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Income inequality and COVID-19 mortality: Age-stratified analysis of 22 OECD countries

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ABSTRACT

Our study builds on a growing body of research that demonstrates an association between income inequality and COVID-19 mortality. Using Poisson multivariate regression, we age-stratify our analysis by separately examining each of four age groups over a nine-month study period in 22 OECD countries. Our full regression model controls for national median income and relative poverty, and a set of pandemic-specific variables to capture exposure, susceptibility and treatment. We found that country-level income inequality, as measured by the disposable income Gini coefficient, is significantly and positively associated with COVID-19 mortality for all four age groups. Consistent with previous studies that analyzed all-cause mortality by age, our regression results found that the point estimate of the Gini coefficient generally declines with age. Our results suggest that inequality is possibly acting through generic and pandemic-specific processes to increase mortality via a more pronounced negative COVID-19 socio-economic status gradient in higher inequality countries.

1. Introduction

COVID-19 has revealed the fault lines in our societies. There is ample national research evidence that being in a lower socio-economic status (SES) group puts individuals at a higher risk of COVID-19 mortality (Chen & Krieger, 2021; Marmot et al., 2020). This study analyzes whether cross-national differences in SES can also influence COVID-19 outcomes, and specifically, the association between national income inequality and national COVID-19 mortality for four age groups.

1.1. Income inequality, population health and COVID-19

Numerous studies have explored the association between country-level income inequality and a series of health outcomes (e.g. see (Pickett & Wilkinson, 2015)). Recent research has explored the association between income inequality and mortality rates for different demographic groups. Based on regression analysis for 21 industrialized countries based on age and gender groups (Torre & Myrskylä, 2014), found that income inequality is significantly associated with higher all-cause mortality for males and females in the 1–14 and 15–49 age groups and to a lesser extent, for females in the 65–89 age group. Also, an empirical meta-analysis (Kim, 2017) found that 19 of the 34 reviewed findings had determined that income inequality was positively and significantly associated with all-cause mortality, with decreasing support from younger to older age groups.

The COVID-19 pandemic provides the opportunity to explore the inequality/mortality association in relation to an infectious disease. We identified three national regression studies examining the association, all conducted within the USA. The results from one study found that State-level income inequality, as measured by the Gini coefficient, was significantly associated with higher COVID-19 mortality rates (Oronce et al., 2020). This result was corroborated by two other studies which found that County-level income inequality was significantly associated with higher COVID-19 mortality rates (Brown & Ravallion, 2020; Mukherji, 2020).

We identified four cross-national regression studies that explored this association. One study used Poisson regression and found that national income inequality, as measured by the Gini coefficient, was significantly associated with higher COVID-19 mortality in 84 (OECD and developing) countries (Elgar et al., 2020). Another study (Wildman, 2021) found a positive and significant association between the Gini coefficient and COVID-19 mortality in 36 OECD countries. Lastly, two broader studies of 141 and 124 (OECD and developing) countries found that income inequality, as measured by the Gini coefficient and relative

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poverty, respectively, was significantly associated with higher COVID-19 mortality (Davies, 2021; IMF, 2021).

1.2. COVID-19 and the three-stage framework

Researchers have developed a three-stage framework to identify three levels at which differences in SES could lead to differential influenza outcomes (Blumenshine et al., 2008). This framework was used to model H1N1 disparities (Quinn et al., 2011) and to understand differences in COVID-19 mortality based on (1) differences in exposure, (2) differences in susceptibility, and (3) differences in access to treatment (Public Health Agency of Canada, 2020). This three-stage framework could help explain how a more pronounced negative COVID-19 SES gradient could lead to higher COVID-19 mortality rates in higher inequality countries.

We used this three-stage framework to help design our study, which set out to explore the inequality/COVID-19 mortality association. Our study design differs in important ways from previous research in this area. First, as age is the most important COVID-19 mortality risk factor (Estiri et al., 2021), we age-stratify our analysis by separately examining each of four age groups. Second, our study period is relatively long – nine months of COVID-19 mortality data for all the 22 OECD study countries. Third, in addition to controlling for median national income, our Poisson regression includes relative poverty, and a set of variables to capture the three-stage framework.

2. Methods

We analyzed the association between income inequality and COVID-19 mortality for each of four age groups over a nine-month (39 weeks) study period for 22 OECD countries. For statistical analysis we selected the Poisson model because it is appropriate for discrete, count data and our data included many zeroes for some age cohorts/countries over the study period. Further, we selected a country-level clustered standard error (SE) specification that, when used with the Poisson model, controls for heteroskedasticity and autocorrelation (Wooldridge, 2010).

