so these Census data would reflect mainly the tail end of the pandemic health shock. However, large shocks of this nature can have scarring effects on the health of those who survived as outlined in Currie and Vogl (2013) which notes how health insults in early life can persist in adulthood and beyond. Other papers noting the immediate and long-lasting impacts of health shocks include Cook et al. (2019) which shows that the impacts of the 1918 pandemic in the US were evident two generations later among the grandchildren of those who were directly affected, and Li and Menon (2021) which demonstrates that the China Famine from 1959-1961 had persistent effects even half a century later. Thus while our data on infant mortality and

1920. The mean sex ratio at birth in 1920 was 122 (out of 100), with a standard deviation of 82 (out of 100). Summary statistics for the variables of interest from 1940, mainly the educational measures disaggregated by gender, are also provided in the Appendix.

As noted above, an advantage of this study is the rich set of controls from the 1920 time period, details on which are also noted in the Appendix. Geographic measures such as altitude are likely to have influenced the spread of the disease as in general, colder climates foster the spread of pathogens. Distance to capital would influence the speed at which the pandemic reached areas with relatively higher populations. Measures on health and sanitation expenditure per capita and the presence of water and sewerage systems would influence how effective public health systems were in combatting the pandemic when it arrived. The number of hospitals and nursing homes would also importantly determine the spread and evolution of the disease, and the care that local populations might have received. In the absence of these controls, estimates of the impact of the pandemic on human capital measures would likely be biased. Furthermore, the 1940 measures on expenditures shares on health and education, school supplies, and payment to teachers, may have influenced literacy rates in this medium term beyond the impacts exerted by the pandemic two decades ago. Not controlling for these variables could also potentially bias effects of the pandemic. Finally, the 1872 measures provide a baseline to understand circumstances that existed before the pandemic's arrival. The inclusion of these disaggregated variables is a novel contribution of this study, and it allows us to control for a plethora of factors that, to the best of our knowledge, other studies on related topics in developing countries have been unable to do. Again, please see Appendix for these details.

Returning to the discussion of the summary statistics, our key variable of interest, respiratory deaths per 1000 inhabitants, has a mean of 1.45 and a standard deviation of 1.11 for the period 1917-1920. Average October's temperature was 68.16 Fahrenheit with a standard deviation of 3.72; while average October's precipitation was 124.41 mm (standard deviation 8.68 mm). The standard deviation for health and sanitation municipality expenditure in 1910 is relatively high. Overall, the data provides evidence of the relatively low levels of development in most districts during the time-period of analysis. Further, there was significant regional variation in these measures especially those pertaining to health and infrastructure.

sex ratios may not be exactly coincident with the timing of the pandemic in Brazil, we have reason to believe that impacts would still have been evident in the 1920 Census data (which we subsequently demonstrate below). Finally, we do not have data on these demographic variables in 1919 (there was no Census then) and so are constrained to go with the next closest year which is 1920. Further, it is possible that infant deaths and stillbirths may have been undercounted in these historical data. This would result in a conservative bias in our estimates, however. Please see Appendix where full details are provided in Tables A2 and A3.

5 Estimation Methodology

5.1 Specification

We examine the impact of the 1918 pandemic by employing the following model:

$$y_d = \beta_0 + \beta_1 Flu_d + \beta_2 X_d + \beta_3 X_{d0} + \beta_4 R + \epsilon_d \quad (1)$$

where y_d is the outcome of interest for district d in either 1920 or 1940 (we estimate separate cross-sectional regressions for the 1920 and 1940 outcomes). Flu_d is the respiratory death rates in district d (from 1917-1920).[12] X_d is a vector of district-level controls including regional variables such as altitude, latitude, longitude, and other controls including the distance to capital and a dummy for the presence of railroads. X_{d0} is a vector of initial conditions obtained from the 1872 census that includes the share of foreigners, the share of literate people, the number of doctors, chemists and midwives, population density, the share of people who were slaves, the share of people of different races, and employment in different economic sectors. Table A3 reports details on the control variables included in X_d andX_{d0}. R denotes region fixed-effects; their presence in Equation 1 means that respiratory deaths are estimated as deviations from regional pre-existing trends that control for possible underlying differences in population health across areas (Deschenes and Greenstone, 2007). ϵ_d is the idiosyncratic error term. The coefficient of interest is β_1, the impact of respiratory death rates on the outcome of interest. We begin by estimating equation (1) using OLS.

Even with region fixed-effects, there are several reasons why respiratory deaths may not be exogenous. First is measurement error. Official published data may understate true death rates particularly during the peak of the health crisis between October and December 1918. This may have happened unintentionally as in the confusion that followed the initial outbreak, doctors had little time to make accurate entries. Further, as Richter and Robling (2013) note, panicked and overwhelmed doctors probably chose to make optimal use of their time by treating long lines of frail patients and focusing on curative work rather than working on long descriptive death reports required by government officials. Others probably struggled to provide the right diagnosis and to assign the cause of death. Figure 4 shows the spatial variation in death rates caused by respiratory infections (left map) and by unknown causes (right map) in 1918. The maximum value for respiratory deaths per 1000 of the population was 4.5 while that of unknown causes stood at 45. This suggests that many cases may have been recorded as deaths caused by unknown diseases given the difficulty of recognizing the symptoms and the public health crisis triggered by the pandemic.[13] Second, omitted variables may be simultaneously correlated with respiratory

[12]We use data from 1917 to 1920 as the data in 1918 alone has a large number of missing values.

[13]By using respiratory deaths alone instead of combining these with unknown deaths in our models, we have a

deaths and the outcomes we consider. This is despite the fact that we control for all that the disaggregated data allow us to do. As we note above, to control for the mortality gradient by socio-economic class, sanitary conditions, literacy and nutrition, we include variables related to health, demography, human capital, levels of economic development, sanitary infrastructure (including water and sewerage), and the municipality's public health expenditure. Models further include a set of demographic and economic initial conditions from the 1872 census (as in Rocha et al. (2017)) to control for differences in baseline conditions and for pre-pandemic trends that may have existed.[14]

The natural selection that results from excess male mortality in response to aggregate health shocks of this nature is evident in our study. As we note above, female fetuses are more resilient to shocks *in utero* (Noymer and Garenne, 2000, Hamoudi and Nobles, 2014, Sanders and Stoecker, 2015). This nature of selection manifests itself in some of our results that follow, and we assume that net of the exhaustive list of controls we include, the distribution of births by gender is only minimally influenced by remaining unobservables.

5.2 Two Stage Least Squares

Our preferred specification uses a 2SLS approach that leverages the fact that seasonal patterns and average environmental conditions observed across regions in the month of October can explain part of the variation in the prevalence of viral respiratory infections and influenza-related diseases.[15] In doing so, we draw on the medical and epidemiological literature that the incidence of an influenza epidemic depends largely on climatic conditions (Polozov et al., 2008, Tamerius et al., 2013, Slutsky and Zeckhauser, 2018). Slutsky and Zeckhauser (2018) notes that sunlight protects against the flu, implying that there is a negative association between temperature and respiratory deaths. If temperature does not decline beyond a certain level (about 21 Celsius or so), rainfall increases the incidence of the flu (Tamerius et al., 2013). We use October's temperature and precipitation. Our regressions also include controls for average temperature and rainfall in the

conservative bias in our results. This is particularly true for districts along the coastline and the northeast where the spatial heterogeneity in Figure 4 shows that unknown deaths were relatively high. However, our use of district level controls and region fixed-effects mean that much of this spatial heterogeneity would be controlled for in our models. Furthermore, in results not reported, there is evidence that in comparison to 1915, the variance of the distribution of deaths caused by unknown reasons rose in 1917-1920 (consistent with the overall panic and confusion), but the mean of the distribution of unknown deaths remained about the same. If the mean had also differed, then we have reason to suspect systematic biases in measurement, and related errors may not be wholly classical in nature. We thank the NBER Summer Institute 2019 participants for this insight.

[14]In Table A5, we show the sample mean differences for selected regional, climatic, demographic, economic and health initial characteristics for two sets of regions, those with above and below median flu exposure as measured by respiratory death rates in 1917-1920. All the variables are included in our analyses.

[15]Barreca (2010) and Donaldson and Keniston (2016) are other papers that use climatic variations in an instrumental variables methodology. In particular, Donaldson and Keniston (2016) rely on measured absolute humidity while controlling for normal October absolute humidity of the district in their analysis of the long run impact of the Spanish Flu in colonial India.

district as well as region fixed-effects to ensure that these instruments are plausibly exogenous as they may be interpreted as deviations from a long-run trend (Deschenes and Greenstone, 2007). As Figures A2 and 3 show, deaths peaked in November 2018. Hence we use the weather measures from a month earlier (October) given evidence that the average time-span from onset of illness to mortality is around 21 days (Klugman et al., 2009). We present tests of instrument validity and instrument sensitivity below.

Figure A5 shows the spatial variation in average October's temperature and precipitation, respectively. As we note above, the mean temperature for all districts is 68.16 Fahrenheit and the mean precipitation is 124.41 mm. In order to ensure that these 1901-1930 averages are accurate, we collect data from the few meteorological stations available in the Annual Statistical Report of 1917. These data reveal a mean of 68.54 Fahrenheit and 119.4 mm for October's temperature and precipitation, respectively, which are reassuringly close to the mean of the weather variables we use. Panels A and B of Figure 5 portray binscatter plots (with regional controls) for respiratory death rates and October's rain and temperature. Panel A (two graphs on top) focuses on the period 1917-1920 while Panel B (two graphs at the bottom) uses only 1918 data. Both panels show that October's rain and temperature impact predicted respiratory death rates; the empirical results that follow confirm that respiratory deaths are inversely related to temperature and positively related to precipitation.

