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Income distribution, poverty and deaths in times of COVID-19. Is there a selective mortality?

Distribución del ingreso, pobreza y muertes en tiempos de COVID-19. ¿Existe una mortalidad selectiva?

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Abstract

Objective: to evaluate whether SARS-CoV2 had asymmetric consequences among Mexico's population; in particular, to analyze whether income distribution, poverty, or both had any effect on the distribution of lethality and mortality rates across municipalities.
Methodology: given the characteristics of the data, we use a Negative Binomial Model to assess the impact of income distribution and poverty on the distribution of deaths across municipalities. We considered and took into account comorbidities and some other sociodemographic variables.
Results: we find that the expected number of deaths increases with income inequality while it decreases with poverty, ceteris paribus. We tested different models' specifications, and the conclusions remained unchanged.
Limitations: These conclusions should be considered as preliminary because we did not have precise information about the deceased's surroundings. In addition, many of the poorest municipalities did not have information on either contagions nor deceases, which may add some bias to the estimates.
Originality: Our study represents a contribution to the growing literature on health inequality. It provides evidence on how income inequality and poverty were related to COVID-19 lethality and mortality rates in a Less Developed Economy.
Conclusions: The relationship between socioeconomic factors and the health conditions of the population is a very important one and needs further study. To the extent that we can identify and quantify the magnitude of this relationship, we could design better health systems that would allow us to face phenomena like COVID-19.

Key Words: SARS-CoV2, probability of death, income distribution, poverty, Poisson models, Mexico.
JEL Classification: I14, I15, O54.

Resumen

Objetivo: evaluar si SARS-CoV2 tuvo consecuencias asimétricas en la población mexicana, en particular, analizar si la distribución del ingreso o la pobreza, o ambas, tuvieron algún impacto sobre la distribución de muertes entre los diferentes municipios en México.
Metodología: dadas las características de los datos, se usa el modelo binomial negativo para evaluar el impacto de la desigualdad y la pobreza sobre la distribución de muertos por COVID-19 entre municipios, controlando por las comorbilidades de las personas y un conjunto de variables sociodemográficas a nivel municipal.
Resultados: se encontró que el número esperado de muertes aumentó con la desigualdad de ingreso, mientras que disminuyó con pobreza, ceteris paribus. Se probaron diferentes especificaciones y las conclusiones permanecieron sin cambio.
Limitaciones: las conclusiones se deben considerar como preliminares debido a que no se contó con información más precisa sobre las condiciones de vida de los fallecidos. Adicionalmente, muchos de los municipios más pobres no presentaron información sobre contagios o decesos, lo cual introduce sesgos a nuestras estimaciones.
Originalidad: este trabajo representa una contribución a la literatura creciente sobre desigualdad en salud y presenta evidencia acerca de cómo la desigualdad en el ingreso y la pobreza estuvieron relacionados con la distribución de mortandad del COVID-19 en un país menos desarrollado.
Conclusiones: Las relaciones entre las condiciones socioeconómicas y la salud de la población son muy importantes y necesitan mayores estudios. En la medida que se puedan identificar y cuantificar las magnitudes de estas relaciones, se podrían diseñar sistemas de salud con mayores capacidades para enfrentar fenómenos como la pandemia del COVID-19.

Palabras clave: SARS-CoV2, probabilidad de morir, distribución del ingreso, pobreza, modelo de Poisson, México.
Clasificación JEL: I14. I15, O54.

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Introduction

One of the inevitable costs of pandemics for mankind has been the number of deaths resulting from such catastrophes. Hays (2005) lists fifty of the most significant epidemics and pandemics in terms of human lives since the 5th Century BC. It includes different types of contagious diseases like smallpox, measles, bubonic plague, cholera, yellow fever, typhoid, and influenza, among others. Hays argues that two of the deadliest were the 6th and 14th Century plague pandemics. DeWitte (2014) also considers the Black Death (c. 1347-1351) to have been one of the deadliest since it killed tens of millions European lives.

According to Yasgar (2018), the first outbreak of a contagious respiratory disease can be traced back as far as 412 BC in northern Greece. Since then, there have been several flu pandemics, including the 1580 one, considered by many to be the first fully registered pandemic. A distinguishing feature of contagious respiratory diseases is that they can affect anyone within a given distance of infected people because their main transmission mechanism is airborne. During the last 120 years, we have witnessed the negative effects of two major outbreaks of infectious respiratory diseases: the 1918-1920 influenza pandemic and the 2003 first pandemic of the Severe Acute Respiratory Syndrome Corona Virus (SARS-CoV)[1].

The 1918 Flu pandemic —considered by many to be the first truly global pandemics— is said to have killed about 50 million people worldwide. On the other hand, the 2003 SARS-CoV outbreak, had an overall fatality rate of 14%-15%[2].

In late December of 2019, a new outbreak emerged in Wuhan, China. The virus causing the disease was a variant of the virus that caused the 2003 pandemic, hence, its acronym, SARS-CoV2.

In Mexico, during the early stages of the pandemic, when the known cases were mostly "imported", there was a popular belief that the virus would affect only the upper income people, or people who had traveled to countries where the epidemic had already started like China, Italy and some other European countries. The perception changed dramatically once the disease became "local"; that is, once people began to get infected from other people who had not traveled to other countries.

By now, many studies carried out by epidemiologists have identified risk factors associated with having a much severe illness or even higher probability of dying of COVID-19 (see, for example, Djaharuddin *et al.,* 2021; Russell *et al.,* 2023). These risk factors are the patients' co- morbidities or multimorbidity. Co-morbidities or multimorbidity are not random but rather result from a phenomenon that is known as health inequality. We argue that the distribution of positive cases and deaths from COVID-19 across Mexico's municipalities may be explained by this phenomenon. In fact, there is an extensive literature about the systematic differences in the health status across different population groups. Health inequality is explained by socioeconomic factors (Braveman *et al.*, 2000; Kawachi *et al.*, 2002; Nathanson, 2010).

The evolution across municipalities with different socio-economic characteristics of both the number of positive cases and deaths has been rather intriguing[3]. In the case of the disease's transmission for instance, municipalities with low inequalities experienced a higher rate than municipalities with high income inequality in the early months. It was not until November 2020 that there was a change in the trend: municipalities

[1] While both are infectious respiratory diseases, the first one is caused by the H1N1 strain of influenza virus, while the second one is caused by the Severe Acute Respiratory Syndrome Corona Virus (SARS-CoV2).

[2] The World Health Organization (2003) explains that the fatality rate (FR) varies according to patient's age. For people younger than 24 the FR was 1%, for persons aged between 25 and 44, the FR was 6%, while for people between 45 and 64 years the FR increased to 15%. The rate is as high as 50% for patients aged 65 or older.

[3] Our period of analysis throughout the paper is from the outset January 2020 until February 2021.

with high income inequality became the hotspots. Municipalities with a high percentage of people living in poverty had the smaller number of positive cases, while municipalities with low poverty (1Q, 2Q and 3Q) had the higher amounts of positive cases until October 2020. Since then, municipalities with high poverty (4Q) exhibited the highest amounts of positive cases. Deaths, on the other hand, were concentrated in municipalities with low levels of poverty (1Q and 2Q). In contrast, municipalities with a higher percentage of people living in poverty (3Q, 4Q and 5Q) exhibit lower amounts of deaths throughout the entire period of analysis.

