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Income inequality and the disease burden of COVID-19: Survival analysis of data from 74 countries

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A R T I C L E I N F O

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A B S T R A C T

The COVID-19 pandemic presents a rare opportunity to assess national performance in responding to a historic crisis. It is not well understood how income inequality might be related to differential disease burden of COVID-19 across countries. Using recent data merged from Our World in Data 2020, the World Bank, and the Global Burden of Disease, we examined the association between income inequality (the Gini index) and COVID-19 infection and death rates among 74 countries with available data. After adjusting for differences in population size, age structure, longevity, population density, GDP per capita, health care expenditures, educational attainment, direct democracy index, stringency of implemented measures, and testing intensity for COVID-19, results from Cox Proportional Hazards regressions revealed that countries with more unequal income distribution carried a higher burden of COVID-19 infections and deaths in 2020. On average, each percentage point increase in the Gini index was associated with an 9% increase in the hazard of having a higher COVID-19 infection rate in the sample (AOR = 1.09, 95% CI 1.01, 1.18). The corresponding associated increase in the hazard of having a higher COVID-19 death rate was 14% (AOR = 1.14, 95% CI 1.06, 1.23). Countries with severe and persistent income inequality should develop national strategies to address this challenge to be better prepared for future pandemics.

1. Introduction

By March 2022 over 6 million people have died of COVID-19 worldwide, making it one of the deadliest pandemics in recent human history (Johns Hopkins Coronavirus Resource Center, 2022). Responses to this global pandemic vary dramatically across countries; some countries have implemented lockdowns and strict travel controls (e.g., Italy and Spain in March 2020), while others have aggressive vaccination initiatives (e.g., in the United States, mandating certain adults to be vaccinated or tested on a weekly basis) (Koh, 2020; Statista, 2021a). The Lowy Institute (Australia) recently ranked the performance of 98 countries and territories in terms of COVID-19 infections, mortality, and the positivity and testing rates (The Lowy Institute, 2021). In January 2021 New Zealand topped the list, followed by Vietnam, Taiwan, Thailand, and Cyprus; the United States, Iran, Colombia, Mexico, and Brazil were at the bottom of the list. By March 4, 2021, the COVID death rate in the United States was 1,573 per million compared to 5 per million in New Zealand (Statista, 2021b).

A relevant yet underexplored factor associated with differential COVID-19 outcomes across countries concerns income inequality. Results based on *meta*-analysis of data from 28 studies involving over 60 million participants revealed a modest, adverse effect of income inequality on health and the existence of a threshold of income inequality beyond which adverse impacts on health begin to emerge (Kondo et al., 2009). Subramanian and Kawachi (2004) conceptualized three pathways linking income inequality to health. The first is a “structural pathway” which points to a causal effect of income inequality on residential segregation and spatial concentrations of poverty in economically disadvantaged communities. The second pathway concerns how income inequality erodes “social cohesion” or “social capital,” which in turn impacts health and health behaviors in a society. The third pathway through which income inequality poses a threat to population health is the policy pathway whereby the adverse influence of income inequality on health may operate through the formulation and implementation of general social policies as well as through health-related policies.

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This study seeks to examine the association between income inequality and COVID-19 outcomes among countries with available data on these variables. The central hypothesis is that, after adjusting for differences across countries in related covariates in the analysis including COVID-19 testing intensity, countries with more unequal income distributions carry a higher burden of COVID-19 infections and deaths.

In the United States, states with higher income inequality experienced a higher rate of deaths due to COVID-19 (Oronce et al., 2020). Similar findings have been reported at the county level where a 1% of increase in income inequality was associated with about 2% to 3% increase in COVID-19 incidence and mortality rates (Liao & De Maio, 2021). Such evidence is not as clear at the international level. Findings based on an examination of the association between income inequality and COVID-19 outcomes among Organization for Economic Cooperation and Development (OECD) countries during the early stage of the pandemic revealed that countries with higher levels of income inequality performed significantly worse in terms of COVID-19 infection and death rates (Wildman, 2021). This study and a second study of 84 countries did not consider differences across countries in COVID-19 testing intensity, an important factor impacting not only the COVID-19 infection rate but an element that is also related to the mortality rate (Elgar et al., 2020; Liang et al., 2020).

2. Methods

2.1. Data

The data used in this study come from three sources. The first one is "Our World in Data" compiled and released by the University of Oxford, which tracks COVID-19 outcomes at the global level and provides daily updates for all countries with available data (Ritchie et al., 2020; Roser et al., 2020). The number of COVID-19 cases and deaths for different countries are constantly updated based on related statistics from official websites, press releases, and social media accounts of national governments, centers for disease control, and ministries of health. "Our World in Data" also contains up-to-date information on important characteristics of countries such as population size (by the year 2019), median population age (by the year 2020), population density (by the year 2017), gross domestic product (GDP) per capita (by the year 2017), life expectancy at birth (by the year 2019), and strictness of country's lockdown policies in response to COVID-19 (throughout the year 2020).

The second data source is the World Bank, which provides the latest available statistics (updated during the period of 2015–2020) on income inequality (as indicated by Gini index), tertiary education, direct democracy index, and health care expenditures per capita, for most countries in the world (The World Bank, 2020a, 2020b, 2021). The third source of our data is the Global Burden of Disease Collaborative Network at the Institute for Health Metrics and Evaluation (IHME) from the University of Washington, which contains information on estimated annual number of deaths by cause for different countries at the global level (Global Burden of Disease Collaborative Network, 2019).

While "Our World in Data" tracks updated statistics for most countries about COVID-19 infection and mortality rates, data on numbers of COVID-19 tests were only available for 82 countries by December 31, 2020. A total of 74 countries have complete data for other variables used in our analysis after merging data from all three sources.