The first stage regression for respiratory death rates is:

$$Flu_d = \alpha_o + \alpha_1 OctTemp_d + \alpha_2 OctRain_d + \alpha_3 X_d + \alpha_4 X_{d0} + \alpha_5 R + u_d \tag{2}$$

where $OctTemp_d$ and $OctRain_d$ denote October's temperature and precipitation for each district, and X_d and X_{d0} are vectors of variables described above. R are region dummies as above and u_d is the standard idiosyncratic error term. Results for the first stage regressions are reported in Table 1.

Columns (1)-(3) in Table 1 report results for the 1917-1920 time-period that is relevant to us. These columns use a measure of respiratory deaths from these years surrounding the pandemic. Given the presence of fixed-effects, what we are measuring is the predictive power of deviations from average October's mean temperature and precipitation in these years in the first three columns of Table 1. The coefficients in column (1) indicate that temperature has a negative effect while precipitation has a positive effect on respiratory death rates. In columns (2) and (3), the results remain essentially unaltered with the inclusion of district-level baseline controls from 1872 and with the inclusion of regional controls. The estimates on temperature and rainfall (along with the full set of controls) explain about 44.30% of the variation in respiratory death rates. The F-statistic on identifying instruments are above the rule-of-thumb threshold value of 10. To ensure that our instruments affect our outcomes of interest only through their effects on respiratory deaths in 1917-1920 (test for relevance), we report regressions in columns (4)-(6) of Table 1 that show that October's mean temperature and precipitation have no impact on respiratory death rates in the 1913-1915 time-period which is well before the arrival of the pandemic.[16] We use the saturated specification in column (3) of Table 1 as our preferred first stage. In the robustness section below, we show that these instruments have no direct impacts on the outcomes that we evaluate in 1920 and 1940, thus underlining that they satisfy the exclusion restriction. Other tests for instrument validity are also presented below. Finally, standard errors are clustered at the mesoregion level in all our models. The underlying intuition is that neighboring districts and municipalities share similar unobservable features, and most 1920 census districts belonged to larger stratifications sharing common initial conditions.[17]

6 Impacts in 1920

6.1 Infant Mortality, Stillbirths and Sex Ratios at Birth

We begin our analysis by evaluating the pandemic's immediate impact on infant mortality, sex ratios at birth, and on the normalized number of stillbirths. Panel A in Table 2 reports results for the infant mortality rate in 1920. Both OLS and 2SLS methodologies yield positive and significant coefficients in all specifications, with and without the inclusion of region fixed-effects and initial and region-level controls. The 2SLS estimates are larger than the OLS results indicating that the latter are underestimates possibly due to attenuation bias in the presence of classical measurement error.[18] In the fully saturated model of column (4), a unit increase in respiratory death rates increases infant mortality by 0.02. Given the mean value of infant mortality in our sample, this is a 0.10% increase. Our estimates of the impact of the pandemic on stillbirths, loss of the baby before the 20th week of pregnancy, are presented in Part B of Table 2. The effects in column (4) of Panel B indicate that for a unit increase in respiratory deaths, there was a significant increase in stillbirths by 21 log points, a 5.50% increase relative to the mean. The last column of Table 2 reports results when we include the railroad expansion in the 1872-1920 time period from Rocha et al. (2017), along with its interactions with October temperature and precipitation

[16] We focus on the 1913-1915 years because these are the only ones that we have almost complete historical respiratory deaths data for. As another falsification test, Table A6 reports first stage regression results using April's temperature and rainfall conditional on the same set of controls. We also test for the relevance and strength of April's instruments holding October's temperature and precipitation constant in columns (3) and (6) of this table. The results indicate that April's instruments are weak for both 1917-1920 and 1913-1915 as the F-statistic remains below 5. We obtain similar results when temperature and rainfall for May or June are used instead. Further, Table A4 reports the first stage regressions with deviations of October's mean temperature and precipitation from their long-term averages over the 1901-2016 time-period. The F-statistic in this case is below the required benchmark level.

[17] Bertrand et al. (2003) notes the importance of clustering standard errors at the largest sensible aggregation.

[18] The standard errors are also larger for the 2SLS coefficients relative to the OLS coefficients, as is usually true in 2SLS analyses.

in the set of instruments. This is a similar strategy to Adda (2016) that uses subway expansion as an instrument to evaluate the effects of the spread of viral diseases. As evident, expanding the set of instruments to include these additional variables does not result in measurably different 2SLS estimates for the outcomes we consider in Table 2.

Table 3 follows methods developed in Conley et al. (2012), Nevo and Rosen (2012), and Clarke and Matta (2018) to estimate bounds for the endogenous variable (normalized respiratory deaths) under weaker assumptions on instrument validity. We report bounds for infant mortality and log stillbirths.[19] As is well known, Conley et al. (2012) relaxes the strict exogeneity condition (the exclusion restriction) for instruments and assumes that they are only plausibly exogenous. Nevo and Rosen (2012) relaxes the assumption that the instruments are strictly uncorrelated with unobservables, that is, they are uncorrelated to the error term. Methods developed here assume that the instruments are correlated to the error term but the correlation has the same sign as the correlation of the endogenous regressor and the error term. Table 3 shows that the 2SLS coefficient in column (4) of Table 2 for both infant mortality and log stillbirths is contained within the bounds under the assumption that the instruments are plausibly exogenous, and under conditions where the instruments are correlated to the error term. These results thus provide additional evidence that even if the exclusion restriction fails to hold precisely, our main results for infant mortality and log stillbirths are valid.

Table 4 reports results for sex ratios at birth in 1920. Using the same set of controls, we find a negative impact on sex ratios as reported in columns (1) to (3) in Panel B. In keeping with the intuition that male fetuses are relatively more vulnerable to shocks as compared to female fetuses, the result in column (3) suggests that sex-ratios declined by about 40.70% relative to the mean, that is, relatively fewer males were born in the immediate aftermath of the pandemic. Column (4) reports results when railroads and their interactions are also included in the instrument set. Again, the impact is negative and comparable in size to that in column (3).[20]

6.2 Literacy Rates

There is substantial evidence that health shocks can have consequences on educational attainment (Currie and Stabile, 2006, Currie, 2009, Parman, 2015). We test this hypothesis by estimating the impact of influenza deaths on male and female literacy rates for different age groups. The

[19] Bounds for other outcomes are available on request.

[20] It is not possible to reconcile the size of this coefficient with the impact on infant mortality rates as by definition, children have to be born to count as part of the sex ratio. Furthermore, we have more complete information on sex ratios than on infant mortality from the 1920 Annuario. There are also a relatively large number of missing observations for the region-level controls such that their inclusion reduces sample sizes especially in Table 2. We did consider constructing a uniform sample for the different specifications but that would mean that we exclude data that exists for some of the outcomes. Given that sample size is already limited, we did not pursue this.

1920 census reports literacy figures for those who can read and write. Intuitively, we do not expect to find significant impacts for younger age groups in 1920, especially those who have yet to start schooling. However, this might not be the case for older school-going age-groups. Table 5 shows that this is indeed the case as results for all ages (that would include both very young populations and those that have completed schooling) are mostly insignificant in Panel B. The 2SLS results reported in Panel B however indicate that the literacy rate for males aged 15 and above rose in 1920, whereas the coefficient for females while positive is measured with error. An explanation for this may be the fact that since men are more likely to be in the labor market, and since relatively weaker prime-age men (possibly from the lower classes) died in greater numbers, the average literacy rate increased as a consequence of differential selection. The last column of Table 5 reports results for the expanded instrument set that includes railroads and its interactions with October temperature and precipitation for the total literacy rate.[21] As before, the effects are similar to those in column (6) which uses only October temperature and precipitation as instruments.

6.3 Heterogeneity

There is evidence that the pandemic's impacts were not distributed equally and that poorer sections of the population were especially hard-hit (Basco et al., 2021). We thus investigate heterogeneity in these impacts by focusing on infant mortality in 1920, and by considering 1872 census measures including median age, share of slaves, share literate, altitude, railroads, share of doctors, and the presence of state-sponsored settlements analyzed in Rocha et al. (2017).[22] These results are reported in Table 6. The expectation is that districts with older populations, lower levels of literacy, at higher altitudes, with railroads, with fewer doctors, and without settlements, would experience relatively larger negative impacts. We use the 75^{th} percentile benchmark of some of the underlying variables to demarcate districts that are below or above the upper quartile of the distribution and, so as not to use measures that may have changed contemporaneously, use variables from 1872 that form part of our baseline controls. Table 6 conditions on the same set of controls as in the fully saturated model of column (4) in Table 2, and reports 2SLS results for both the effect of normalized respiratory deaths and its interaction with each of the measures considered. In general, the impacts are in keeping with expectation. Districts with older populations, greater share of slaves (and thus perhaps richer), greater literacy, larger share of doctors, and those that

[21] In order to keep the number of columns manageable, models with the expanded instrument set that includes railroads and their interactions with October temperature and precipitation are estimated when 2SLS coefficients with the original instrument set (October temperature and precipitation alone) are significant.

[22] The state of Sao Paulo had an immigration policy that involved the initiation, promotion, and maintenance of state-sponsored settlements aimed at introducing Europeans as independent farmers in rural areas between 1880 and 1930. Rocha et al. (2017) exploits exogenous variation in this policy to consider the persistent human capital effects of attracting immigrants with relatively higher literacy rates as compared to the native population. In our sample, 131 districts had settlements while 754 did not.

had state-sponsored settlements, experience smaller net effects of the pandemic. Districts at higher altitude and with railroads experience larger net impacts. The use of interactions means that many of these parameters are not measured with precision, perhaps by virtue of being correlated. In Table A7, we consider impacts by sub-samples of these same factors. There, many more of the coefficients are measured with significance and have signs consistent with expectations.[23]

7 Impacts in 1940

7.1 Literacy Rates

As discussed above, we use the 1940 census to study impacts beyond the immediate short-run.[24] The Census of 1940 included seven questionnaires related to literacy. Compared to 1920 however, questions were not limited to the ability to read and write. We are therefore able to compute a municipality's literacy rate for people receiving some form of instruction. Given the evidence in Musacchio et al. (2014) that Sao Paulo experienced a rapid increase in the number of schools, students and teachers during the 1889-1930 period, we control for the share of total municipality expenditures allocated to education and health in 1940, the number of teachers (per person aged 10 and above), and the share of total education expenditures spent on school supplies and on teachers' salaries. Other controls are the same as those noted above.