Mexican health authorities implemented social distancing measures to minimize the spread of the disease in late March of 2020. Among the measures taken was the suspension of classes at all educational levels, and of all nonessential economic activities[4]. It was thought that normal activities would resume after one or two months; however, the number of positive cases kept growing at even higher rates for several weeks. Official statistics indicate that the spread of the disease decelerated in August and September, but in October a second wave started as the number of new cases began climbing again. The peak of this second wave (in terms of transmission rate) was reached in January of 2021; and then the number of new cases started to decline significantly. Within Mexico, a preliminary analysis of both the mortality rate (MR) and the lethality rate (LR) across federal entities (see **Table A.2** in appendix) shows the existence of a wide dispersion of both rates: LR from 5.8 (Baja California Sur) to 22 (Sinaloa), whereas the MR went from 37.1 (Chiapas) to 384.9 (Mexico City) per 100,000 inhabitants; which would indicate the heterogenous nature of the disease contagion and death rates across regions.

Worldwide, Mexico was one of the hardest hit countries by the virus. As of March 30th, 2021, there were 2,227,842 confirmed cases and 201,826 deaths[5], which placed Mexico in third position after the United States and Brazil. Even if we consider the population, the mortality rate is still among the highest in the world: about 156 per 100,000 inhabitants. The percentage of infected people who died, was 9.1% which was the highest in the world[6].

From the outset, social distancing measures implied a high cost in terms of production and employment given that, in practice, they meant to lockdown the economy. It was estimated that in the second quarter of 2020, the world economy's GDP fell by about 4.9%, while that of OECD countries fell by 9.8%[7]. Mexico's GDP, in turn, fell by 18.1%[8]. Since the third quarter of 2020, some economies began relaxing their economic lockdown, which meant a slow process of economic recovery.

By now, it is evident that the lockdown negative effects have not been evenly distributed across all population segments. They were particularly stronger among people without employment sta-

[4] Mexico's health authorities divided the evolution of the pandemic into three stages. Stage one was when the imported cases prevailed. It began on February 28th and ended on March 23rd. Stage two began when the transmission of the disease was mainly local. It began on March 23rd and ended on April 20th. One of the first measures to reduce the spread of the disease was the suspension of classes at all levels on March 16th, 2020. Initially, the federal government determined the temporary suspension of some economic activities, but this suspension was not mandatory. Stage three began on March 31st with the suspension of all nonessential activities (see SEP, 2020).

[5] Source: Johns Hopkins University, Coronavirus Resource Center. https://coronavirus.jhu.edu/map.html. Accessed: march 30th, 2021.

[6] **Table A.1** in the appendix lists the countries with the highest number of confirmed cases and deaths associated to the virus.

[7] OECD statistics. https://www.OECD.org/sdd/na/GDP-growth-second-quarter-2020-OECD.htm. Date of access: April 10th, 2021

[8] Source: INEGI-National Accounts, https://www.inegi.org.mx/temas/pibti/. Date of access: April 10th, 2021.

bility and social benefits; that is, people working in the informal sector and in the commerce and service sectors. Bottan *et al.,* (2020), for instance, found that in Latin America increased economic inequality mainly due to lost jobs and closed small businesses. Lustig and Martinez (2021), on the other hand, argued that people who lost the most were the moderate poor and the vulnerable to poverty. Further, people living in urban areas were hit harder than those living in rural areas.

It is evident that SARS-CoV2 had a devastating effect on the lives of millions of people. Early estimates indicated that the number of people living below US$1.9 a day increased between 68 and 100 million worldwide (Valensisi, 2020). Within Latin America, Lustig *et al.* (2020) estimated that SARS-CoV2 induced higher poverty and income inequalities in Argentina, Brazil, Colombia and Mexico. Government programs of social assistance in Argentina and Brazil had some offsetting effects, while in Colombia had much less effect. Unlike the latter countries, Mexico did not have a particular assistance program.

From a long-term perspective, there is also evidence that pandemics in the past have had both direct and indirect bearings on wealth distribution and poverty. Alfani (2020), for instance, analyzed the distributive consequences of the Black Death and Cholera in pre-industrial societies in Europe and Latin America. Overall, he obtained mixed results. He found that in some Italian regions, inequality declined after the pandemics to later resume its long-term trend. In Spain, on the contrary, inequality not only did not decline but rather increased. In Latin America, inequality and poverty also declined in dense areas. Alfani further argued that the decline in inequality is explained by the higher wages paid to scarce labor caused by its high mortality rate. In Latin America, the decline was mainly explained by the high mortality rate among poor indigenous people. Alfani also sustained that the plagues of the XVII century were not correlated with the changes in inequality because of the institutional framework which protected private property from the risk of dispersion or transfer to other population segments.

While recent studies have focused on the likely impacts of COVID-19 on poverty and income inequality, we are interested instead in analyzing whether poverty or income distribution had any effect on the high lethality rate in Mexico. In other words, whether deaths across municipalities depended on income distribution and/or poverty.

The paper is divided in to five additional sections. On COVID-19 and its relationship with income inequality and poverty, briefly reviews some works that associate poverty and income inequality to deaths. COVID-19 in Mexico: some characteristics describes the evolution of the disease in terms of positive cases and deaths and relate them to some socio-economic characteristics at the municipal level. In empirical model to estimate, we present the empirical model used to estimate the degree of association between the number of deaths and our two key variables (poverty and income inequality). Next, we carry out the empirical analysis, while concludes.

On COVID-19 and its relationship with income inequality and poverty

History books on pandemics seem to indicate that they decimated populations indiscriminately, without distinction of people's socio-economic levels. Or, at least, they don't provide much information about the distribution of the victims. Alfani (2020), for instance, argues that "Black Death" is usually considered the best example of a mortality crisis that cuts across all social groups without discriminating between rich and poor. However, recent work based on skeletal sources provided evidence that this pandemic was selective with respect to pre-existing health conditions, but such conditions depended on age much more than on social-economic status. Many studies of plagues have reported that, from the fifteenth century, plagues increasingly tended to focus on the poor." (p. 32).

Health inequality is a somewhat new line of research. Bouchard *et al.*, (2015) sustain that one of the first papers was one that dealt with racial discrimination in access to medical care in the US. It was not until Great Britain's report about the socioeconomic determinants of health distribution that paved the way for further research on this area. In effect, in 1980, UK's Department of Health and Social Security published a report about inequalities in health also known as the "Black Report". According to the Black Report book review by Gray (1982), it presented evidence about the degree at which the diseases and deaths not only were unequally distributed across Britain's different population segments, but also that the inequality had grown since Britain established its Health National Service.

In 2005, the World Health Organization (WHO) established the Commission on Social Determinants of Health whose main task was to collect and review data on the necessary interventions to reduce health inequities. The final report was published in 2008 (WHO, 2008). One of the most important conclusions was that very often socio-economic variables condition health characteristics of individuals, so that the person's health conditions do not depend only on congenital transmissions from generation to generation but may result from his/her socioeconomic living conditions. For example, a badly treated cold can lead to pneumonia, which, in turn, can lead to death. Infectious diseases caused by poor hygienic conditions (lack of piped water) that are not well treated by the public health system may end up in death. In this last case, the health problem is the result of the interaction of three elements: lack of health knowledge, poor living conditions, and poor public health system.

Throughout Latin America, the SARS-CoV2 pandemic has exposed not only the inadequacy of its public health systems to face this type of health crisis due to the lack of enough doctors, nurses, medicine, and poor infrastructure. It has uncovered the overall poor health condition of their population. Within OECD members, Mexico is one of the countries with the highest income inequality[9]. Even for Latin America's standards, Mexico remains as one of the countries with the highest income inequality.

Quinn and Kumar (2014), following a study by Blumenshine *et al.,* (2008), argue that a pandemic can show disparities among the population if social and health disparities are not considered in their model. For instance, disparities in the disease transmission rate can be explained by differential exposure to the virus, differential susceptibility to disease, and differential access to health care.

Sanmartin *et al.,* (2003), on the other hand, in a comparative analysis between United States (US) and Canada about the relationship between income inequality and working age mortality, find that in the case of the US there is a clear positive relationship between income inequality and working age mortality; however, this result does not hold for Canada. Their results indicate that income inequality generated by labor market exclusion plays a role in explaining the patterns of working age mortality.