We decided to compare countries on COVID-19 outcomes up to the end of 2020 in consideration of the crucial role of COVID-19 vaccination in shaping the pandemic outcomes starting from 2021, which would complicate our analysis. Thus, the working sample used in this study included 74 countries with needed data on COVID-19 outcomes, income inequality, and other variables included in our analysis at the country level.

2.2. Measures

2.2.1. Outcome variables

The infection and death rates of COVID-19 were calculated as total number of infections (cases) or deaths caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2).

by December 31, 2020 divided by the country's population and multiplied by 1,000,000 to adjust for differences in population size between countries. These rates were dichotomized by splitting the sample evenly into countries with higher rates of COVID-19 infections or deaths and the other half countries with lower rates to be used as outcome variables in survival analysis.

2.2.2. Explanatory variables

A key explanatory variable used in our study is the Gini index, the most commonly used indicator of income distribution in a country. The Gini index measures the extent to which the distribution of income among individuals or households within an economy deviates from a perfectly equal distribution (The World Bank, 2020b). The index ranges between 0 and 100 with 100 indicating the highest level of income equality and 0 indicating no income inequality.

Other explanatory variables at the country level include population size (in million), population density (higher or lower than the median population density in the sample based on number of people per square kilometers), median age of the population, GDP per capita (in thousands of US dollars), life expectancy at birth, health care expenditures per capita in U.S dollars (higher or lower than the sample median), percentage of the population with tertiary education, and direct democracy index (ranging from 0 to 1 with 0 indicating the lowest level of direct democracy and 1 the highest level) (The World Bank, 2020a). We also incorporated into our analysis two COVID-19 variables. One was the intensity for COVID-19 testing (higher or lower than the sample median based on cumulative number of COVID-19 tests up to December 31, 2020 per thousand residents). The other variable was a 'stringency index' measuring the strictness of countries' lockdown policies, which is represented by a value between 0 and 100 (with 0 indicating the lowest level of strictness and 100 the highest level of strictness). This index was calculated by using the simple averages of nine indicators denoting containment and closure policies such as school closures and restrictions in movements as well as health system policies such as the COVID-19 testing regime (Hale et al., 2021).

These explanatory variables were incorporated into our analysis as potential confounders because they either characterize important profiles of a country or factors directly related to the reporting of COVID-19 infections or deaths. While population size, density, and median age reflect important demographics, GDP per capita, tertiary education, direct democracy index, life expectancy at birth, and per capita health care expenditure are indicative of the level of socioeconomic development and overall health of the population. COVID-19 testing intensity is important for our analysis because it is positively related to the identification and reporting of COVID-19 infections and deaths. Stringency index is also related to COVID-19 outcomes since it captures the overall strictness of implemented regulations or measures in response to the pandemic. For ease of interpretation, several explanatory variables including population density, intensity of COVID-19 testing, and stringency index were dichotomized into two categories (lower half versus upper half the sample).

2.3. Statistical analysis

Countries included in our analysis differ substantially from each other in terms of the timing when the first COVID-19 case was officially reported. In an effort to adjust for these important differences, we ran Cox Proportional Hazards (CPH) regressions to estimate the association between the Gini index and COVID-19 infection and death rates with and without controlling for the effect of certain covariates included in the analysis. The two outcome events in the CPH analysis are respectively defined as having COVID-19 infection or death rates equal to or higher than the median rates in the sample (i.e., to reach rates in the higher half of the sample). The survival time in the CPH analysis denotes the duration when the event of interest has not occurred yet since the first reported case of COVID-19 in the country. Thus, for countries that experienced the event (i.e., reaching the top 50% of COVID-19 infection or death rate in the sample) by the end of 2020, their survival time is the number of days from the day of reporting the first COVID-19 case to the day when the country reached the top 50% in the COVID-19 infection or death rates. For countries that had not experienced the event, their survival time is calculated as the number of days from the day when the first COVID-19 case was reported until the end of December 2020.

In order to examine how the inclusion or exclusion of certain variables impact the observed association between Gini index and COVID-19 outcomes, we included two models in our analysis with Model 1 including Gini index, country demographics, GDP per capita, life expectancy, direct democracy index, and health care expenditures per capita; and Model 2 adding the stringency index COVID-19 testing intensity to Model 1.

For the CPH regressions, sensitivity analyses were conducted by excluding outliers in the outcome variables that were beyond two standard deviations from the mean. All statistical analyses were conducted using SAS version 9.7 (SAS Institute Inc, 2021). Two-tailed p values < 0.05 were considered statistically significant.

3. Results

The 74 countries in the sample consisted of 28 countries from Europe, 16 from Asia, 15 from Africa, 7 from South America, 6 from North America, and 2 from Oceania. Out of those, 28 countries, or 38% in the sample, were members of The Organization for Economic Cooperation and Development (OECD). A detailed list of the 74 countries in the sample can be found in the Appendix.

There was substantial variation in the Gini index across countries in the sample, ranging from 24 to 63 with a mean of 37 (see Table 1). Countries also differed substantially in terms of COVID-19 outcomes. The average number of COVID-19 infections by the end of 2020 was 4,653 per million residents in the lower half of the sample compared to 15,961 infections per million residents in the upper half of the sample. Similar differences were also observed in the case of the COVID-19 death rate, which ranges from less than one to 1,685 deaths per million residents. COVID-19 testing also varied tremendously across countries. The average number of COVID-19 tests per 1,000 residents is 50.8 in the lower half of the sample compared to an average of 511.2 tests per 1,000 residents in the upper half of the sample. Population size, median age, population density, GDP per capita, life expectancy, health care expenditures per capita, tertiary education, and the direct democracy index, also showed substantial variation across countries.