In Table 7 which reports a broad cohort style analysis, we find that female literacy was negatively impacted in districts with greater influenza exposure whereas male literacy rates were positively affected.[25] For the age group 20-29 years old (born from 1911-1920), the cohort that was directly impacted by the 1918 pandemic, we find that respiratory death rates from 1917-1920 lead to a significant fall in the literacy rate for females in column (3).[26] No such effect is found for female aged 30-39 years old (born from 1901-1910) who were already eight years old or older when the pandemic arrived (column (7)). Alternatively, we find that there is a significant positive increase in male literacy rate for those aged 20-29 and 30-39 years old in columns (1) and (5) that use the original set of instruments, and in columns (2) and (6) that use the expanded instrument set with railroads and their interactions (the F-statistics for those in the 30-39 age group gives us little confidence though). The 2SLS coefficient for 20-29 year old males in column (1) indicates a

[23] Corresponding results for the literacy rate in 1920 are available on request.

[24] The 1940 census provides municipality-level data.

[25] We should be clear that we do not know whether these individuals were born in these districts or whether they were in the district when enumerated during the Census. Also, as above, we report 2SLS results with the expanded instrument set for only those columns in this table where results from the original set of instruments, October temperature and precipitation, are significant.

[26] As above, in order to keep the number of columns manageable, models with the expanded instrument set that includes railroads and their interactions with October temperature and precipitation are estimated when 2SLS coefficients with the original instrument set (October temperature and precipitation alone) are significant.

7.80% rise in literacy rates relative to the mean.

In Table 8, we further explore the pandemic's effects on literacy rates for broader age groups and on alternative measures of educational attainment.[27] We estimate the impact on males and females aged 5 and above and aged 18 and above in columns (1) through (6), and again find a significant positive impact on the male literacy rate in column (1) but no effect on the female literacy rate in column (3) of Table 8. The estimated effects in columns (4) through (6) for the older age group are similar. To be clear, these age groups are as of 1940. The fact that the estimate for males ages 5 and up is significant suggests that the pandemic had lasting impacts on even those who were not directly affected by it. This is further emphasized on comparing the magnitude of the estimates in columns (1) and (4), where the latter measures the impact on those who were more directly affected. These results support the hypothesis that the 1918 pandemic may have had intergenerational repercussions on educational attainment.

We provide several explanations for the positive impact on male literacy in the aftermath of the pandemic. First, as noted above, excess male mortality in response to health shocks of this nature implies that the males that are born may be positively selected. This could play a role in understanding the positive literacy coefficient. Second, investing in males/boys at the expense of females/girls is entirely consistent in poor country contexts where labor markets may be segmented. Looking to other contexts, in the aftermath of the 2004 tsunami in Indonesia for example, Frankenberg et al. (2013) find that literacy rates for males rose. Other studies where male literacy has been found to have increased as a consequence of the 1918 pandemic include Parman (2015). Finally, the education parameters that other researchers have considered and where negative impacts have been found are high school graduation rates and years of schooling. Although not inconsistent with literacy rates, these variables are different. Constrained by our historical data to focus on literacy rates means that it is harder for us to compare the size of our estimates to studies from countries at other levels of economic development that consider alternate outcomes such as years of schooling or completion of high school.

8 Robustness Checks

8.1 CEM Estimates

We underline the validity of our 2SLS results in 1920 and 1940 in two ways. We first use a non-linear definition of respiratory deaths (either above or below the median value of normalized

[27] As above, we report results with the expanded set of instruments that includes railroads and their interactions with October temperature and precipitation in cases where the results from the original set of instruments (only October temperature and precipitation) are significant.

respiratory deaths) and employ this variable in a 2SLS framework to demonstrate that our results discussed above are not specific to the linear functional form. Next, we use CEM methods from Blackwell et al. (2009) to construct 'treatment' and 'control' samples for analysis that are close in terms of the parameters we match on. In every case, we use variables from the pre-pandemic time-period of 1872 to facilitate the match. 2SLS methods are then applied to the matched samples. As is known, matching results in smaller sample sizes. In order to demonstrate the validity of our 2SLS results, our aim is to show that the magnitude of the CEM estimates are in the same ballpark (even if they are measured with error due to the reduced sample size) as those from the 2SLS analysis. Results in Tables 9, 10, and 11 confirm that this is the case. In each case, the coefficient returned by the CEM estimator is close to that from the 2SLS coefficient, thus providing re-assurance that the 1920 and 1940 2SLS results are robust.

8.2 Check on October 1918 Temperature and Rainfall

As discussed above, the first stage regression results using April 1918 temperature and rainfall indicate that April's instruments are weak for both 1917-1920 and 1913-1915 as the F-statistic is below 5. We obtain similar results when temperature and rainfall for May or June are considered instead. Further, the first stage regressions with deviations of October's mean temperature and precipitation from their long-term averages over the 1901-2016 time-period also result in F-statistics that are below the required benchmark level.[28]

8.3 Representativeness of Births Based on Parental Observables

We test to ensure that the sample of births in the flu-years is representative. We rely on male and female literacy rates in 1872 as a measure of parental characteristics and compare these to the rates in 1920 in order to rule out selection on parental observables. The test of differences in means between the 1872 and 1920 literacy rates cannot reject that these are the same ($p = 0.41$). We then generate an indicator variable that takes a value of 1 if a district in 1918 had flu exposure above the median value in the sample (that is, if respiratory deaths per 1000 inhabitants exceeded 1.21 in 1918). We then test for differences in sample means in literacy rates across these two groups. Results indicate that the samples are comparable along this dimension.[29]

[28] Please see Table A4 in the Appendix.

[29] These results are reported in Table A8 in the Appendix. Given data constraints, we have no other variable to benchmark parental characteristics.

8.4 Falsification Tests

We carry out falsification tests by demonstrating that the respiratory death rate during a non-pandemic year (1915) has no impact on outcome variables either in 1920 or in 1940. All 2SLS (and most OLS) coefficients are statistically zero for sex ratios and literacy rates in 1920, and literacy rates in 1940.[30]

8.5 Tests of the Exclusion Restriction

In order to ensure that the instruments have no direct effects on the outcomes we study, we regress October 1918 mean temperature and precipitation on outcomes from 1920 and 1940. Conditional on the same variables as above, the results indicate that the instruments do not directly impact outcomes.[31]

9 Conclusion

Using archival data from the 1872, 1920, and 1940 Brazilian censuses for more than 300 districts in the state of Sao Paulo, Brazil, we study the impact of the 1918 Spanish Flu pandemic across different time horizons. We match these data to district-level deaths by cause during the pandemic years, and combine this matched dataset with an array of historical and regional information drawn from several original documents. We show that the pandemic had significant short-run demographic and literacy impacts in 1920. We then study dynamics on literacy rates in 1940 to demonstrate persistent medium-run effects. The results are robust to a variety of robustness, falsification, and specification checks. Our results underline that a comprehensive understanding of the legacy of health shocks in developing country contexts provides scope for targeted present-day policy-making in order to improve equity, and to ameliorate the negative consequences that may originate from weak institutions and limited resources.

[30]Please see Table A9 in the Appendix.

[31]Please see A10 in the Appendix. Table Results for the other outcomes are available on request.

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Figure 1: A Newspaper Extract in October 1918

de Outubro de 1918

GAZETA DE NOTICIAS

A GRANDE EPIDEMIA

As providencias do governo de muito pouco valeram até agora

Continuamos entregues á Divina Providencia

: E os casos fataes augmentam :

A gravidade da situação e as providencias do governo

Os mortos de bontem

A Caixa Economica

Uma nota da Directoria de Saude Publica

O expediente nas delegacias de saude

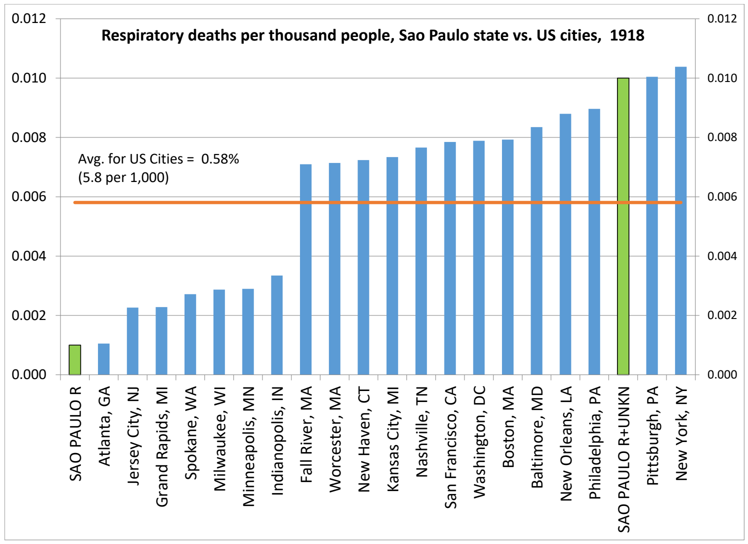
O serviço sanitario na Guanabara

O trabalho no palacio do Cattete

A Gazeta de Notícias critica o governo federal pelo imobilismo diante da disseminação da epidemia (imagem: Biblioteca Nacional)

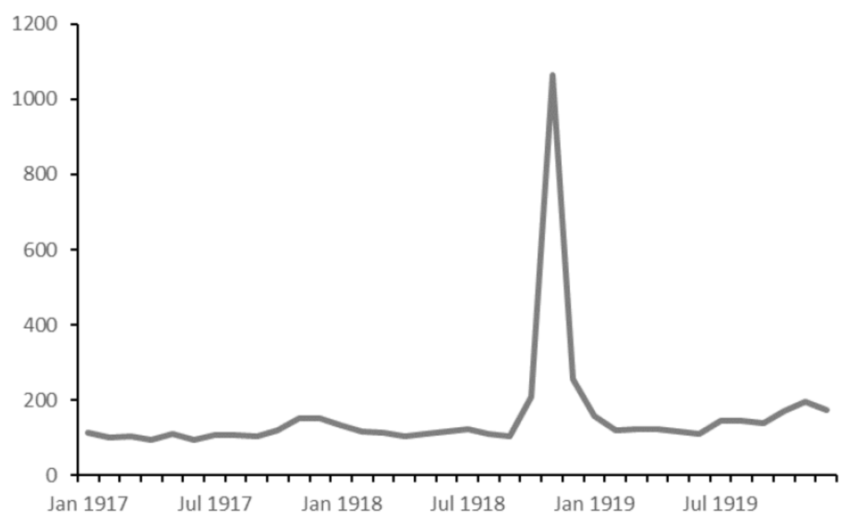
Notes: This extract conveys that the government was criticized for its lack of involvement during the pandemic in 1918. Translated headline: the government's input of very little value until now. Source: Biblioteca Nacional.