We can identify two channels through which poverty and income inequality can affect the pandemic outcome. First, both variables have direct incidence upon contagions and mortality rates. Second, poverty takes control over people's living conditions because their housing, nutrition, access to health services, and education, among other things, are limited by their level of wealth; thus affecting pre-existing health conditions.

It has been argued that the velocity at which SARS-CoV2 spreads not only depends on the di-

[9] According OECD official statistics, South Africa, Costa Rica, Mexico and Chile are the four countries with the highest income inequality. Source: https://stats.OECD.org/Index.aspx?DataSetCode=IDD. Date of consultation feb. 12th, 2021.

sease natural reproductive velocity, but also, and perhaps, more importantly, on people's living and working environments; that is, the velocity of transmission depends on people's social behavior, which is associated to their socio-economic characteristics. Rangel *et al.,* (2021) also present evidence that contagion and death growth rates in Mexican states were negatively dependent on people's mobility. Thus, the rate of spread may not be homogenous over time. In other words, we may expect the rate of spread to be different across regions (or municipalities) and even over time.

In summary, this brief literature review points toward the existence of a strong causal relationship between socioeconomic factors and the distribution of contagion and deaths caused by the disease. In contrast to the forecast made by some statistical models about the contagion and death rates caused by the disease[10], we argue that the introduction of these socio-economic variables not only are the basis of a better forecast but also provide an explanation of the disease trajectory over time and the differences across regions.

COVID-19 in Mexico: some characteristics

In this section, we present some descriptive statistics to characterize the disease in Mexico. We use the information provided by the open-access database of Mexico's Ministry of Health[11]. We focus on the number of positive cases and deaths caused by SARS-CoV2[12, 13]. We start with the total number of cases and deaths included in the open data base.

[10] Ramirez-Valverde and Ramirez Valverde (2021), for instance, estimate a Gompertz model to forecast the number of contagions and deaths in Mexico.

[11] Open Data by Secretaría de Salud, https://www.gob.mx/salud/documentos/datos-abiertos-152127. Last access date: April 15th, 2021.

[12] Positive cases are those that were confirmed by any of these: Epidemiological Clinical Association, a Judgment Committee, a Polimerase Chain Reaction (PCR) test, or an Antigen Test.

[13] The data base was accessed on February 12th, 2021.

Table 1 presents the number of people who were tested for COVID-19 up until February 12th, 2021, nationwide. About 51.8% of total people who were tested for COVID-19 were women. The proportion of women who tested positive was 49.9% of total positive cases. However, in terms of deaths, women had a much smaller proportion of total deaths, 37.4%. This difference can also be seen across the other federal entities. **Figure 1** shows that the Male/Female ratio of positive cases across Mexican states fluctuates around 1, indicating that both women and men were infected in the same proportion. The exceptions were Durango and Sonora, where the proportion of women infected by the disease was greater than that of men. In the case of deaths, the situation changed dramatically since the proportion of men was much greater than that of women. The difference fluctuates between 40% and 60%.

Figure 2, in turn, presents the scatter points between the mortality and lethality rates across Mexico's federal entities . As can be observed, Mexico City was by far the entity with the largest mortality rate with more than 384 persons per each 100,000 inhabitants; yet it presented one of the lowest lethality rates within the country (6.7%). Baja California, which ranked second in terms of mortality (258.3), was, at the same time, one of the entities with the largest lethality rates (21.6%). Chiapas and Oaxaca, on the other hand, exhibited the lowest mortality rates, 37.1 and 78.6 out of 100,000 inhabitants, respectively. Their performance in terms of lethality rates, however, were quite dissimilar: while Oaxaca showed a lethality rate below 9 %, Chiapas presented the second highest rate with 22 %[15]. This is rather intriguing, because both federal entities

[14] Mortality rate is the proportion of deaths with respect to the state's population per 100,000 inhabitants, while the lethality rate is the percentage of positive cases that did not survive the virus. The estimates are through December 31st, 2020.

have the same socio-economic characteristics, i.e., both have many very small municipalities (less than 15,000 inhabitants each), with a high degree of marginalization.

As of March 30th, 2021, Mexico's mortality and lethality rates were 156 and 9.1 per 100,000 inhabitants, respectively[16], which placed it among the hardest hit countries by COVID-19. At the state level, the mortality and lethality rates were significantly higher in some states[17].

We now describe some characteristics of the disease evolution. **Table 2** shows the number of positive cases and deaths according to municipalities size[18] from March 1st, 2020, to February 12th, 2021. For each type of locality, it presents municipalities' size in terms of population, mortality rate (MR), and lethality rates (LR). Several characteristics emerge from the data. First, in absolute terms, the prime areas of infection have been intermediate- and large-size municipalities; that is, municipalities with populations between 100,000 and 1,000,000 carried out the bulk of positive cases and deaths. They together represent about 65.5% of total cases and 60.5 % of total deaths, respectively. However, the perception about what types of communities were hit the hardest changes drastically when we look at MR and LR. Mortality rates increased steadily by municipality size so that municipalities with more than 1 million inhabitants have mortality rates of about 308 per 100 000 people. Lethality rate, on the other hand, is higher among smaller localities: communities with less than 50 000 people exhibit rates higher than 14 %, i.e., more than 14 % percent of positive cases died because of COVID-19.

Like many other countries, by the end of February 2021 Mexico had experienced at least two waves of high rates of contagion and deaths. **Figure 3** and **Figure 4** present the monthly growth rate (MGR) of both contagion and deaths for municipalities of different sizes. The first wave went until August, when the MGR of new positive cases and deaths became negative in most of the municipalities (**Figure 3**)[19]. The second wave started in November and lasted until January 2021. In short, the behavior of the virus infection and deaths, over time, seems to have been quite similar across localities of different population's size except for deaths in very large municipalities which had controlled the death toll during the first wave. It is important to note that by the end of December 2020, Mexico's government began its national vaccination plan against COVID-19. The first ones to receive the vaccine were Health Workers dealing with the disease. Older people were next, and the campaign continued during the following months, so by the end of September 2021, 97.5 million doses had been administered.

We now turn to the analysis of the relationship between the number of deaths and different social and economic indicators. **Figure 5** shows the relation between municipalities' size and the number of deaths (in logs). There is a clear positive relation between the number of deaths and the size of the municipality; moreover, the larger the municipality size the higher the number of deaths.

[15] The lethality rate presented in this essay should be considered as a gross estimate of the actual one since it depends on the number of tests taken. Mexico's authorities were criticized for no conducting massive tests.

[16] In the Appendix, **Table A.1** we reproduce the number of positive cases and deaths from COVID-19 for a selected group of countries. Source: Coronavirus Resource Center-John Hopkins University.

[17] They were Baja California, Sinaloa, Chihuahua, Estado de México, Hidalgo, Tlaxcala, Coahuila, Aguascalientes and Quintana Roo.

[18] We follow INEGI's (2015) definition of urban centers according to their population size: rural community (< 2,500), population centers (between 2 500 and 14 999), small municipality (between 15 000-49 999), medium size (50,000-99,999), intermediate (100,000-499,999), large (500,000-999,999) very large (greater than 1,000,000).

[19] Our estimates suggest that the deaths' MGR in very large municipalities became negative in June; that is, they could somehow control the speed of deaths two months earlier than the rest of municipalities.

The graph also shows that the bulk of deaths falls within middle-sized municipalities.

Figure 6 and **Figure 7**, on the other hand, show the number of deaths by municipality percentage of people without health services (HS) and people without social services (SS), respectively. In the first case, we observe that the municipalities which have between 14 % and 26 % of their population without health services have the higher number of deaths. In the case of people without access to social security, **Figure 7** points out that most cases fell in municipalities with 60 % or less of their population without social security.