Table 2 reported the hazard ratios (HR) of the association between the Gini index and the COVID-19 infection rate for the three estimated models. In Model 1, Gini index showed a positive, though not significant, association with the infection rate. The association, however, became statistically significant in Model 2 where the variables on stringency index and COVID-19 testing intensity had been incorporated into the analysis. In this model, a one percentage point increase in the Gini index was associated with an 9% increase in the hazard of having a higher COVID-19 infection rate (AOR = 1.09, 95% CI 1.01–1.18). The results also revealed a positive association between intensity for COVID-19 testing and COVID-19 infection rate (AOR = 7.74, 95% CI 1.63–36.84).

Results based on Table 3 revealed a positive and statistically significant association between the Gini index and COVID-19 mortality. The association became more pronounced in Model 2 when the stringency index and COVID-19 testing intensity had been added to the survival analysis. In this model, each percentage point increase in the Gini index was associated with an 14% increase in the hazard of having higher COVID-19 mortality in the sample (AOR = 1.14, 95% CI 1.06, 1.23).

According to results from Model 2 in Table 3, countries with older populations carried a higher hazard of ending up with higher COVID-19 mortality rate in the sample (AOR = 1.14, 95% CI 1,05, 1.25). The results also pointed to a positive association between the stringency index and COVID-19 mortality (AOR = 4.54, 95% CI 1.54, 13.37). Better education at the national level was associated with lower COVID-19 mortality (AOR = 0.98, 95% CI 0.96, 1.00).

We further assessed the robustness of our findings by replicating the analysis in Tables 2 and 3 after removing outliers of COVID-19 outcomes (>2 standard deviations from the sample average). The significant association between the Gini index and COVID-19 infection and death rates remained to hold, as indicated in the Appendix.

Table 1
Descriptive statistics of the 74 countries in the sample by 2020.

Variables	Mean	Std Dev	Minimum	Maximum
Gini index	37.4	7.7	24.2	63.0
COVID-19 infection rate (number of COVID-19 infections per million residents)				
Low (lower half of the sample)	4653.0	4812.8	54.7	15484.3
High (higher half of the sample)	15961.3	832.6	15618.0	20732.6
COVID-19 death rate (number of COVID-19 deaths per million residents)				
Low (lower half of the sample)	61.2	65.5	0.3	224.1
High (higher half of the sample)	751.6	348.9	247.6	1685.0
Intensity of COVID-19 Testing (# of COVID-19 tests per 1,000 residents)				
Low (lower half of the sample)	50.8	39.1	3.6	156.8
High (higher half of the sample)	511.2	415.6	159.3	2112.2
Population size (in million)	41.4	63.0	0.9	331.0
Median age of the population	33.4	9.3	16.4	48.2
Population density (population per square kilometers of land area in 2017)				
Low (lower half of the sample)	44.6	27.8	2.0	85.1
High (higher half of the sample)	225.0	210.5	87.3	1265.0
GDP per capita (in thousands of U.S. $)	21.3	17.3	1.4	67.3
Life expectancy (at birth)	74.9	6.9	54.7	84.6
Health care expenditures per capita (in hundreds of US$)	16.4	23.6	0.2	106.2
Percentage of the population with tertiary education	69.1	6.0	60.8	81.2
Direct democracy index	0.2	0.2	0.0	0.8
Average stringency index in 2020				
Low (lower half of the sample)	51.0	8.4	16.5	59.6
High (higher half of the sample)	69.0	6.0	60.8	81.2

4. Discussion

This study revealed a significant association between income inequality and the disease burden of COVID-19. After adjusting for differences in population age structure, longevity, population density, GDP per capita, health care expenditures, educational level, direct democracy index, stringency of implemented measures in response to COVID-19, and testing intensity for COVID-19, countries with more unequal income distributions carried a higher burden of COVID-19 infections and deaths in 2020 before worldwide COVID-19 vaccination efforts began. Overall, the association between income inequality and the COVID-19 mortality rate was more pronounced than the association between income inequality and the COVID-19 infection rate.

Previous studies have documented several pathways through which income inequality can impact population health including spatial

Table 2
Cox proportional hazards regression on having higher COVID-19 infection rates among 74 countries in the sample by the end of 2020 (hazard ratios and 95% CIs).

Covariates	Model 1		Model 2
Gini Index	1.06 (0.98, 1.14)		1.09* (1.01, 1.18)
Population size (in million)	0.99 (0.98, 1.00)		1.00 (0.99, 1.01)
Median age of country population	1.10* (1.02, 1.20)		1.09* (1.00, 1.19)
Population density (population per square kilometers of land area in 2017)			
Low (lower half of the sample)	Reference		Reference
High (higher half of the sample)	2.02+ (0.88, 4.62)		2.16+ (0.89, 5.27)
GDP per capita (in thousands of US$)	1.00 (0.97, 1.05)		0.98 (0.93, 1.03)
Life expectancy (at birth)	1.01 (0.88, 1.16)		1.03 (0.88, 1.21)
Health care expenditures per capita (in hundreds of US$)	1.00 (0.97, 1.03)		1.01 (0.98, 1.04)
Percentage of the population with tertiary education	1.01 (0.99, 1.02)		0.99 (0.98, 1.01)
Direct democracy index	1.57 (0.25, 10.03)		0.47 (0.06, 3.74)
Average stringency index in 2020			
Low (lower half of the sample)			Reference
High (higher half of the sample)			1.15 (0.47, 2.79)
Intensity of COVID-19 Testing (# of COVID-19 tests per 1,000 residents)			
Low (lower half of the sample)			Reference
High (higher half of the sample)			7.74* (1.63, 36.84)
Model Fit Statistics			
Criterion	**Without Covariates**	**With Covariates (Model 1)**	**With Covariates (Model 2)**
−2 LOG L	292.62	261.82	253.82
Testing Global Null Hypothesis: BETA = 0			
Test	**Chi-Square**	**DF**	**P Value**
Likelihood Ratio (Model 1)	30.80	9	<0.001
Likelihood Ratio (Model 2)	38.80	11	<0.001

Notes: +p < 0.1; *p < 0.05; **p < 0.01.