Figure 2: Respiratory Death Rates for US Cities and Sao Paulo (state)



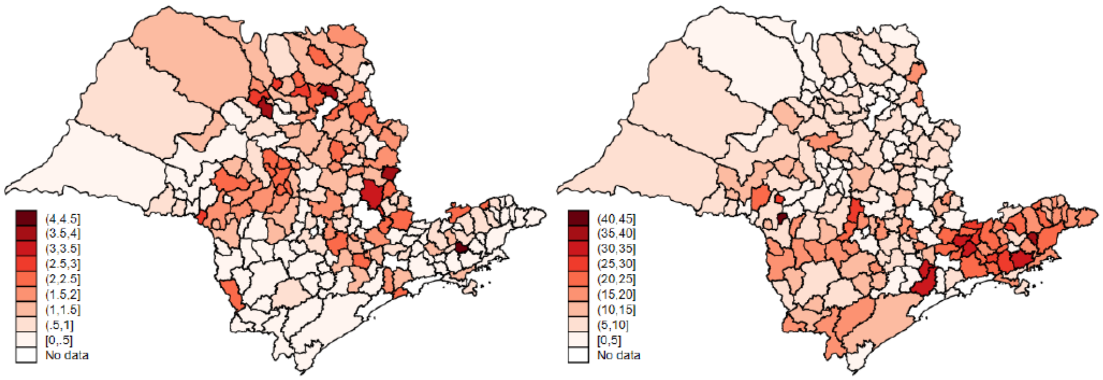
Notes: Source for US cities data is Crosby (1989). The green bar on the left shows the influenza-related death rates proxied by respiratory deaths only while the green bar on the right includes deaths caused by both respiratory and unknown causes.

Figure 3: Monthly Total Deaths per 100,000 of the Population (January 1917-December 1919)



Source: Authors' calculations from the Annual Statistical Reports Vol. 1 (1917, 1918, 1919) for Sao Paulo City.

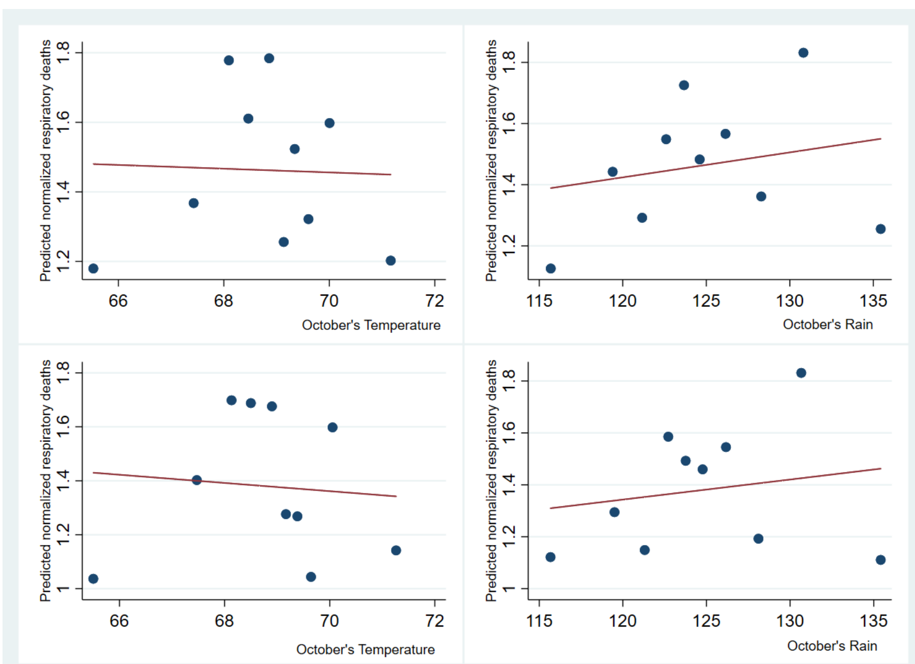
Figure 4: Spatial Variation in Respiratory and Unknown Deaths per 1000 of the Population in Sao Paulo state, 1918



(a) Respiratory Deaths (per 1000) in Sao Paulo (State), 1918 (b) Unknown Deaths (per 1000) in Sao Paulo (State), 1918

Source: Authors' calculations from the Annual Statistical Report of 1918, Vol.1. The data is aggregated to the municipality level. 1920 boundaries are reported.

Figure 5: Binscatter Plots for Respiratory Death Rates and October's Rain and Temperature



Notes: Panel A (top graphs: 1917-1920) and Panel B (Bottom graphs: 1918 only). Regressions condition on altitude, longitude and latitude.

Table 1: First Stage Regressions: Dependent Variable is Respiratory Deaths per 1000 of the Population

	For 1917-1920			For 1913-1915		
	(1)	(2)	(3)	(4)	(5)	(6)
October's mean temperature	-0.245***	-0.246***	-0.252***	-0.320	-0.290	0.0337
	(0.056)	(0.056)	(0.056)	(0.361)	(0.464)	(0.338)
October's mean precipitation	0.032**	0.032**	0.029**	0.167	-0.001	-0.077
	(0.013)	(0.013)	(0.013)	(0.128)	(0.109)	(0.0394)
Region FEs	Yes	Yes	Yes	Yes	Yes	Yes
Region-level controls	No	No	Yes	No	No	Yes
Initial period controls from 1872	No	Yes	Yes	No	Yes	Yes
F-Statistic	10.24	10.24	10.53	1.08	2.69	3.135
p-value for the F-stat	[0.000]	[0.000]	[0.000]	[0.342]	[0.070]	[0.045]
R-squared	0.442	0.442	0.443	0.736	0.735	0.735
Observations	939	937	933	414	413	410

Notes: Table reports OLS regressions. Standard errors reported in parentheses are clustered at the mesoregion level. Controls include those reported in Table A3. p-values for F-statistics are reported for the identifying instruments and are in square brackets. ***$p < 0.01$, **$p < 0.05$ and *$p < 0.10$.

Table 2: Effects on Infant Mortality and Stillbirths in 1920

	(1)	(2)	(3)	(4)	(5)
Panel A: Dependent variable: Infant mortality					
OLS					
Norm. respiratory deaths	0.009***	0.008***	0.010***	0.009***	0.011***
	(0.000)	(0.000)	(0.002)	(0.001)	(0.002)
2SLS					
Norm. respiratory deaths	0.017***	0.018***	0.020***	0.019***	0.025***
	(0.003)	(0.005)	(0.006)	(0.007)	(0.006)
Region FEs	No	Yes	Yes	Yes	Yes
Region-level controls	No	No	Yes	Yes	Yes
Initial period controls from 1872	No	No	No	Yes	Yes
Include railroad and interactions in IV set	No	No	No	No	Yes
Mean of infant mortality	22.568	22.568	22.568	22.568	22.568
K-P F-stat	51.330	30.390	28.070	21.140	16.010
p-value for the F-stat	[0.000]	[0.000]	[0.000]	[0.001]	[0.000]
Observations	443	443	305	305	305
Panel B: Dependent variable: Log stillbirths					
OLS					
Norm. respiratory deaths	-0.001	0.028	0.063*	0.069**	0.056*
	(0.023)	(0.019)	(0.029)	(0.029)	(0.031)
2SLS					
Norm. respiratory deaths	0.038	0.199	0.190*	0.211**	0.181*
	(0.123)	(0.130)	(0.101)	(0.083)	(0.103)
Region FEs	No	Yes	Yes	Yes	Yes
Region-level controls	No	No	Yes	Yes	Yes
Initial period controls from 1872	No	No	No	Yes	Yes
Include railroad and interactions in IV set	No	No	No	No	Yes
Mean of log stillbirths	3.840	3.840	3.840	3.840	3.840
K-P F-stat	34.160	20.190	24.720	52.490	24.680
p-value for the F-stat	[0.000]	[0.001]	[0.000]	[0.000]	[0.000]
Observations	603	603	399	399	399

Notes: Table reports OLS and 2SLS results. Standard errors reported in parentheses are clustered at the mesoregion level. Controls include those reported in Table A3. The K-P F-stat refers to the Kleibergen-Paap F-statistic for instruments. ***$p < 0.01$, **$p < 0.05$ and *$p < 0.10$.

Table 3: Effects on Infant Mortality and Stillbirths in 1920: Bounds for Instrumental Variables Estimates Under Weaker Assumptions on Instrument Validity

	(1)	(2)	(3)	(4)
	Instruments are plausibly exogenous		Instruments are correlated to unobservables	
	Lower bound	Upper bound	Lower bound	Upper bound
Panel A: Infant mortality				
Norm. respiratory deaths	0.008	0.042	0.010	0.021
Region FEs	Yes	Yes	Yes	Yes
Region-level controls	Yes	Yes	Yes	Yes
Initial period controls from 1872	Yes	Yes	Yes	Yes
Observations	305	305	399	399
Panel B: Log stillbirths				
Norm. respiratory deaths	-0.274	0.805	-0.049	0.422
Region FEs	Yes	Yes	Yes	Yes
Region-level controls	Yes	Yes	Yes	Yes
Initial period controls from 1872	Yes	Yes	Yes	Yes
Observations	305	305	399	399

Notes: Table reports tests based on Conley et al. (2012), Nevo and Rosen (2012), and Clarke and Matta (2018). $^{***}p < 0.01$, $^{**}p < 0.05$ and $^{*}p < 0.10$.