Low education reduces knowledge and life skills that allow people to get access to information and resources to promote health (Link and Phelan, 1995). **Figure 8** shows the percentage of people in municipalities without basic education and their number of deaths. This shows that the great majority of such cases are concentrated in municipalities that have less than 19% of their population without basic education. That is, municipalities where population cannot be defined as illiterate had the highest number of deaths.

One final relationship we evaluate is the one existing between income inequality and deaths. **Figure 9** shows the number of deaths for municipalities' Gini index[20]. The data shows that as income inequalities increases, a larger number of municipalities present a higher number of deaths (**Figure 9**).

But the question about whether deaths are concentrated in municipalities with a high proportion of people living in poverty remains. **Table 3** presents the distribution of the number of deaths by municipalities degree of poverty and income inequality[21]. The bulk of deaths were concentrated in municipalities with low levels of poverty and high degree of income inequality. That is, 65.2 % of total deaths fell in two groups of municipalities: (POV-1Q, GINI-4Q) and (POV-1Q, GINI-5Q).

In the Appendix we present additional information about distribution of deaths by income inequality and municipalities population size (**Table A.3**) and by poverty and municipalities population size (**Table A.4**). From an inspection of both tables, we draw two preliminary conclusions. First, municipalities with more than 100,000 inhabitants and high-income inequality (4th and 5th quintile)[22] concentrated about 68.4% of total deaths. Second, municipalities with a low percentage of people living in poverty (1Q) and a population greater than 100,000 people had about 72.9% of the country's total deaths. In short, deaths were concentrated in large cities (greater than 100,000 inhabitants) and high-income inequality. Poverty, on the other hand, does not seem to have been a critical variable associated to the number of deaths.

Empirical model to estimate

Our interest is to evaluate whether the number of deaths —as a consequence of getting infected by SARS-CoV2— is somewhat associated with people's socio-economic characteristics. That is, we analyze the extent to which income distribution and poverty influenced the number of deaths. Data limitations force us to choose municipalities as units of analysis. This is because socio-economic information for individual COVID-19 patients is non-existent.

The Generalized Linear Model (GLM) serves as a mathematical depiction of the relationship between the response (dependent variable) and the covariates (independent variables). It acts as an expansion of the standard linear model, under the assumption that the response variable adheres to one of the exponential distribution families, encompassing normal, Poisson, binomial, and

[20] It should be noted that the Gini Index is estimated using data from the 2010 Population Census.

[21] Both economic indicators were grouped by quintiles.

[22] Gini greater than 0.388. The Municipal Gini Index fluctuated from 0.252 to 0.565.

gamma distributions. Exponential distributions are applied in scenarios involving count-based data, which comprises discrete non-negative integers and can display high skewness. As a result, ordinary linear regression models, designed for continuous and normally distributed variables, are inadequate for effectively modeling such datasets. The most commonly employed GLMs for count data include Poisson Regression (PR) and Negative Binomial Regression Model (NBRM).

In our research, we utilize the NBRM to analyze the impact of socio-economic and socio- demographic factors on COVID-19 mortality. We chose the NBRM over the Poisson Regression Model due to overdispersion in the data, which is characterized by a variance that exceeds the mean, and an excessive number of zero values in the dependent variable. The NBRM is a model that combines a Poisson gamma distribution and is suitable for analyzing discrete dependent variables with an excessive number of zero values by categorizing them into two states: the zero state and the Negative Binomial state. The zero state has a probability of *p* and only produces zero observations, while the Negative Binomial state has a probability of $(1-p)$ and a Negative Binomial distribution with a mean of μ with $0 \leq p \leq 1$.

A preliminary analysis of the data suggests that the assumption that the first two moments are equal is violated. In fact, we find that the conditional mean is smaller than the conditional variance. In this case, the sample mean was 95.9, while the sample standard deviation was 413.1 which suggest the existence of overdispersion. Hence, as we mentioned above, our proposed model is the negative binomial, $NB(\mu,\alpha)$.

$$\Pr\left(Y=y \middle| \mu,\alpha = \frac{\Gamma(\alpha^{-1}+y)}{\Gamma(\alpha^{-1})\Gamma(y+1)}\right) \left(\frac{\alpha^{-1}}{\alpha^{-1}+\mu}\right)^{\alpha-1}\left(\frac{\mu}{\mu+\alpha^{-1}}\right)^{y} \quad (1)$$

where y_i is the number of deaths in municipality i[th], μ is the expected mean $E(y)=\mu$, whereas α is the variance parameter of the Gamma Distribution. It is thus, assumed that the marginal distribution of y exhibits a Poisson-gamma mixture. The NB model is more general than the Poisson model because it accommodates overdispersion and it reduces to the Poisson model as $\alpha \to 0$.

Cameron and Trivedi (2010) argue that a more flexible version of the model allows a quadratic variance (NB2). In this case,

$$E(y|\mu,\alpha)=\mu \text{ and}$$
$$var(y|\mu,\alpha)=\mu(1+\alpha\mu) \quad (2)$$

The NB model let $\mu=\exp(X'\beta)$. Where X is a matrix of explanatory variables.

A test of overdispersion:

The variance function of the model NB2 is,

$$Var(y|X)=E(y|X)+\alpha^2 E(y|X) \quad (3)$$

To test the existence of overdispersion is to test whether the variance parameter is cero or greater that cero. That is, the null hypothesis is $H_0\!:\alpha=0$, while the alternative is $H_\alpha\!:\alpha>0$.

We now turn to the definition of the variables included in the matrix $\mathbf{X}$. The literature on the virus SARS-CoV2's mortality stresses the fact that people with certain type of comorbidities are more likely to die once she/he becomes infected. Among these health problems are: Pneumonia, Hypertension, Diabetes, Asthma, Chronic Obstructive Pulmonary Disease, Immunodeficiency Disease, Cardiovascular Disease, Obesity and Chronic Renal Insufficiency.

According to Zhou *et al.* (2020), a study on 16,110 COVID-19 patients from nine countries presented evidence that the most common comorbidities linked to higher risk factors were obesity (42%), hypertension (40%), and diabetes (17%). Similarly, Sánchez-Pájaro et al. (2021) reported that out of 23,593 patients evaluated in Mexico, 3,844 tested positive for COVID-19. Among these, 17.4% had obesity, 14.5% had diabetes, 18.9% had hypertension, and 2.8% had cardiovascular disease. The study concluded that individuals with obesity were 1.4 times more likely to develop severe COVID-19 upon hospital admission. At the same time, patients with diabetes or hypertension were 1.9 and 1.8 times more likely to develop severe COVID-19, respectively. Additionally, it was noted that the association with obesity was stronger in patients under 50 years of age.

Obesity is the most common comorbidity in severe cases of COVID-19 in Mexico. Data from the Encuesta Nacional de Salud y Nutrición (National Health and Nutrition Survey – ENSANUT, 2018) shows that in 2018, 75% adults older than 20 years of age were overweight or obese, 22% children between 0 and 4 years old were at risk of obesity, and 8.2% were already obese. Additionally, 38% of adolescents between 12 and 19 years old were either obese or overweight. The survey also reported that 8.6 million Mexicans suffered from diabetes in 2018, and there was a 26.7% incidence of hypertension among the population aged 70 to 79. Obesity is the most significant risk factor to the development of other serious disorders, such as diabetes, hypertension, and infectious diseases (Huttunen and Syrjanen, 2010; Milner and Beck, 2012).

According to Onder *et al.* (2020), from a demographic perspective, the primary characteristic of COVID-19 is that older people, particularly those older than 70 years of age, were more likely to experience severe cases. Data from the Istituto Superiore di Sanitá (Italian Higher Institute of Health) indicates that a person in the 40 to 49 age group who was infected with COVID-19 was 27 times less likely to die than someone aged between 70 to 79 years old.