Table 3
Cox proportional hazards regression on having higher COVID-19 mortality rates among 74 countries in the sample by the end of 2020 (hazard ratios and 95% CIs).

Covariates	Model 1		Model 2
Gini Index	1.12** (1.04, 1.21)		1.14** (1.06, 1.23)
Population size (in million)	1.00 (0.99, 1.01)		1.00 (1.00, 1.01)
Median age of country population	1.07+ (1.00, 1.16)		1.14** (1.05, 1.25)
Population density (population per square kilometers of land area in 2017)			
Low (lower half of the sample)	Reference		Reference
High (higher half of the sample)	0.72 (0.31, 1.68)		0.57 (0.24, 1.38)
GDP per capita (in thousands of US$)	1.00 (0.95, 1.06)		1.01 (0.95, 1.08)
Life expectancy (at birth)	1.19* (1.04, 1.37)		1.12 (0.96, 1.30)
Health care expenditures per capita (in hundreds of US$)	1.00 (0.97, 1.03)		1.01 (0.98, 1.04)
Percentage of the population with tertiary education	0.99 (0.98, 1.01)		0.98* (0.96, 1.00)
Direct democracy index	3.05 (0.55, 16.84)		2.50 (0.37, 16.72)
Average stringency index in 2020			
Low (lower half of the sample)			Reference
High (higher half of the sample)			4.54** (1.54, 13.37)
Intensity of COVID-19 Testing (# of COVID-19 tests per 1,000 residents)			
Low (lower half of the sample)			Reference
High (higher half of the sample)			2.46 (0.74, 8.19)
Model Fit Statistics			
Criterion	**Without Covariates**	**With Covariates (Model 1)**	**With Covariates (Model 2)**
−2 LOG L	295.44	256.31	243.81
Testing Global Null Hypothesis: BETA = 0			
Test	**Chi-Square**	**DF**	**P Value**
Likelihood Ratio (Model 1)	39.13	9	<0.001
Likelihood Ratio (Model 2)	51.63	11	<0.001

Notes: +p < 0.1; *p < 0.05; **p < 0.01.

concentration of poverty in economically disadvantaged communities, psychosocial stress resulting from social comparisons and relative deprivation, erosion of social cohesion or social capital, and underinvestment in human resources such as education, health care and other social infrastructure (Alvarez & El-Sayed, 2017; Kondo et al., 2008; Lynch and Kaplan, 1997a; Lynch and Kaplan, 1997b; Smith, 1996; Subramanian & Kawachi, 2004). Residents from economically disadvantaged communities face elevated risks of COVID-19 infections and deaths due to a host of factors including but not limited to crowded living arrangements, lack of access to health services, and disproportionate involvement in sectors with high exposure to COVID-19 infections such as factories, food production and processing, grocery stores, and public transportation (Centers for Disease Control and Prevention, 2020). Studies in the United States consistently showed that racial and ethnic minorities were disproportionately impacted by the COVID-19 pandemic (Karaca-Mandic et al., 2021; Laurencin & McClinton, 2020; Moore et al., 2020; Tai et al., 2021; Williamson et al., 2020).

Income inequality erodes "social cohesion" or "social capital," which in turn impacts health and health behaviors in a society (Subramanian & Kawachi, 2004). Social capital, defined as "social networks, trust, and norms that facilitate coordination and cooperation for mutual benefit", becomes uniquely important when countries around the world are mobilizing national resources and collective efforts to contain and mitigate the COVID-19 pandemic (Putnam, 2000). Part of these efforts include enforcing preventive measures such as wearing a face mask and maintaining physical distance in public spaces. Recent data from the United States revealed a positive association between social capital and wearing a face mask (Hao et al., 2021).

This social capital pathway, also referred to as the "psychosocial interpretation", has been based on the observation that higher levels of income inequality are associated with reduced interpersonal trust, increased anxieties and distress, and disinvestment in social capital (Pearce and Davey Smith, 2003). According to the relative income hypothesis, people's sense of accomplishments and happiness is not so much determined by their absolute level of material wellbeing; instead, they are more related to personal comparisons with other people (Wilkinson, 1997). In societies with severe income inequalities, except for those on the top of the economic ladder, many others will develop a sense of relative deprivation or even chronic stress, which can lead to more divisiveness and alienation in the population and hinder trust building and the formation of social capital (Su et al., 2012). Empirical evidence from the United States revealed a strong association between income inequality and lack of social trust at the state level (Kawachi et al., 1997).

Income inequality might also pose a threat to population health through its adverse influence on the formulation and implementation of general social policies as well as health-related policies (Subramanian & Kawachi, 2004; Wilkinson, 1997). Exceeding levels of income inequality are related to underinvestment in human resources such as education, health care and other social infrastructure (Lynch and Kaplan, 1997a; Lynch and Kaplan, 1997b; Smith,1996). In the U.S., states with higher levels of income inequality are also those that invest less in education and medical care (Kaplan et al., 1996; Lynch and Kaplan, 1997a; Lynch and Kaplan, 1997b; Smith,1996), which eventually will impact the readiness and capacity for the state to respond to the pandemic. Higher levels of income inequality at the county level in the U.S. were associated with worse COVID-19 infection and death rates (Liao & De Maio, 2021).