Table 4: Effects on Sex Ratios at Birth in 1920

	Dependent variable: Sex ratio at birth			
	(1)	(2)	(3)	(4)
Panel A: OLS				
Norm. respiratory deaths	-0.054**	-0.048*	-0.044	-0.044
	(0.023)	(0.023)	(0.026)	(0.026)
Panel B: 2SLS				
Norm. respiratory deaths	-0.479**	-0.470***	-0.497***	-0.469***
	(0.221)	(0.143)	(0.173)	(0.149)
Region FEs	Yes	Yes	Yes	Yes
Region-level controls	No	No	Yes	Yes
Initial period controls from 1872	No	Yes	Yes	Yes
Include railroad and interactions in IV set	No	No	No	Yes
Mean of sex ratio at birth	1.220	1.220	1.220	1.220
K-P F-stat	7.980	10.240	19.600	13.290
p-value for the F-stat	[0.007]	[0.003]	[0.000]	[0.000]
Observations	580	580	576	576

Notes: Table reports OLS and 2SLS results. Standard errors reported in parentheses are clustered at the mesoregion level. Controls include those reported in Table A3. The K-P F-stat refers to the Kleibergen-Paap F-statistic for instruments. $^{***}p < 0.01$, $^{**}p < 0.05$ and $^{*}p < 0.10$.

Table 5: Literacy Rates by Gender and Age Groups in 1920

	All ages			*Ages 15 and above*				
	Male	Female	Total	Male	Male	Female	Total	Total
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A: OLS								
Norm. respiratory deaths	0.012***	0.012***	0.012***	0.016***	0.016***	0.015***	0.016***	0.016***
	(0.003)	(0.003)	(0.003)	(0.004)	(0.004)	(0.003)	(0.003)	(0.004)
Panel B: 2SLS								
Norm. respiratory deaths	0.021	-0.025	0.001	0.097**	0.103***	0.009	0.064**	0.090***
	(0.025)	(0.021)	(0.022)	(0.039)	(0.018)	(0.023)	(0.031)	(0.014)
Region FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region-level controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Initial period controls from 1872	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Include railroad and interactions in IV set	No	No	No	No	Yes	No	No	Yes
Mean of the dependent variable	0.282	0.164	0.226	0.418	0.418	0.221	0.326	0.326
K-P F-stat	4.640	4.640	4.640	4.640	17.900	4.640	4.640	17.900
p-value for the F-stat	[0.032]	[0.032]	[0.032]	[0.032]	[0.000]	[0.032]	[0.032]	[0.000]
Observations	669	669	669	669	669	669	669	669

Notes: Table reports OLS results in Panel A and 2SLS results in Panel B. Standard errors reported in parentheses are clustered at the mesoregion level. Controls include those reported in Table A3. The K-P F-stat refers to the Kleibergen-Paap F-statistic for instruments. Models with the expanded instrument set that includes railroads and their interactions with October temperature and precipitation are estimated when 2SLS coefficients with the original instrument set (October temperature and precipitation alone) are significant. ***$p < 0.01$, **$p < 0.05$ and *$p < 0.10$.

Table 6: 2SLS Heterogeneous Effects of the Pandemic on Infant Mortality in 1920

	Measures considered:						
	Median age	Share slaves	Share literate	Altitude	Railroads	Doctors	Settlements
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Norm. respiratory deaths	0.022*	0.019	0.021***	0.021***	0.012	0.019	0.024
	(0.013)	(0.018)	(0.007)	(0.007)	(0.071)	(0.015)	(0.017)
Norm. respiratory deaths*	-0.001	-0.013	-0.001	0.002	0.006	-0.013	-0.008
measure considered	(0.007)	(0.134)	(0.011)	(0.018)	(0.045)	(0.104)	(0.112)
Region FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region-level controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Initial period controls from 1872	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	305	305	305	305	305	305	305

Notes: Table reports the 2SLS coefficient when the dependent variable is infant mortality. The sub-samples are created using the initial conditions from the 1872 census. In order to consider values at the upper quartile of the distribution, we use a below/above 75^{th} percentile approach to classify districts by median age, share of slaves, share literate, altitude, and share of doctors. Railroads is non-linear based on whether there was a railroad in the district by 1920. Settlements denotes districts that belonged to a municipality that had a state-sponsored settlement in the state of Sao Paulo as noted in Rocha et al. (2017). The same instruments, controls, and fixed-effects used in the model of Tables 2 are included here. ***$p < 0.01$, **$p < 0.05$ and *$p < 0.10$.

Table 7: Literacy Rates by Gender and Age Groups in 1940

	20-29 years old				30-39 years old		
	Male (1)	Male (2)	Female (3)	Female (4)	Male (5)	Male (6)	Female (7)
Panel A: OLS							
Norm. respiratory deaths	0.010**	0.010**	0.004*	0.004*	0.001	0.001	-0.003
	(0.004)	(0.004)	(0.002)	(0.002)	(0.008)	(0.008)	(0.007)
Panel B: 2LS							
Norm. respiratory deaths	0.046**	0.029**	-0.047***	-0.009	0.054**	0.110***	0.023
	(0.022)	(0.015)	(0.017)	(0.016)	(0.021)	(0.023)	(0.025)
Region FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region-level controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Initial period controls from 1872	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Include railroad and interactions in IV set	No	Yes	No	Yes	No	Yes	No
Mean of the dependent variable	0.588	0.588	0.414	0.414	0.584	0.584	0.321
K-P F-stat	12.450	6.910	11.200	6.510	8.900	4.150	6.830
p-value for the F-stat	[0.002]	[0.005]	[0.003]	[0.006]	[0.006]	[0.027]	[0.014]
Observations	506	506	506	506	506	506	506

Notes: Table reports OLS results in Panel A and 2SLS results in Panel B. Standard errors reported in parentheses are clustered at the mesoregion level. Controls include those reported in Table A3. The K-P F-stat refers to the Kleibergen-Paap F-statistic for instruments. Models with the expanded instrument set that includes railroads and their interactions with October temperature and precipitation are estimated when 2SLS coefficients with the original instrument set (October temperature and precipitation alone) are significant. ***$p < 0.01$, **$p < 0.05$ and *$p < 0.10$.

Table 8: Literacy Rates by Gender and Age Groups in 1940

	Literacy rate: Ages 5+			Literacy rate: Ages 18+		
	Male (1)	Male (2)	Female (3)	Male (4)	Male (5)	Female (6)
Panel A: OLS						
Norm. respiratory deaths	0.019**	0.019**	0.015**	0.013**	0.013**	0.010*
	(0.006)	(0.006)	(0.005)	(0.005)	(0.005)	(0.005)
Panel B: 2LS						
Norm. respiratory deaths	0.081***	0.112***	0.030	0.067***	0.087***	0.009
	(0.022)	(0.014)	(0.022)	(0.024)	(0.015)	(0.026)
Region FEs	Yes	Yes	Yes	Yes	Yes	Yes
Region-level controls	Yes	Yes	Yes	Yes	Yes	Yes
Initial period controls from 1872	Yes	Yes	Yes	Yes	Yes	Yes
Include railroad and interactions in IV set	No	Yes	No	No	Yes	No
Mean of the dependent variable	0.489	0.489	0.348	0.521	0.521	0.325
K-P F-stat	7.770	14.590	7.770	7.770	14.590	7.770
p-value for the F-stat	[0.008]	[0.000]	[0.008]	[0.008]	[0.000]	[0.008]
Observations	674	674	674	674	674	674

Notes: Table reports OLS results in Panel A and 2SLS results in Panel B. Standard errors reported in parentheses are clustered at the mesoregion level. Controls include those reported in Table A3. The K-P F-stat refers to the Kleibergen-Paap F-statistic for instruments. Models with the expanded instrument set that includes railroads and their interactions with October temperature and precipitation are estimated when 2SLS coefficients with the original instrument set (October temperature and precipitation alone) are significant. ***$p < 0.01$, **$p < 0.05$ and *$p < 0.10$.

Table 9: Effects on Demographic Measures in 1920: Non-Linear and CEM Results

	Dependent variable:		
	Infant mortality	Log stillbirths	Sex ratios at birth
	(1)	(2)	(3)
2SLS (non-linear)	0.032***	0.368***	-0.850*
	(0.010)	(0.130)	(0.483)
2SLS (CEM)	0.035*	0.547*	-0.823*
	(0.018)	(0.309)	(0.452)
Region FEs	Yes	Yes	Yes
Region-level controls	Yes	Yes	Yes
Initial period controls from 1872	Yes	Yes	Yes
Mean of the dependent variable	22.568	3.840	1.220
Observations (for non-linear)	305	399	576
Observations (for CEM)	180	341	571

Notes: In the first row, the table reports the 2SLS coefficient for a binary variable that equals 1 if the district had respiratory deaths above the median value, 0 otherwise, during the pandemic years. We report the CEM coefficient next. The same instruments, controls, and fixed-effects used in the model of Table 2 are included here. ***$p < 0.01$, **$p < 0.05$ and *$p < 0.10$.