Table A.5, in the Appendix, reports the number of positive cases and deaths for women and men for the different types of pre-existing conditions. It should be noted that the information about comorbidities is provided by the patient when he/she registered in the system. The health pre-existing condition most associated with the number of positive cases is Hypertension, followed by Pneumonia and Asthma. The sequential order does not change very much in the case of deaths because in this case Pneumonia is the leading disease associated, followed by Hypertension and Asthma[23]. **Table A.6**, on the other hand, presents the number of diseases associated with death. More than 51 % of total patients who died, had one or two pre-existing health conditions. The table also indicates that only 9.2 % of total deaths did not have any pre-existing health condition.

If we were to closely measure the impact of a particular comorbidity on the expected number of deaths, we would have to eliminate all cases where the patient had more than one comorbidity. A total de 830,332 cases would be eliminated, including 143,015 cases of death. For this reason, we decided to keep all cases. We should keep in mind, therefore, that our estimate of the comorbidity impact of death would be biased[24].

We now present covariates' descriptive statistics. Remember that our unit of observation is the municipality. The municipal data is obtained by adding the number of cases of deaths, COVID-19 cases, women, pneumonia, diabetes, COPD, asthma, immunodeficiency, hypertension, cardiovascular, obesity and chronic renal. On the other hand, all socio-economic variables are at the municipal level using the "2015 Conteo de Población", except for the inequality index (Gini coefficient), which is estimated using the 2010 population census.

On average, the number of deaths is 96 but

[23] It should be noted that the sum of the pre-existing health condition does add to the total number of positive cases or deaths because a person might have more than one disease.

[24] **Table A.6**, in the Appendix, reports the number of deaths for the different number of co-morbidities.

with high dispersion (the range of cases goes from 0 cases to 6786). In the case of people who tested positive for COVID-19, the intermunicipal average is 819, with an average age of 44 years. On the other hand, the average number of people with hypertension and obesity were 1399 and 1208, respectively. As for the economic indicators, we have that the average Gini Index (2010) is 0.374, while the average percentage of people living below the poverty line is 65.5. **Table 4** also shows the average number of people living in the six different sizes of municipalities in our database: 5648, 27313, 70525, 206719, 703179 and 1436283, respectively. **Table 4** also presents some information about the percentage of workers in Retail (t_trabcmenor), Hotels and Lodging (t_trabhot), and in the Communications and Transport sector (t_transp). The last variable included is the number of workers who earn 2 or less minimum wage rate (in logs), lpo2sm2015.

Empirical analysis

In what follows, we present the main results of our empirical analysis. We assume that the variance's variability is associated to municipalities' population size. We estimated seven specifications to assess the relationship between deaths, on one hand, and poverty and income inequality, on the other. The results are presented in the Appendix (see **Table A.7**).

To summarize some of the general results. First, having been tested positive for the disease does not increase the expected number of deaths. We did not find it to be statistically significant different from zero. Second, women have lower expected number of deaths than men. This result remains consistent in all regressions. Third, the average age across municipalities is between 40 and 60 years; thus, this group of age results statistically significant. However, when we run the model using individual data, the expected number of deaths increases with the person's age. Fourth, only three out of the ten different types of pre-existing health conditions, resulted significant in all regressions: pneumonia, diabetes and Chronic Obstructive Pulmonary Disease. The evidence about the association between cardiovascular disease and chronic renal insufficiency and deaths is mixed at best.

Among the socio-demographic variables we included the density rate (dens15), defined as the number of people living in one square Km in 2015; the percentage of people 18 years or older with a maximum of secondary education in 2015, Rezedu15, and the percentage of people without health services, sssal15, in 2015. We found evidence that the higher the degree of density, the higher the expected number of deaths. In the case of lagged education, we found evidence that where the percentage of people without higher education is greater, the expected number of deaths because of COVID-19 falls in a larger amount. Even if the percentage of people without higher education is small (2Q), the effect on the expected number of deaths is negative (although smaller in absolute value than the case where the proportion is higher). To some extent, this result is consistent with the finding that the disease has not been deadliest among the poorest. With regard to the percentage of people without health services, we did not find concluding evidence of a positive relationship between the latter and the expected number of deaths. This is an unexpected result in that we hypothesized that the higher the percentage of people without health services, the higher the expected number of deaths.

We now turn to the analysis of the relation between the number of deaths and poverty and income distribution. Model 1 uses both indexes as such. In Models 2 and 3, we measure the impact of both variables on the expected number of deaths after we split them into quintiles. Models 4 and 5, in turn, evaluate the impact of the different combinations of poverty and inequality. Models 6 and 7 assess whether the impact of poverty and inequality changes across the size of municipalities.

Overall, the results indicate that the expected number of deaths increases with income inequality, while it decreases with poverty, ceteris paribus. We tested different model specifications. The conclusions did not change, i.e., the expected number of deaths is higher among municipalities with higher inequality. Poverty, on the other hand, exhibits a negative relationship with death: the higher the percentage of people living below the poverty line, the lower the expected number of deaths. Models 1, 2 and 3 reflected these two conclusions.

To explore if the previous results remain unchanged to different measures of inequality and poverty, we grouped municipalities according to some combination of these variables' quintiles. Combining inequality with poverty's quintiles (Model 4), confirmed that the expected number of death declines as poverty increases. Model 5, in turn, showed that as we move to municipalities with higher inequality (for a given poverty), the expected number of deaths increases, at a much slower pace than in the previous models, though. Models 6 and 7 confirmed the results for a combination of inequality and size and poverty and size.

As a way of conclusion

Perhaps the most relevant conclusion is that we found some evidence that the distribution of death across Mexico's municipalities was associated to their level of income inequality. We did not find, however, that deaths at the municipal level were associated to their poverty level. These conclusions should be considered as preliminary since we did not have precise information about the surroundings of the deceased. For example, it is well known that the pandemic demanded maximum resources from the health system. As health centers became saturated, the location where patients were finally treated or died did not necessarily were the same as their place of residence. This fact may have introduced a bias to our estimates. Another element that may add some bias to our results is the fact that many of the poorest municipalities did not present any information about contagions nor deceases.

This study resumes the health inequality hypothesis that argues that income distribution and poverty are key variables that could explain the distribution of the number of infections and deaths from COVID-19 across municipalities. Given the characteristics of the dependent variable (number of deaths in each municipality) we use a Negative Binomial Distribution model to estimate the effect of income inequality and poverty on the number of deaths, after controlling for the number of comorbidities, age, access to the health system, municipality density, education level. As already noted, we found evidence about a positive relationship between municipality density and the expected number of deaths: the higher the density the higher the expected number of deaths. Evidence about the impact of income inequality on the number of deaths is robust to different model specifications. However, our results do not support the hypothesis that the poorest municipalities were the hardest hit by COVID-19. This is an unexpected result that needs further investigation. Education and access to health services, on the other hand, also provide somewhat odd results that call for further research.

The relationship between socioeconomic factors and health conditions is a very important one and needs further study. To the extent that we can identify and quantify the magnitude of this relationship, we could design better health systems that would allow us to face phenomena like COVID-19.

Table 1

Number of cases and deaths[13]

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Gender	N	Positive Cases	Deaths
Male	2,416,516	986,657	144,056
Female	2,599,571	981,877	86,578
Total	5,016,087	1,968,534	230,634

Source: open data, general directorate of epidemiology.

Table 2

Positive cases and deaths by municipality's size

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Municipality's size	Positive cases	Deaths	Pop. 2015	MR	LR
< 15K	38746	5967	7331501	81.4	15.4
N	1246	1246	1298		
15-50K	125719	18243	19950878	91.4	14.5
N	730	730	730		
50K-100K	137707	18253	14669175	124.4	13.3
N	208	208	208		
100K-500K	678780	73045	35762456	204.3	10.8
N	173	173	173		
500K-1M	609549	66383	26017627	255.1	10.9
N	37	37	37		
> 1 M	377884	48722	15799113	308.4	12.9
N	11	11	11		
TOTAL	1968385	230613	119530765	192.9	11.7
	2405	2405	2457		

Source: own estimates based on open access database (Health Secretary).