One unique finding from this study concerns the relevance of COVID-19 testing intensity and the stringency index in explaining differences in reported burden of COVID-19 infections. Not surprisingly, countries with higher level of testing were far more likely to report more infections. The significant, positive association between the stringency index and the COVID-19 mortality rate implies that the implemented public health measures such as mandatory lockdowns and travel restrictions in the included countries might be more in response to a worsening pandemic rather than proactive, preventive measures implemented before pandemic escalations. A more interesting finding is that incorporating these two variables into the analysis actually strengthened the observed association between income inequality and COVID-19 infections. This points to potential underestimates of the association between income inequality and disease burden of COVID-19 in previous studies whereby the intensity of COVID-19 testing or the stringency index was not included in the analysis (Liang et al., 2020; Wildman, 2021).

4.1. Limitations of the study

Several limitations of the study are noteworthy. First, due to data constraints, especially the lack of data on COVID-19 testing intensity for many countries, we were only able to include 74 countries in our analysis. Cautions need to be taken before generalizing our findings to other countries, especially many of the low-income countries that do not report or update statistics on testing for COVID-19.

Secondly, while we cited three potential pathways through which income inequality can impact a country's performance in containing the pandemic (e.g. racial segregation and concentrated poverty, erosion of social capital and public trust, lack of policy support and investment in medical infrastructure and human capital in underserved communities), we did not include direct measures on these pathways in our analysis. Future research can analyze how income inequality is related to specific regulatory responses to the pandemic across countries and public compliance with mandatory or recommended measures for a more in-depth understanding of the revealed association between income inequality and the disease burden of COVID-19.

Finally, the COVID-19 data used in our analysis were updated until the end of 2020. We did not use more recent records in consideration of the influence of COVID-19 vaccination efforts and lack of updated information on this variable for some countries. Future studies can assess the robustness of our findings after incorporating the vaccination rate into the analysis.

5. Conclusions and policy implications

Differences in containing and mitigating COVID-19 across countries have more to do with income distribution in a country than with factors such as the standard of living. This finding elevates the need for addressing severe and persistent income inequalities as an integral part of national strategies when coping with the current and future pandemics. While providing emergency financial assistance and tax relief for low-income residents (as the U.S. and many other countries did during the pandemic) might help with national responses to the pandemic in the short term, these measures are inadequate for addressing the long-term issues associated with severe and persistent income inequalities such as depleted social capital and social cohesion, concentrated poverty, as well as the lack of investment in medical infrastructure and human capital development in underserved communities. Ignoring these challenges will eventually compromise responses to future pandemics for countries that stay on this path.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

6. Appendix

Table A-1: A list and description of the 74 countries included in the study.

Country	Gini Index	COVID-19 Infection Rate (per Million)	COVID-19 Mortality Rate (per Million)	COVID-19 Tests Rate (per Thousand)	OECD Country
Albania	33.2	20264.1	410.4	86.0	No
Argentina	41.4	35966.1	956.8	93.9	No
Australia	34.4	1114.7	35.7	441.6	Yes
Austria	29.7	40062.1	690.8	426.0	Yes
Bangladesh	32.4	3118.1	45.9	19.6	No
Belarus	25.2	20560.6	150.7	415.3	No
Belgium	27.4	55782.4	1685.0	600.9	Yes
Bosnia and Herzegovina	33.0	33828.5	1234.5	156.8	No
Bulgaria	40.4	29109.5	1090.3	165.4	No
Canada	33.3	15484.3	414.2	387.1	Yes
Chile	44.4	31856.4	868.8	337.5	Yes
Colombia	50.4	32285.4	849.3	159.3	Yes

(continued on next page)

(*continued*)

Country	Gini Index	COVID-19 Infection Rate (per Million)	COVID-19 Mortality Rate (per Million)	COVID-19 Tests Rate (per Thousand)	OECD Country
Costa Rica	48.0	33238.6	428.9	84.0	No
Cote d'Ivoire	41.5	852.6	5.2	9.8	No
Croatia	30.4	51357.7	954.9	248.2	No
Cyprus	31.4	25138.7	135.9	1184.7	No
Denmark	28.7	28334.0	224.1	1813.7	Yes
Dominican Republic	43.7	15743.6	222.5	79.3	No
Ecuador	45.4	12045.1	795.4	39.7	No
Estonia	30.4	21100.0	172.6	481.5	Yes
Ethiopia	35.0	1080.9	16.7	15.7	No
Fiji	36.7	54.7	2.2	23.8	No
Finland	27.4	6516.7	101.3	452.2	Yes
Ghana	43.5	1762.7	10.8	21.6	No
Greece	34.4	13321.4	464.2	324.5	Yes
Guatemala	48.3	7703.5	268.7	33.5	No
Hungary	30.6	33385.3	987.2	230.5	Yes
Indonesia	37.8	2717.1	80.9	18.0	No
Ireland	32.8	18587.0	453.0	481.0	Yes
Israel	39.0	48900.7	384.2	968.7	Yes
Italy	35.9	34851.2	1226.5	439.9	Yes
Japan	32.9	1864.5	26.0	35.5	Yes
Jordan	33.7	28863.1	375.8	311.2	No
Kazakhstan	27.5	10715.2	147.0	295.0	No
Kenya	40.8	1793.9	31.1	19.4	No
Latvia	35.6	21685.9	336.7	465.0	Yes
Lithuania	37.3	51640.0	535.6	603.2	Yes
Madagascar	42.6	639.7	9.4	3.6	No
Malaysia	41.0	3491.6	14.6	103.3	No
Mexico	45.4	11060.8	975.8	26.4	Yes
Mongolia	32.7	372.2	0.3	183.3	No
Morocco	39.5	11898.9	200.2	120.8	No
Myanmar	30.7	2290.6	49.3	33.4	No
Namibia	59.1	9422.2	80.7	82.3	No
Nepal	32.8	8943.8	63.7	66.3	No
Netherlands	28.5	47177.6	672.6	302.3	Yes
Nigeria	35.1	425.0	6.3	4.6	No
Norway	27.0	9143.1	80.4	520.4	Yes
Pakistan	33.5	2182.9	46.1	30.3	No
Paraguay	46.2	15132.4	317.1	78.6	No
Peru	42.8	30788.0	1142.8	55.7	No
Philippines	44.4	4326.2	84.4	58.5	No
Poland	29.7	34213.9	754.5	183.4	Yes
Portugal	33.8	40569.8	677.3	557.2	Yes
Romania	36.0	32865.9	819.6	248.3	No
Rwanda	43.7	647.2	7.1	56.0	No
Senegal	40.3	1143.1	24.5	16.6	No
Serbia	36.2	49661.0	471.9	337.5	No
Slovenia	24.2	58757.1	1297.3	359.5	Yes
South Africa	63.0	17824.7	480.0	111.4	No
Spain	34.7	41242.1	1087.3	485.3	Yes
Sri Lanka	39.8	2022.1	9.5	58.4	No
Switzerland	32.7	52260.7	883.3	384.3	Yes
Thailand	36.4	102.6	0.9	23.4	No
Togo	43.1	438.8	8.2	21.6	No
Turkey	41.9	26187.8	247.6	290.6	Yes
Uganda	42.8	769.9	5.5	16.4	No
Ukraine	26.1	24854.9	440.9	127.7	No
United Arab Emirates	32.5	21012.5	67.6	2112.2	No
United Kingdom	34.8	36770.9	1084.5	774.2	Yes
United States	41.1	60345.6	1044.9	761.1	Yes
Uruguay	39.7	5503.9	52.1	184.3	No
Zambia	57.1	1127.3	21.1	32.7	No
Zimbabwe	44.3	933.0	24.4	14.6	No