Table 10: Effects on the Literacy Rate in 1920: Non-Linear and CEM Results

	Dependent variable: Literacy rate for ages 15 and above	
	Male	Total
	(1)	(2)
2SLS (non-linear)	0.182**	0.121**
	(0.077)	(0.060)
2SLS (CEM)	0.178*	0.122
	(0.105)	(0.085)
Region FEs	Yes	Yes
Region-level controls	Yes	Yes
Initial period controls from 1872	Yes	Yes
Mean of the dependent variable	0.418	0.326
Observations (for non-linear)	669	669
Observations (for CEM)	669	669

Notes: In the first row, the table reports the 2SLS coefficient for a binary variable that equals 1 if the district had respiratory deaths above the median value, 0 otherwise, during the pandemic years. We report the CEM coefficient next. The same instruments, controls, and fixed-effects used in the model of Table 5 are included here. ***$p < 0.01$, **$p < 0.05$ and *$p < 0.10$.

Table 11: Effects on the Literacy Rate in 1940: Non-Linear and CEM Results

	Dependent variable: Literacy rates for the following age groups:				
	20-29 years old		30-39 years old	Ages 5+	Ages 18+
	Male	Female	Male	Male	Male
	(1)	(2)	(3)	(4)	(5)
2SLS (non-linear)	0.087*	-0.093***	0.104*	0.151**	0.163**
	(0.050)	(0.035)	(0.057)	(0.063)	(0.060)
2SLS (CEM)	0.101**	-0.085**	0.073	0.169**	0.254**
	(0.047)	(0.036)	(0.054)	(0.069)	(0.097)
Region FEs	Yes	Yes	Yes	Yes	Yes
Region-level controls	Yes	Yes	Yes	Yes	Yes
Initial period controls from 1872	Yes	Yes	Yes	Yes	Yes
Mean of the dependent variable	0.588	0.414	0.584	0.489	0.521
Observations (for non-linear)	506	506	506	674	674
Observations (for CEM)	506	506	506	674	674

Notes: In the first row, the table reports the 2SLS coefficient for a binary variable that equals 1 if the district had respiratory deaths above the median value, 0 otherwise, during the pandemic years. We report the CEM coefficient next. The same instruments, controls, and fixed-effects used in the models of Table 7 and Table 8 are included here. ***$p < 0.01$, **$p < 0.05$ and *$p < 0.10$.

Appendix

Sources of Data and Details on Summary Statistics

Climate Data

The Annual Statistical Reports of Sao Paulo provide few meteorological observations. For instance, the 1917 report provides monthly temperature for less than 65 regions and monthly precipitation for less than 35 municipalities. Atmospheric pressure, humidity level and detailed air temperature-related statistics are only available at the aggregate level. Given these limitations, we compile our climate data using information from the World Bank Climate Change Knowledge Database, where we extract relevant data on temperature and rainfall in October for the time-period 1901-1930, using latitude and longitude coordinates of districts.[32]

Sanitary and Health Infrastructure

We collect information on the number of doctors, chemists and midwives, and the number of people with mental and physical deficiencies (per 1000 inhabitants) as of 1872, and match these to the 1920 district-level data for use as proxies for historical health indicators in a period before the pandemic struck. Information on water and sewage systems is obtained from the *Sanitary Service Report of the state of Sao Paulo: Annual Demographic and Sanitary Statistics Section (1920)*. This report is also used to obtain the number of hospitals, old-age homes, and specialized maternity hospitals. The *1910 Annual Statistical Report of Sao Paulo (Volume II)* is used to obtain the pre-pandemic public expenditures on cleaning, waste disposal, and maintenance of sanitary conditions in 132 municipalities.

Geography and Railroads

We control for altitude, latitude and longitude in our models. Altitude and related data are collected from the different volumes of *The Encyclopedia of Brazil Municipalities (IBGE 1957, 1958)* for Sao Paulo.

The dummy for the presence of railway in the district is created from the *Secretariat Report of Agriculture, Commerce and Public Works of the state of Sao Paulo; Coffee: Statistics of*

[32] This is an online platform provided by the World Bank Group. Amongst many other services, it provides spatial and temporal averages of rainfall and temperature for the periods 1901-1930, 1931-1960, 1961-1990, 1991-2016, and 1901-2016 with variation at extremely local levels. Please see CCKP_Metadata_November%202021.pdf available at *climateknowledgeportal.worldbank.org* which describes the temperature and precipitation information collected from "extensive networks of local weather station observations" and presented in 0.5 degree latitude by 0.5 degree longitude grid cells (these are at fine resolution and very local). We emphasize that our models include district-level averages for temperature and rainfall. This means that we estimate the impact of location specific deviations in these weather-related measures from their trend.

Production and Commerce (1920). We know the number of railway stations in 1920, and the year in which the railroad network was established. Distance to capital comes from the same report.

Census Data

We use the 1872, 1920, and 1940 censuses for the state of Sao Paulo. The first round of 1872 allows us to obtain pre-pandemic initial conditions. Controlling for initial conditions is important to ensure that we have a baseline for the degree of development, urbanization, infrastructure, social aspects, health-service, and the sanitary environment before the pandemic arrived (that is, these variables help to control for pre-trends that may have existed).[33] The 1920 census is used to compute demographic and economic variables including infant mortality rates, sex ratios, and literacy rates by age groups and gender. The 1940 census is used to construct medium-run measures on literacy rates also by age groups and gender.

Summary Statistics

Tables A2 and A3 present summary statistics for the dependent variables and selected explanatory variables in our analysis. Variables in Panel A of Table A2 are the dependent variables in the short-run of the pandemic and include infant mortality, stillbirths, the literacy rate for males and females, and the sex ratio at birth. The mean value for the infant mortality rate is 22.57 (per 1000 live births) and that for stillbirths per total births is 0.05. Male literacy is higher than female literacy and the mean sex ratio at birth in 1920 was 122 (out of 100), with a standard deviation of 82 (out of 100). Panel B of Table A2 reports statistics for the variables of interest from 1940.

Table A3 reports summary statistics for the variables used as controls. These are arranged by panels that focus on deaths by cause, regional geography, variables from the 1872 census, and other measures. Our key variable of interest is in Panel A of Table A3, respiratory deaths per 1000 inhabitants, which has a mean of 1.45 and a standard deviation of 1.11 for the period 1917-1920. Average October's temperature was 68.16 Fahrenheit with a standard deviation of 3.72; while average October's precipitation was 124.41 mm (standard deviation 8.68 mm). We note the relatively high standard deviation for health and sanitation municipality expenditure in 1910.

[33] We use these measures in proportion to population size at that time.

Figures

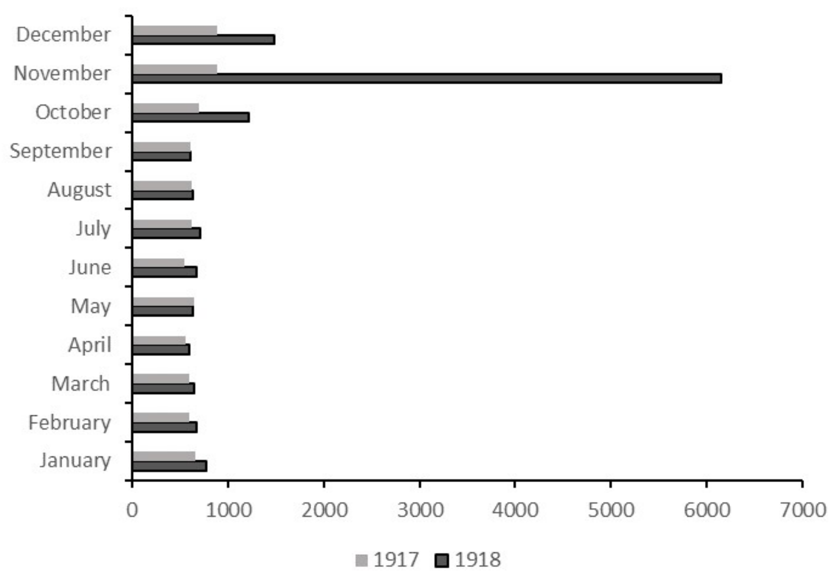
Figure A1: Headline of the Correio da Manha in October 1918


SÃO INNUMEROS OS PEDIDOS DE SOCCORROS AO PALACIO DO CATTETE

O governo faz um appello aos medicos, pharmaceuticos e estudantes, para auxiliarem a Saude Publica nesta difficil emergencia

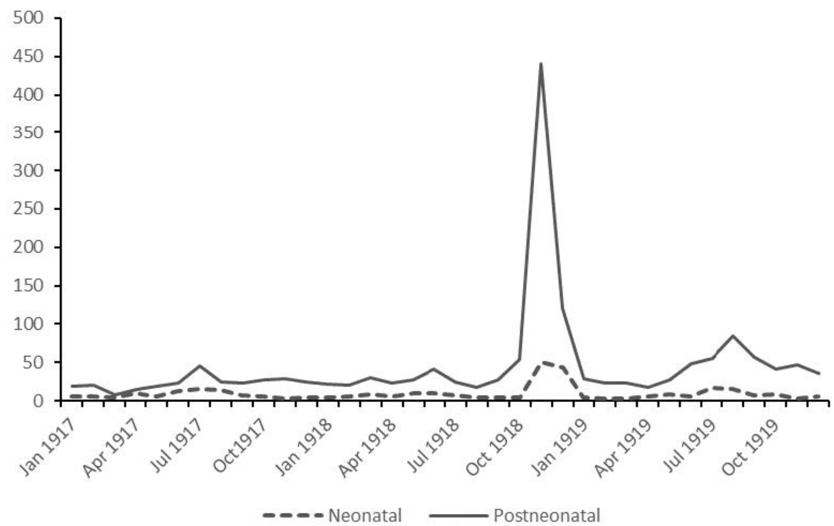
Notes: This extract conveys that the government needed help from medical experts and students at the peak of the outbreak in October 1918. Translated headline: The government appeals to doctors, chemists and students to help during this public health emergency. Source: Collections of the Morning Mail in the Brazilian digital newspaper archive.