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Table 3
Distribution of deaths by poverty and inequality

	GINI-1Q	GINI-2Q	GINI-3Q	GINI-4Q	GINI-5Q	TOTAL
POV-1Q	29	3479	28475	73988	76374	182345
POV-2Q	95	785	6685	12640	11666	31871
POV-3Q	239	900	3445	2846	4049	11479
POV-4Q	362	1027	1232	854	531	4006
POV-5Q	273	252	128	93	42	788
TOTAL	998	6443	39965	90421	92662	230489

Source: own estimates.

Table 4
Descriptive statistics

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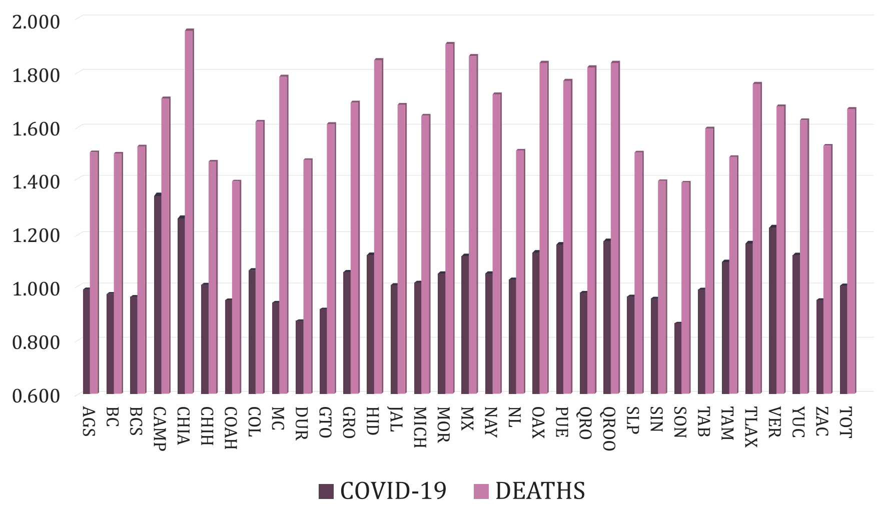
Covariates	Obs	Mean	Std. Dev.	Min	Max
Deaths	2404	96	413	0	6786
COVID-19	2404	819	4012	0	78578
Women	2404	1081	5872	0	141108
Age (years)	2456	44	11	0	98
Pneumonia	2404	182	795	0	14573
Diabetes	2404	218	1023	0	22655
COPD	2404	20	84	0	1592
Asthma	2404	51	259	0	4459
Immunodeficiency	2404	18	85	0	1616
Hypertension	2404	294	1399	0	29290
Cardiovascular	2404	30	141	0	2742
Obesity	2404	258	1208	0	24140
Chronic Renal	2404	28	116	0	2126
Gini 2010	2,456	0.374	0.049	0.2521	0.565
Lagged Educ 2015	2,446	27.9	10.1	2.5	60.6
Density 2015	2,457	296.6	1203.5	0.145	16898
Poverty 2015	2,446	65.5	21.5	2.7	99.9
Tam 1 (< 15 K)	1298	5648		87	14974
Tam 2 [15K-50K)	729	27313		15010	49651
Tam 3 [50K –100K)	208	70525		50377	99493
Tam4 [100K–500K)	173	206719		206719	495563
Tam5 [500K-1M)	37	703179		502547	988417
Tam6 [> 1M)	11	1436283		1039867	1827868
t_trabcmenor	2,457	0.034	0.020	0.0000	0.277
t_trabhot	2,408	0.013	0.018	0.0000	0.491
t_transp	1,286	0.004	0.009	0.0000	0.130
lpo2sm2015	2,457	3.957	0.366	2.1	4.5

Source: own estimates.

p. 82

Figure 1

Ratio male/female across states



Source: own estimates using open data, general directorate of epidemiology.

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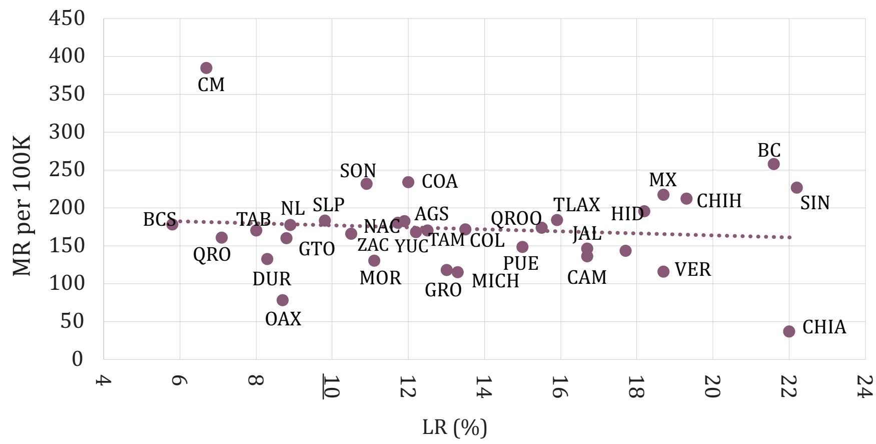
Figure 2

Mortality and lethality rates across states



Source: own estimates.

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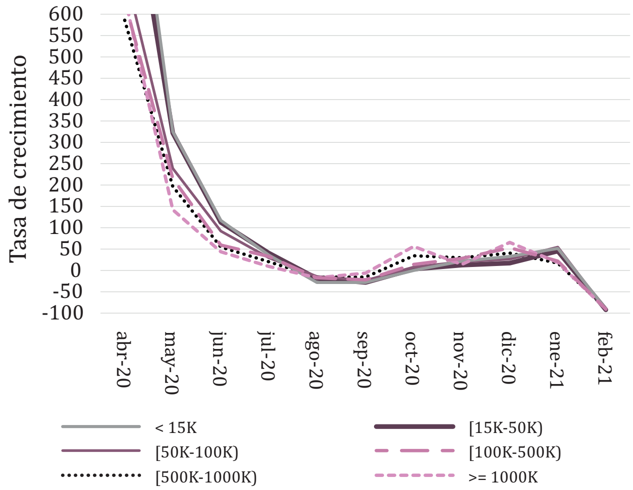
Figure 3

MGR of positive cases



Source: own estimates based on open access data base.

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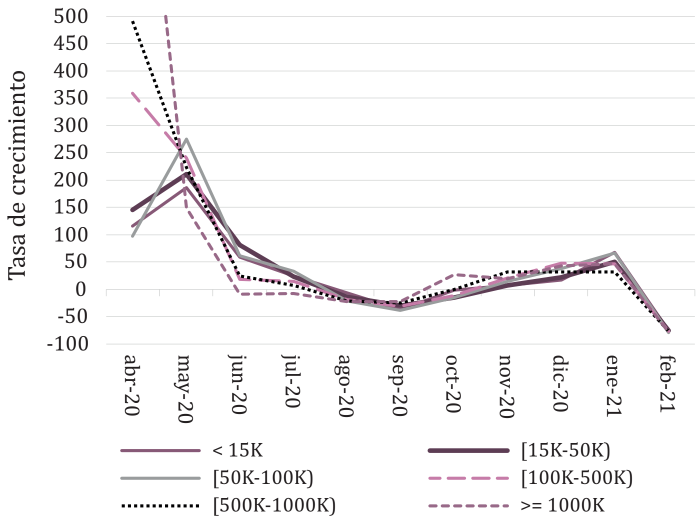
Figure 4