Table A-2: Cox proportional hazards regression on having higher COVID-19 infection rates in the sample **after removing outliers** (hazard ratios and their 95% confidence intervals; n=69)

Covariates	Model 1	Model 2
Gini Index	1.06 (0.98,1.14)	1.10* (1.02,1.19)
Population size (in million)	0.99 (0.98,1.00)	1.00 (0.99,1.01)

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Covariates	Model 1	Model 2
Median age of country population	1.12* (1.03,1.22)	1.09+ (0.99,1.20)
Population density (population per square kilometers of land area in 2017)		
Low (lower half of the sample)	Reference	Reference
High (higher half of the sample)	1.99 (0.85,4.68)	2.39+ (0.91,6.28)
GDP per capita (in thousands of US$)	1.00 (0.96,1.04)	0.97 (0.93,1.02)
Life expectancy (at birth)	1.01 (0.88,1.15)	1.02 (0.86,1.19)
Health care expenditures per capita (in hundreds of US$)	1.00 (0.97,1.03)	1.01 (0.98,1.04)
Tertiary Education (in percentage of population)	1.00 (0.99,1.02)	1.00 (0.98,1.01)
Direct democracy index	1.08 (0.16,7.16)	0.35 (0.05,2.71)
Average of stringency index for the year 2020		
Low (lower half of the sample)		Reference
High (higher half of the sample)		1.20 (0.46,3.15)
Intensity of COVID-19 Testing (# of COVID-19 tests per 1,000 residents)		
Low (lower half of the sample)		Reference
High (higher half of the sample)		12.00** (2.19,65.84)

Model Fit Statistics			
Criterion	**WithoutCovariates**	**WithCovariates (Model 1)**	**WithCovariates (Model 2)**
-2 LOG L	271.60	242.25	232.26
Testing Global Null Hypothesis: BETA=0			
Test	**Chi-Square**	**DF**	**P Value**
Likelihood Ratio (Model 1)	29.35	9	<.001
Likelihood Ratio (Model 2)	39.34	11	<.001

Notes: +p<0.1; *p<0.05; **p<0.01

Table A-3: Cox proportional hazards regression on having higher COVID-19 Mortality rates in the sample after removing outliers (hazard ratios and 95% confidence intervals; n=69).

Covariates	Model 1	Model 2
Gini Index	1.13** (1.05,1.21)	1.15** (1.06,1.24)
Population size (in million)	1.00 (0.99,1.01)	1.00 (1.00,1.01)
Median age of country population	1.08+ (1.00,1.17)	1.14** (1.04,1.26)
Population density (population per square kilometers of land area in 2017)		
Low (lower half of the sample)	Reference	Reference
High (higher half of the sample)	0.72 (0.29,1.78)	0.59 (0.22,1.56)
GDP per capita (in thousands of US$)	1.00 (0.94,1.06)	1.01 (0.95,1.08)
Life expectancy (at birth)	1.19* (1.04,1.37)	1.12 (0.96,1.31)
Health care expenditures per capita (in hundreds of US$)	1.00 (0.96,1.03)	1.01 (0.97,1.04)
Tertiary Education (in percentage of population)	0.99 (0.97,1.01)	0.98*(0.96,1.00)
Direct democracy index	3.36 (0.57,19.83)	2.84 (0.40,20.05)
Average of stringency index for the year 2020		
Low (lower half of the sample)		Reference
High (higher half of the sample)		4.68** (1.55,14.09)
Intensity of COVID-19 Testing (# of COVID-19 tests per 1,000 residents)		
Low (lower half of the sample)		Reference
High (higher half of the sample)		3.24+ (0.94,11.16)