Figure A2: Monthly Deaths for 1917 and 1918 for Sao Paulo (City)



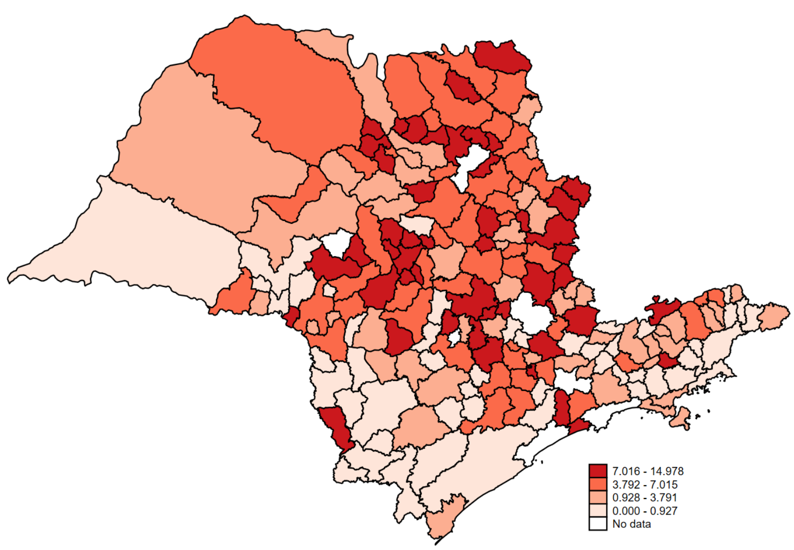
Source: Annual Statistical Reports Vol. 1 (1917, 1918, 1919) for Sao Paulo City.

Figure A3: Monthly Neo-Natal and Post-NeoNatal Influenza-Related Mortality Rate (Deaths per 1000 Live Births for January 1917-December 1919)



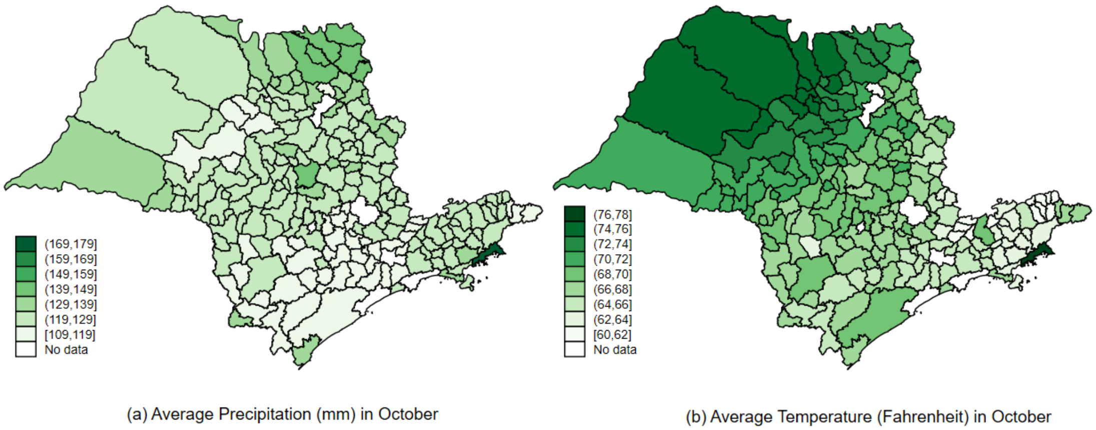
Source: Authors' calculations from the Annual Statistical Reports Vol. 1 (1917, 1918, 1919) for Sao Paulo City.

Figure A4: Spatial Variation in Influenza-Related Deaths per 1000 of the Population in Sao Paulo state, 1917-1920



Source: Authors' calculations from the Annual Statistical Reports Vol.1 (1917, 1918, 1919, 1920). The data is aggregated to the municipality level for each year during this period. 1920 boundaries are reported.

Figure A5: Average October's Rain and Temperature, 1901-1930



Source: Authors' compilation of data using latitude and longitude coordinates of districts from the World Bank Climate Change Knowledge Database (an online platform provided by the World Bank Group that provides access to climate change data).

Tables

Table A1: Data Description and Sources

Data description	**Sources**
Panel A: Geography	
Altitude (in M)	The Encyclopedia of Brazil Municipalities (IBGE 1957,1958)
Latitude	The Encyclopedia of Brazil Municipalities (IBGE 1957,1958)
Longitude	The Encyclopedia of Brazil Municipalities (IBGE 1957,1958)
Distance to capital (in km)	Secretariat Report of Agriculture, Commerce and Public Works, Sao Paulo (1920)
October's 1918 temperature (Fahrenheit)	World Bank Climate Change Knowledge Database
October's 1918 precipitation (mm)	World Bank Climate Change Knowledge Database
Panel B: Deaths by cause (per 1000)	
14 disease categories for 1912-1921	Annual Statistical Reports of Sao Paulo, 1912-1921
Panel C: Initial period controls from 1872	
Literacy rate	1872 Demographic Census for Sao Paulo, Brazil
Share of foreigners	1872 Demographic Census for Sao Paulo, Brazil
Share of slaves	1872 Demographic Census for Sao Paulo, Brazil
Shares of race Branca, Parda, Preta	1872 Demographic Census for Sao Paulo, Brazil
Share emp. in agriculture, manufucturing	1872 Demographic Census for Sao Paulo, Brazil
Share with physical/mental diseases	1872 Demographic Census for Sao Paulo, Brazil
Doctors, chemists, midwives (per 1000)	1872 Demographic Census for Sao Paulo, Brazil
Population density (per sq.Km)	1872 Demographic Census for Sao Paulo, Brazil
Panel D: Dependent variables in 1920	
Infant mortality (per live births)	Annual Statistical Report, Sao Paulo (1920)
Stillbirths (per total births)	Annual Statistical Report, Sao Paulo (1920)
Total population	Demographic Census for Sao Paulo, Brazil (1920)
Literacy rate (total)	Demographic Census for Sao Paulo, Brazil (1920)
Literacy rate (male)	Demographic Census for Sao Paulo, Brazil (1920)
Literacy rate (female)	Demographic Census for Sao Paulo, Brazil (1920)
Sex ratio of adults	Demographic Census for Sao Paulo, Brazil (1920)
Sex ratio at 12 months	Demographic Census for Sao Paulo, Brazil (1920)
Sex ratio at birth	Demographic Census for Sao Paulo, Brazil (1920)
Share of foreigners	Demographic Census for Sao Paulo, Brazil (1920)
Panel E: Dependent variables in 1940	
Literacy rate	Demographic Census for Sao Paulo, Brazil (1940)
Panel F: Other controls	
Health&sanitation exp.per capita (1910)	Annual Statistical Report of Sao Paulo Vol. 2 (1910)
Railway station dummy	Secretariat Report of Agriculture, Commerce and Public Works of state of Sao Paulo (1920)
Water&sewerage system dummy (1920)	Sanitary Service Report of the state of Sao Paulo (1920)
No. hospitals&nursing homes (1920)	Sanitary Service Report of the state of Sao Paulo (1920)
Share of exp.on health&education (1940)	Annual Statistical Report for Sao Paulo (1940)
Share of education exp. on school supplies (1940)	Annual Statistical Report for Sao Paulo (1940)
Share of education exp. on payment of teachers (1940)	Annual Statistical Report for Sao Paulo (1940)

Notes: Authors' compilation.

Table A2: Summary Statistics for Dependent Variables

	Mean (1)	Standard Dev. (2)	Obs. (3)
Panel A: Variables in 1920			
Infant mortality (per 1000 live births)	22.568	20.510	460
Stillbirths (per total births)	0.053	0.026	870
Sex ratio at birth (Male babies/Female babies)	1.220	0.821	730
Literacy rate:			
Total (all ages)	0.226	0.081	977
Male (all ages)	0.282	0.088	977
Female (all ages)	0.164	0.079	977
Total (ages 15 and above)	0.326	0.104	977
Male (ages 15 and above)	0.418	0.118	977
Female (ages 15 and above)	0.221	0.098	977
Panel B: Variables in 1940			
Literacy rate:			
Male (20-29 years)	0.588	0.127	860
Female (20-29 years)	0.414	0.138	860
Male (30-39 years)	0.584	0.127	860
Female (30-39 years)	0.321	0.124	860
Male (ages 5 and above)	0.489	0.113	854
Female (ages 5 and above)	0.348	0.113	854
Male (ages 18 and above)	0.521	0.099	854
Female (ages 18 and above)	0.325	0.106	854

Notes: See Appendix 1 for data description and sources. Authors' calculations from district-level data.

Table A3: Summary Statistics for Control Variables

	Mean (1)	Standard Dev (2)	(3)
Panel A: Deaths by cause (Per 1000)			
Respiratory	1.447	1.114	835
Panel B: Regional geography			
Altitude (in meters)	618.574	196.680	879
Latitude	-22.468	1.088	882
Longitude	-47.633	1.265	882
Distance to capital (in km)	222.574	108.129	504
October's temperature (Fahrenheit)	68.161	3.724	882
October's precipitation (mm)	124.410	8.676	882
Panel C: Variables from the 1872 Census			
Share literate	0.210	0.100	885
Share of foreigners	0.024	0.026	885
Share of slaves	0.151	0.077	885
Share of race Branca	0.542	0.089	885
Share of race Parda	0.242	0.058	885
Share of race Preta	0.170	0.059	885
Share emp. in agriculture	0.648	0.099	885
Share emp. in manufacturing	0.131	0.044	885
Share with physical/mental diseases	0.109	0.559	885
Doctors (per 1000)	0.215	0.273	885
Chemists (per 1000)	0.176	0.170	885
Midwives (per 1000)	0.267	0.351	885
Population density (per sq. km)	10.492	7.744	882
Median age (in years)	20.685	2.938	885
Panel D: Other controls			
Health & sanitation exp. per capita (1910 Reais)	199.422	424.472	300
Railway station dummy (1920)	0.380	0.486	885
Water & sewerage system dummy (1920)	0.223	0.416	885
No. hospitals & nursing homes (1920)	0.558	0.973	885
Share of foreigners (1920)	0.126	0.098	879
Share of exp. on health & education (1940)	0.608	0.125	1093
Share of education exp. to school supplies (1940)	0.136	0.205	1031
Share of education exp. to payment of teachers (1940)	0.808	0.486	960

Notes: See Appendix 1 for data description and sources. Authors' calculations from district-level data.