MGR of deaths

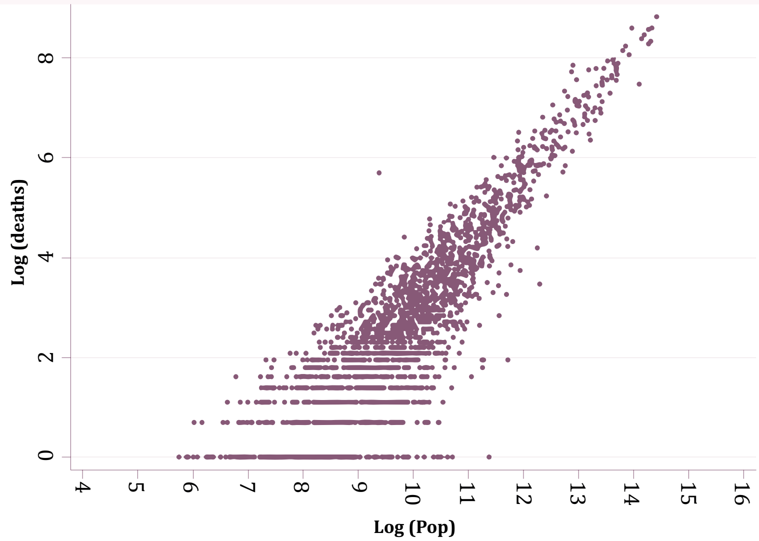


Source: own estimates based on open access data base.

Figure 5

Number of deaths by municipality's size

p. 83



Source: own estimates.

Figure 6

Deaths by % of people w/o HS

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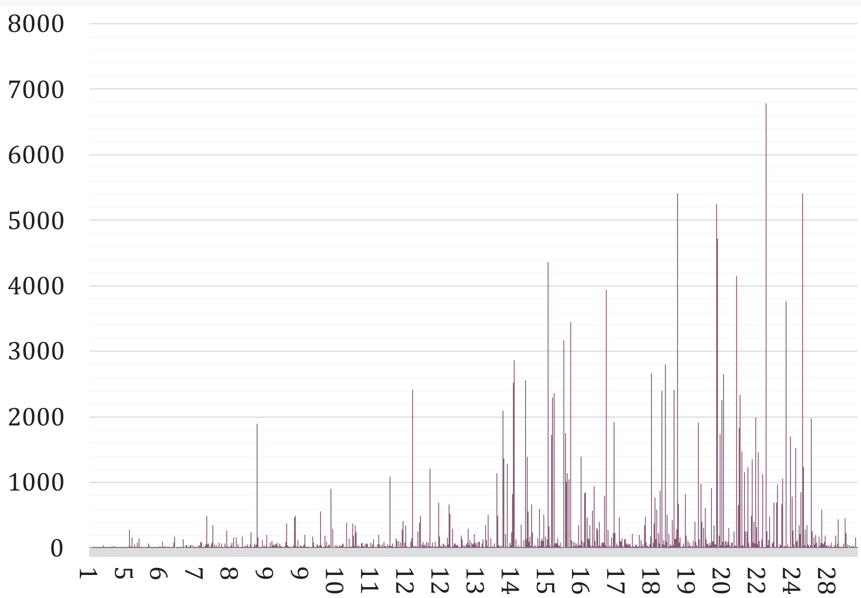
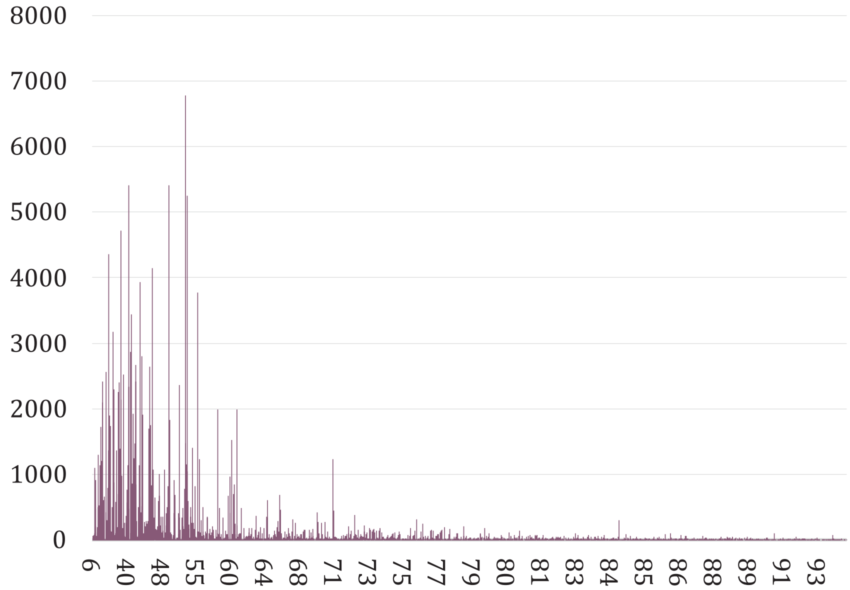


Source: own estimates.

p. 84

Figure 7

Deaths by % of people w/o SS



Source: own estimates.

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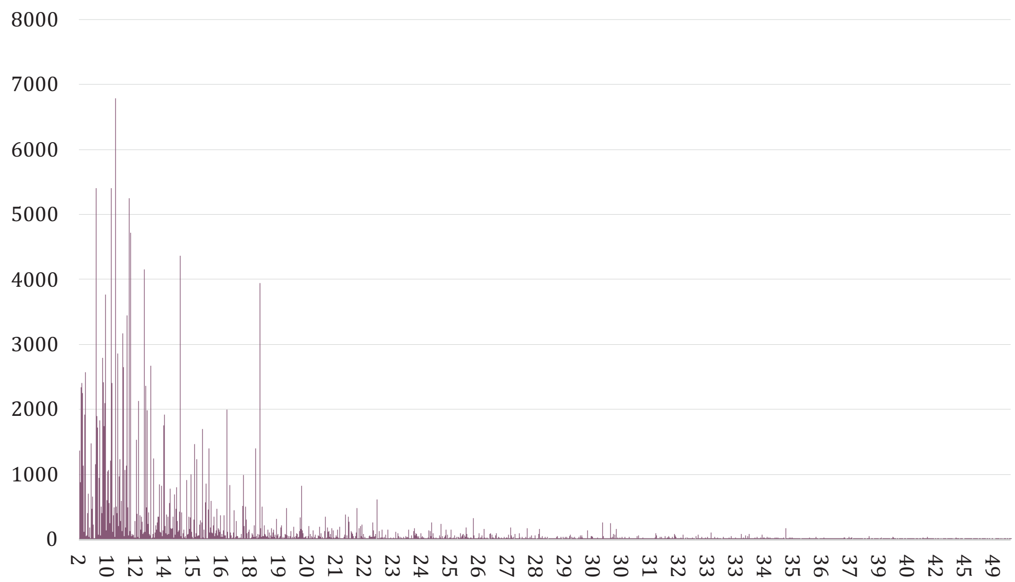
Figure 8

Deaths by % of people w/o BE, 15 years or older



Source: own estimates.