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Covariates		**Model 1**	**Model 2**
Gini Index		1.13**	1.15**
		(1.05,1.21)	(1.06,1.24)
Population size (in million)		1.00	1.00
		(0.99,1.01)	(1.00,1.01)
Median age of country population		1.08+	1.14**
		(1.00,1.17)	(1.04,1.26)
Population density (population per square kilometers of land area in 2017)			
Low (lower half of the sample)		Reference	Reference
High (higher half of the sample)		0.72	0.59
		(0.29,1.78)	(0.22,1.56)
GDP per capita (in thousands of US$)		1.00	1.01
		(0.94,1.06)	(0.95,1.08)
Life expectancy (at birth)		1.19*	1.12
		(1.04,1.37)	(0.96,1.31)
Health care expenditures per capita (in hundreds of US$)		1.00	1.01
		(0.96,1.03)	(0.97,1.04)
Tertiary Education (in percentage of population)		0.99	0.98*(0.96,1.00)
		(0.97,1.01)	
Direct democracy index		3.36	2.84
		(0.57,19.83)	(0.40,20.05)
Average of stringency index for the year 2020			
Low (lower half of the sample)			Reference
High (higher half of the sample)			4.68**
			(1.55,14.09)
Intensity of COVID-19 Testing (# of COVID-19 tests per 1,000 residents)			
Low (lower half of the sample)			Reference
High (higher half of the sample)			3.24+
			(0.94,11.16)
Model Fit Statistics			
Criterion	**WithoutCovariates**	**WithCovariates (Model 1)**	**WithCovariates (Model 2)**
Model Fit Statistics			
Criterion	**WithoutCovariates**	**WithCovariates (Model 1)**	**WithCovariates (Model 2)**
-2 LOG L	274.51	236.77	223.21
Testing Global Null Hypothesis: BETA=0			
Test	**Chi-Square**	**DF**	**P Value**
Likelihood Ratio (Model 1)	37.74	9	<.001
Likelihood Ratio (Model 2)	51.30	11	<.001

Notes: +p<0.1; *p<0.05; **p<0.01.

References

Alvarez, F.N., El-Sayed, A.M., 2017. National income inequality and ineffective health insurance in 35 low- and middle-income countries. Health Pol. Plann. 32 (4), 487–492. https://doi.org/10.1093/heapol/czw156.

Centers for Disease Control and Prevention. (2020). Introduction to COVID-19 Racial and Ethnic Health Disparities. Retrieved from: https://www.cdc.gov/coronavirus/2019-ncov/community/health-equity/racial-ethnic-disparities/index.html.

Elgar, F.J., Stefaniak, A., Wohl, M.J.A., 2020. The trouble with trust: Time-series analysis of social capital, income inequality, and COVID-19 deaths in 84 countries. Soc. Sci. Med. 263, 113365.

Hale, T., Angrist, N., Goldszmidt, R., Kira, B., Petherick, A., Phillips, T., Webster, S., Cameron-Blake, E., Hallas, L., Majumdar, S., Tatlow, H., 2021. A global panel database of pandemic policies (Oxford COVID-19 Government Response Tracker). Nat. Hum. Behav. 5 (4), 529–538.

Hao, F., Shao, W., & Huang, W. (2021). Understanding the influence of contextual factors and individual social capital on American public mask wearing in response to COVID–19. *Health & Place*, *68*, 102537.

Kaplan, G.A., Pamuk, E.R., Lynch, J.W., Cohen, R.D., Balfour, J.L., 1996. Inequality in income and mortality in the United States: analysis of mortality and potential pathways. BMJ 312 (7037), 999–1003.

Karaca-Mandic, P., Georgiou, A., Sen, S., 2021. Assessment of COVID-19 hospitalizations by race/ethnicity in 12 states. JAMA Int. Med. 181 (1), 131–134.

Kawachi, I., Kennedy, B.P., Lochner, K., Prothrow-Stith, D., 1997. Social capital, income inequality, and mortality. Am. J. Public Health 87 (9), 1491–1498.

Koh D. (2020). COVID-19 lockdowns throughout the world. *Occupational Medicine (Oxford, England)*, kqaa073. https://doi.org/10.1093/occmed/kqaa073.

Kondo, N., Kawachi, I., Subramanian, S.V., Takeda, Y., Yamagata, Z., 2008. Do social comparisons explain the association between income inequality and health?: Relative deprivation and perceived health among male and female Japanese individuals. Soc. Sci. Med. 67 (6), 982–987.

Kondo, N., Sembajwe, G., Kawachi, I., van Dam, R. M., Subramanian, S. V., & Yamagata, Z. (2009). Income inequality, mortality, and self rated health: meta-analysis of multilevel studies. *BMJ (Clinical research ed.)*, *339*, b4471. Doi: 10.1136/bmj.b4471.

Laurencin, C.T., McClinton, A., 2020. The COVID-19 pandemic: a call to action to identify and address racial and ethnic disparities. J. Racial Ethn. Health Dispar. 7 (3), 398–402.

Liang, L.L., Tseng, C.H., Ho, H.J., Wu, C.Y., 2020. Covid-19 mortality is negatively associated with test number and government effectiveness. Sci. Rep. 10 (1), 12567. https://doi.org/10.1038/s41598-020-68862-x.

Liao, T.F., De Maio, F., 2021. Association of Social and Economic Inequality With Coronavirus Disease 2019 Incidence and Mortality Across US Counties. JAMA Network Open 4 (1), e2034578.

Lynch, J.W., Kaplan, G.A., 1997. Understanding how inequality in the distribution of income affects health. J. Health Psychol. 2 (3), 297–314. https://doi.org/10.1177/135910539700200303.