Table A4: First Stage Regressions with Deviations of the Climate Instruments from their 1901-2016 Averages

	Dependent variable: Respiratory death rates				
	(1)	(2)	(3)	(4)	(5)
Deviation of Oct. mean temperature	-0.007	-0.007	-0.004	-0.026**	-0.026*
	(0.008)	(0.008)	(0.009)	(0.013)	(0.014)
Deviation of Oct. mean precipitation	0.202**	0.202**	0.190**	0.419***	0.418***
	(0.084)	(0.084)	(0.085)	(0.104)	(0.108)
Interaction of Deviations					0.000
					(0.006)
Region FEs	Yes	Yes	Yes	Yes	Yes
Region-level controls	No	No	Yes	Yes	Yes
Initial period controls from 1872	No	Yes	Yes	Yes	Yes
K-P F-stat	2.90	2.90	2.63	8.57	5.71
p-value for the F-stat	[0.056]	[0.056]	[0.072]	[0.000]	[0.001]
R-squared	0.432	0.431	0.431	0.446	0.446
Observations	939	937	933	933	933

Notes: Table reports OLS regressions. The instruments are the deviations of October average temperature and October average precipitation from their long-term averages (1901-2016). In column (4), we add the long-term average for October temperature and precipitation (and their interaction). In column (5), we consider the interaction between the deviation of October temperature and the deviation of October precipitation from their long-term averages. Controls include those reported in Table A3. p-values for F-Statistics are reported for the identifying instruments and are in square brackets. $^{***}p < 0.01$, $^{**}p < 0.05$ and $^{*}p < 0.10$.

Table A5: Differences in Sample Means for Selected Characteristics in Districts With Above and Below Influenza-Related Deaths during 1917-1920

	Below median		Above median			
Variables	Mean	Std. Dev.	Mean	Std. Dev.	Difference	
Municipality expenditure (per capita)						
Cleaning and waste disposal	258.89	611.61	152.40	125.80	106.49	***
Maintenance of sanitary conditions	110.12	106.07	110.59	124.29	-0.47	
Regional and Climate						
Altitude (meters)	624.13	189.49	602.74	197.22	16.39	
Latitude	-22.23	1.05	-22.65	1.09	0.42	***
Longitude	-47.88	1.17	-47.63	1.39	-0.25	***
Distance to capital	260.06	108.58	209.41	112.51	50.65	***
October's temperature	20.61	1.98	19.91	2.10	0.70	***
October's precipitation	124.85	7.54	123.67	9.18	1.18	**
Demographic						
Overall median age	20.75	2.92	20.62	2.96	0.13	
Population density	9.56	6.53	10.62	8.38	-1.06	**
Dependency ratio	88.91	21.23	89.70	21.66	-0.79	
Sex ratio	109.93	6.77	108.66	8.32	1.27	**
Literacy rate	0.22	0.11	0.21	0.10	0.02	**
Economic						
Share of employment in agriculture	0.64	0.09	0.65	0.10	-0.00	
Share of employment in manufacturing	0.13	0.04	0.13	0.04	0.01	**
Share of employment in services	0.22	0.09	0.22	0.09	-0.11	
Share of slaves	0.15	0.07	0.15	0.08	0.00	
Health						
Physical or mental disease	11.07	5.19	10.80	5.50	0.28	
Doctors	0.22	0.28	0.18	0.24	0.03	*
Chemists	0.18	0.17	0.17	0.17	0.02	
Midwives	0.27	0.33	0.25	0.35	0.02	

Notes: Table shows summary statistics and sample means differences for initial characteristics from 1872. $^{***}p < 0.01$, $^{**}p < 0.05$ and $^{*}p < 0.10$.

Table A6: First Stage Regressions with April's Temperature and Precipitation as Instruments

	Dependent variable: Respiratory death rates					
		1917-1920			1913-1915	
	(1)	(2)	(3)	(4)	(5)	(6)
April's mean temperature	-0.181**	-0.182**	-0.171**	-0.214	0.473**	0.526
	(0.0753)	(0.0754)	(0.0750)	(0.379)	(0.225)	(1.384)
April's mean precipitation	-0.0168	-0.0166	-0.0190	-0.0527	0.00879	-0.0349
	(0.0175)	(0.0175)	(0.0173)	(0.0415)	(0.0175)	(0.148)
Region FEs	Yes	Yes	Yes	Yes	Yes	Yes
Region-level controls	No	No	Yes	No	No	Yes
Initial period controls from 1872	No	Yes	Yes	No	Yes	Yes
K-P F-stat	4.16	4.17	4.04	1.08	2.69	0.27
p-value for the F-stat	[0.016]	[0.016]	[0.018]	[0.342]	[0.070]	[0.761]
R-squared	0.433	0.433	0.448	0.736	0.735	0.735
Observations	939	937	937	415	414	412

Notes: Table reports OLS regressions. Controls include those from the model in column(3) of Table 1. p-values for F-Statistics are reported for the identifying instruments and are in square brackets. ***$p < 0.01$, **$p < 0.05$ and *$p < 0.10$.

Table A7: 2SLS Heterogeneous Effects of the Pandemic on Infant Mortality in 1920

	Sub-samples considered:													
	Median age		Share slaves		Share literate		Altitude		Railroads		Doctors		Settlements	
	Above	Below	More	Fewer	More	Less	Higher	Lower	Yes	No	More	Fewer	Yes	No
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Norm. respiratory deaths	0.019***	0.018*	0.020***	0.017***	0.001	0.021**	0.037***	0.029***	0.025***	0.011	0.054	0.013***	-0.006	0.023***
	(0.004)	(0.009)	(0.010)	(0.003)	(0.003)	(0.008)	(0.003)	(0.008)	(0.007)	(0.011)	(0.087)	(0.003)	(0.006)	(0.010)
Region FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region-level controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ini. per. con. from 1872	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	125	180	87	218	80	225	67	238	267	165	88	217	65	272

Notes: Table reports the 2SLS coefficient when the dependent variable is infant mortality. The sub-samples are created using the initial conditions from the 1872 census. In order to consider values at the upper quartile of the distribution, we use a below/above 75^{th} percentile approach to classify districts by median age, share of slaves, share literate, altitude, and share of doctors. Railroads is non-linear based on whether there was a railroad in the district by 1920. Settlements denotes districts that belonged to a municipality that had a state-sponsored settlement in the state of Sao Paulo as noted in Rocha et al. (2017). The same instruments, controls, and fixed-effects used in the model of Tables 2 are included here. In column (13), we exclude distance to capital in order to identify effects given the smaller sample size. $***p < 0.01$, $**p < 0.05$ and $*p < 0.10$.

Table A8: Test of Sample Mean Differences in Literacy Rates for Districts in 1918

	Respiratory Death Rates					
	Below Median		*Above Median*			
Literacy Rates:	Mean	Std. Dev.	Mean	Std. Dev.	Difference	p-value
Brazilian Male	0.257	0.059	0.249	0.007	0.007	0.480
Brazilian Female	0.174	0.060	0.160	0.007	0.014	0.174
Brazilian Total	0.217	0.059	0.206	0.073	0.011	0.290
Foreign Male	0.562	0.153	0.524	0.149	0.038	0.083
Foreign Female	0.305	0.143	0.271	0.179	0.035	0.155
Foreign Total	0.461	0.152	0.425	0.155	0.035	0.120

Notes: Authors' calculations.

Table A9: Falsification Test Using 1915 Deaths from Respiratory Infections

	1920	1920			1940			
	Sex ratios	Literacy rate: All ages			Literacy rate (5+)		Literacy rate (18+)	
	(at birth)	Male	Female	Total	Male	Female	Male	Female
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A: OLS								
Norm. Respiratory Deaths	-0.028	0.008	0.009*	0.009*	0.079	0.011	0.010	0.011
	(0.050)	(0.005)	(0.005)	(0.004)	(0.008)	(0.008)	(0.008)	(0.006)
Panel B: 2SLS								
Norm. Respiratory Deaths	-0.179	0.038	0.041	0.038	0.036	0.020	0.0685	0.0324
	(0.440)	(0.043)	(0.045)	(0.043)	(0.035)	(0.028)	(0.044)	(0.027)
Region FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region-level controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Initial period controls from 1872	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mean of the dependent variable	1.22	0.28	0.18	0.23	0.49	0.35	0.52	0.33
K-P F-stat	3.61	2.15	2.15	2.15	2.52	2.52	2.52	2.52
Observations	124	131	131	131	119	119	119	119

Notes: We use the same models as in the original regressions for these outcomes. ***$p < 0.01$, **$p < 0.05$ and *$p < 0.10$.

Table A10: Impact of October 1918 Temperature and Precipitation on 1920 and 1940 Outcomes

	1920				1940	
	Sex ratios at birth		Log stillbirths		Literacy rates	
					Male	Female
	(1)	(2)	(3)	(4)	(5)	(6)
October's mean temperature	-0.026	-0.041	0.013	0.016	0.004	0.002
	(0.025)	(0.042)	(0.011)	(0.011)	(0.004)	(0.005)
October's mean precipitation	0.109	0.002	-0.000	-0.000	0.001	0.000
	(0.009)	(0.015)	(0.004)	(0.005)	(0.001)	(0.002)
Region FEs	Yes	Yes	Yes	Yes	Yes	Yes
Region-level controls	Yes	Yes	Yes	Yes	Yes	Yes
Initial period controls from 1872	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.466	0.571	0.253	0.255	0.460	0.447
Observations	500	105	490	164	553	553

Notes: Table reports OLS coefficients for the period 1917-1920 in columns (1), (3) and (5), and for the year 1918 only in columns (2), (4), and (6). Controls include those reported in Table A3. ***$p < 0.01$, **$p < 0.05$ and *$p < 0.10$.