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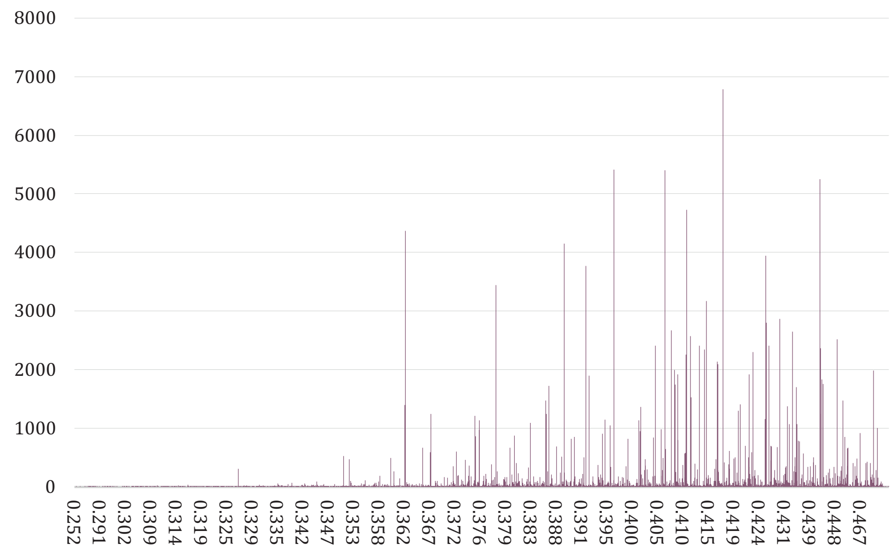
Figure 9

Deaths by Gini index



Source: own estimates.

Appendix

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Table A.1
Number of cases and death for selected countries

Country	Cases	Deaths	Population	MR **(100K)**	LR **(%)**
USA	30378314	550688	331341050	166	1.8
Brazil	12573615	313866	212821986	147	2.5
Mexico	2227842	201826	129166028	156	9.1
India	12095855	162114	1382345085	12	1.3
UK	4355840	126912	67948282	187	2.9
Italy	3561012	108879	60446035	180	3.1
Russia	4486078	96817	145945524	66	2.2
France	4646004	95495	65298930	146	2.1
Germany	2803628	76183	83830972	91	2.7
Spain	3275819	75305	46757980	161	2.3
Colombia	2389779	63079	50976248	124	2.6
Iran	1875234	62569	84176929	74	3.3
Argentina	2322611	55611	45267449	123	2.4
South Africa	1545979	52710	59,308,690	89	3.4
Poland	2288826	52392	37839255	138	2.3
Peru	1533121	51635	33050211	156	3.4
Indonesia	1505775	40754	273523615	15	2.7
Ukraine	1713684	34043	43,733,762	78	2.0
Turkey	3277880	31385	84339067	37	1.0
Czechia	1523668	26222	10708981	245	1.7
Romania	946647	23409	19,317,384	121	2.5
Chile	989492	23107	19,116,201	121	2.3
Belgium	872936	22921	11,492,641	199	2.6
Canada	978498	22887	37,742,154	61	2.3
Netherlands	1284347	16654	17,474,677	95	1.3

Source: John Hopkins University, Coronavirus Resource Center.
https://coronavirus.jhu.edu/map.html. Accessed: 30 march 2021.

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Table A.2
Number of cases and deaths by states

State	Tests COVID-19	Cases	Deaths	POP 2020	LR (%)	MR (100K)	N Mun w/ High Marg
CM	1602293	514405	34711	9,018,645	6.7	384.9	0
BC	111516	43462	9389	3,634,868	21.6	258.3	0
COAH	144905	62687	7541	3,218,720	12.0	234.3	0
SON	115388	65500	7123	3,074,745	10.9	231.7	1
SIN	72814	32392	7176	3,156,674	22.2	227.3	3
MX	554429	203107	37910	17,427,790	18.7	217.5	19
CHIH	77130	41758	8077	3,801,487	19.3	212.5	15
HID	63568	33213	6040	3,086,414	18.2	195.7	26
TLAX	48417	16050	2546	1,380,011	15.9	184.5	0
SLP	124651	53982	5266	2,866,142	9.8	183.7	31
AGS	71487	22045	2624	1,434,635	11.9	182.9	0
BCS	70037	24846	1436	804,708	5.8	178.4	0
NL	239812	111418	9963	5,610,153	8.9	177.6	4
QROO	42431	19075	2979	1,723,259	15.5	174.4	3
COL	21742	9989	1348	785,153	13.5	171.7	0
TAB	159127	55046	4386	2,572,287	8.0	170.5	0
TAM	122262	49865	6224	3,650,602	12.5	170.5	6
YUC	81749	31214	3802	2,259,098	12.2	168.3	68
Zac	53161	26265	2765	1,666,426	10.5	165.9	3
QRO	101678	51958	3676	2,279,637	7.1	161.3	3
GTO	242847	113159	9977	6,228,175	8.8	160.2	5
PUE	153820	65293	9798	6,604,451	15.0	148.4	135
JAL	167448	73753	12309	8,409,693	16.7	146.4	7
NAY	25687	10405	1846	1,288,571	17.7	143.3	3
CAM	28242	8177	1363	1,000,617	16.7	136.2	4
DUR	67894	29852	2483	1,868,996	8.3	132.9	9
MOR	70765	238	2664	2,044,058	11.1	130.3	1
GRO	65343	33402	4329	3,657,048	13.0	118.4	69
VER	105571	52835	9903	8,539,862	18.7	116.0	127
MICH	94563	41816	5569	4,825,401	13.3	115.4	28
OAX	59096	37576	3257	4,143,593	8.7	78.6	426
CHIA	55019	9677	2126	5,730,367	22.0	37.1	103
NAC	5014892	1968076	230599	127,792,286	11.7	180.4	--

Source: open data base on february 12th, 2021. Ministry of Health; Population Census 2020, INEGI.

Table A.3
Distribution of deaths by municipalities' size and income inequality

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	GINI- 1Q	GINI-2Q	GINI-3Q	GINI-4Q	GINI-5Q	TOTAL
< 15 K	700	1193	1356	1437	1281	5967
15K-50K	298	2394	5425	5302	4801	18220
50K-100K	1	891	4686	5978	6697	18253
100K-500K	--	1982	13772	23928	33363	73045
500K-1M	--	--	10370	27151	28862	66383
> 1 M	--	--	4364	26625	17733	48722
TOTAL	999	6460	39973	90421	92737	230590

Source: own estimates.

Table A.4
Distribution of deaths by municipalities' size and poverty

p. 84

	POBR- 1Q	POBR- 2Q	POBR- 3Q	POBR- 4Q	POBR- 5Q	TOTAL
< 15 K	1404	1746	1337	990	453	5930
15K-50K	4915	6727	4221	2009	284	18156
50K-100K	7996	6424	3167	654	12	18253
100K-500K	56155	14982	1516	353	39	73045
500K-1M	63153	1992	1238	--	--	66383
> 1 M	48722	--	--	--	--	48722
TOTAL	182345	31871	11479	4006	788	230489

Source: own estimates.

Table A.5
Pre-existing health conditions

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	Positive cases			Deaths		
Health condition	Men	Women	Total	Men	Women	Total
Pneumonia	168440	112678	281118	100132	59296	159428
Hypertension	170829	172892	343721	58750	44561	103311
Diabetes	134977	129968	264945	50016	36624	86640
Asthma	16644	27907	44551	1856	2231	4087
Chronic Obstructive Pulmonary Disease	11222	11043	22265	6216	5001	11217
Immunodeficiency Disease	7750	9032	16782	3480	2833	6313
Cardiovascular Disease	17438	14002	31440	7864	4991	12855
Obesity	139445	151055	290500	26766	21433	48199
Chronic Renal Insufficiency	16769	12995	29764	10638	7434	18072

Source: open access data base. Information up to february 12th, 2021.

Table A.6
Death by number of pre-existing health condition

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Number of Pre- existing health conditions	Cases Males	Cases Females	TOTAL
None	14,167	6,675	20,842
1	42,295	20,204	62,499
2	38,754	23,522	62,276
3	28,037	20,255	48,292
4	12,713	10,079	22,792
5	3,994	3,173	7,167
6	1,057	839	1,896
7	278	179	457
8	52	42	94
9	15	5	20
10/11	11	5	16
Total	141,373	84,978	226,351

Source: open data on february 12th, 2021.

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