Moore, J.T., Ricaldi, J.N., Rose, C.E., Fuld, J., Parise, M., Kang, G.J., Driscoll, A.K., Norris, T., Wilson, N., Rainisch, G., Valverde, E., Beresovsky, V., Agnew Brune, C., Oussayef, N.L., Rose, D.A., Adams, L.E., Awel, S., Villanueva, J., Meaney-Delman, D., Honein, M.A., Bautista, G., Cowins, J., Edge, C., Grant, G., Gray, R., Griffing, S., Hayes, N., Hughes, L., Lavinghouze, R., Leonard, S., Montierth, R., Palipudi, K., Rayle, V., Ruiz, A., Washington, M., Davidson, S., Dillaha, J., Herlihy, R., Blackmore, C., Troelstrup, T., Edison, L., Thomas, E., Pedati, C., Ahmed, F., Brown, C., Lyon Callo, S., Como-Sabetti, K., Byers, P., Sutton, V., Moore, Z., de Fijter, S., Zhang, A., Bell, L., Dunn, J., Pont, S., McCaffrey, K., Stephens, E., Westergaard, R., 2020. Disparities in incidence of COVID-19 among underrepresented racial/ethnic groups in counties identified as hotspots during June 5–18, 2020–22 states, February–June 2020. Morb. Mortal. Wkly Rep. 69 (33), 1122–1126.

The Lowy Institute. (2021). Covid performance. Retrieved from: https://interactives.lowyinstitute.org/features/covid-performance/.

Johns Hopkins Coronavirus Resource Center, 2022. COVID-19 Data Repository by the Center for Systems Science and Engineering (CSSE) at Johns Hopkins University. https://coronavirus.jhu.edu/ [accessed March 7, 2022].

Oronce, C., Scannell, C.A., Kawachi, I., Tsugawa, Y., 2020. Association Between State-Level Income Inequality and COVID-19 Cases and Mortality in the USA. J. Gen. Intern. Med. 35 (9), 2791–2793. https://doi.org/10.1007/s11606-020-05971-3.

Pearce, N., Davey Smith, G., 2003. Is social capital the key to inequalities in health? Am. J. Public Health 93 (1), 122–129.

Putnam, R.D., 2000. Bowling alone: The collapse and revival of American community. Simon and schuster.

Ritchie, H., Mathieu, E., Rodés-Guirao, L., Appel, C., Giattino, C., Ortiz-Ospina, E., Hasell, J., Macdonald, B., Beltekian, D., & Roser. M. (2020). Coronavirus Pandemic (COVID-19). *Our World in Data [Internet]*. Retrieved from: https://ourworldindata.org/coronavirus.

Roser M., Ritchie H., Ortiz-Ospina E., & Hasell J. (2020). Coronavirus pandemic (COVID-19). *Our world in data [Internet]*. Retrieved from: https://ourworldindata.org/coronavirus.

SAS Institute Inc, 2021. SAS/ACCESS® 9.7 Interface to ADABAS: Reference. SAS Institute Inc., Cary, NC.

Smith, G.D., 1996. Income inequality and mortality: why are they related? BMJ (Clinical research ed.) 312 (7037), 987–988. https://doi.org/10.1136/bmj.312.7037.987.

Statista. (2021a). The Countries Where Vaccination Is Mandatory. Retrieved from: https://www.statista.com/chart/25326/obligatory-vaccination-against-covid-19/.

Statista. (2021b). COVID-19 deaths worldwide per million population as of March 4, 2021, by country. Retrieved from: https://www.statista.com/statistics/1104709/coronavirus-deaths-worldwide-per-million-inhabitants/.

Su, D., Esqueda, O.A., Li, L., Pagán, J.A., 2012. Income inequality and obesity prevalence among OECD countries. J. Biosoc. Sci. 44 (4), 417–432.

Subramanian, S.V., Kawachi, I., 2004. Income inequality and health: what have we learned so far? Epidemiol. Rev. 26, 78–91. https://doi.org/10.1093/epirev/mxh003.

Tai, D. B. G., Sia, I. G., Doubeni, C. A., & Wieland, M. L. (2021). Disproportionate impact of COVID-19 on racial and ethnic minority groups in the United States: a 2021 update. J. Rac. Ethnic Health Dispar., 1-6. Doi: 10.1007/s40615-021-01170-w.

The World Bank. (2020a). Direct democracy. Retrieved from: https://govdata360.worldbank.org/indicators/h9c4b2b74?country=BRA&indicator=41866&viz=line_chart&years=1975,2019.

The World Bank. (2020b). Gini index (World Bank estimate). Retrieved from: https://data.worldbank.org/indicator/SI.POV.GINI.

The World Bank. (2021). School enrollment, tertiary. Retrieved from: https://data.worldbank.org/indicator/SE.TER.ENRR.

Wildman J. (2021). COVID-19 and income inequality in OECD countries. The European journal of health economics: HEPAC: health economics in prevention and care, 22 (3), 455–462. Doi: 10.1007/s10198-021-01266-4.

Wilkinson, R. G. (1997). Socioeconomic determinants of health: Health inequalities: relative or absolute material standards?. *Bmj*, *314*(7080), 591.

Williamson, E.J., Walker, A.J., Bhaskaran, K., Bacon, S., Bates, C., Morton, C.E., Curtis, H.J., Mehrkar, A., Evans, D., Inglesby, P., Cockburn, J., McDonald, H.I., MacKenna, B., Tomlinson, L., Douglas, I.J., Rentsch, C.T., Mathur, R., Wong, A.Y.S., Grieve, R., Harrison, D., Forbes, H., Schultze, A., Croker, R., Parry, J., Hester, F., Harper, S., Perera, R., Evans, S.J.W., Smeeth, L., Goldacre, B., 2020. Factors associated with COVID-19-related death using OpenSAFELY. Nature 584 (7821), 430–436.