2.1. Case selection, COVID-19 deaths and population

To maximize country and data comparability, we restricted our initial universe of countries to the 37 member-states of the OECD. Lack of available inequality and age-specific COVID-19 mortality data excluded seven countries. We set an overall cumulative COVID-19 mortality exposure threshold of 0.5 per 100,000 population to ensure that we had sufficient data points for modelling and set the end of the observation period at January 15, 2021 to ensure that we only included the pre-vaccination phase of the pandemic. To maximize our study period, we set it at 273 days after each country had reached the exposure threshold. These criteria excluded another eight countries; therefore, we included 22 OECD countries in our study, as presented in Fig. 1.

We used the Johns Hopkins dataset for COVID-19 deaths (Johns Hopkins Coronavirus Resource Center, 2021) and OECD data for national population (OECD, 2021). To minimize day-of-the-week variability and reporting irregularities, we applied a locally estimated scatterplot smoothing (LOESS) regression to smooth all mortality series. We estimated COVID-19 mortality for four age groups, at 15–44, 45–64, 65–79 and ≥ 80 years, and these represent an average of 1.23%, 8.76%, 29.57% and 60.40% of mortality (respectively) over the study period. We did not include the 0–14 age group in our analysis because it accounted for only 0.04% of mortality. We selected the age intervals of the groups based on the availability of cumulative age-specific COVID-19 mortality data from national agencies. We selected larger intervals for younger age groups (e.g. 15–44 years) to ensure that we had sufficient data points for modelling purposes.

To present graphically the evolution of mortality for the 273-day study period, Fig. 1 presents the LOESS-smoothed daily mortality rate

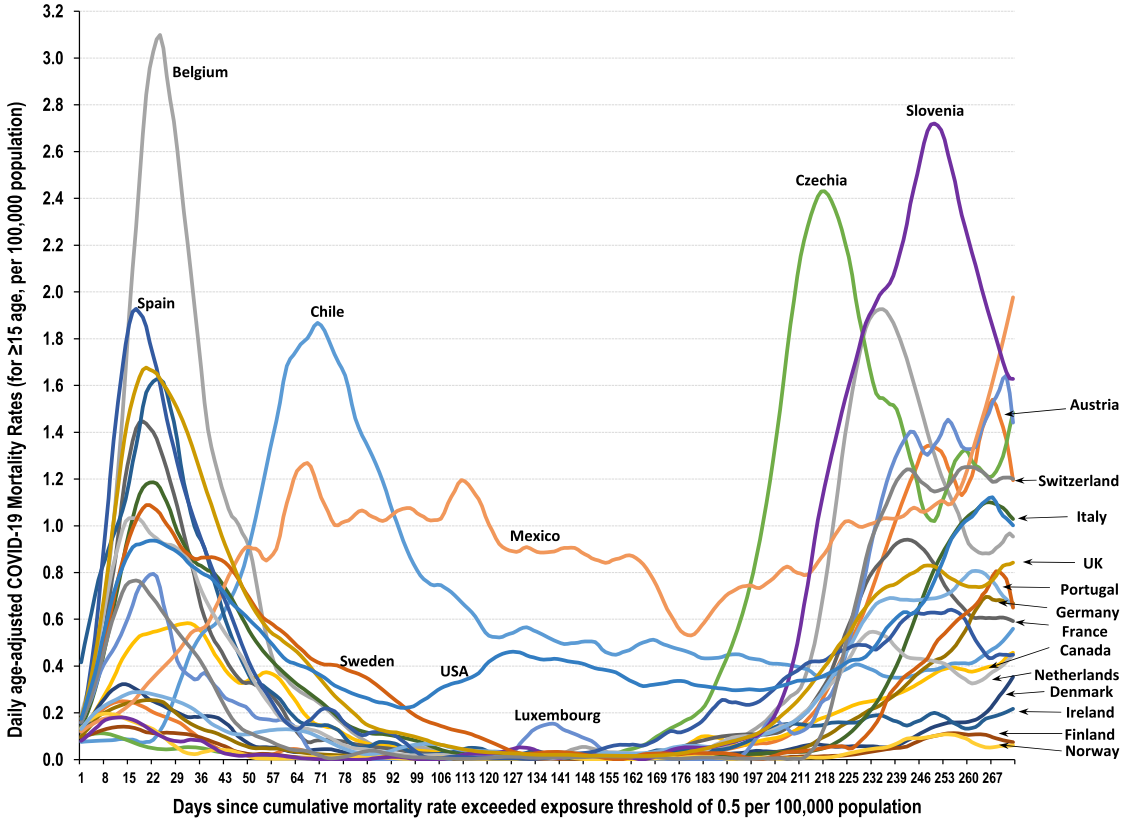

Fig. 1. Daily age-adjusted mortality rate for ≥15 age population per 100,000, after each country has exceeded the exposure threshold criteria.

for the ≥15 age population covering the four age groups. To control for age differences across countries, we age-adjusted the mortality rate presented in Fig. 1 based on the average group weight across the 22 study countries.

2.2. Income inequality, income and other variables

We included variables to capture generic *and* three-stage framework-specific processes that could be expected to influence COVID-19 mortality. We included time fixed effects to control for unobserved characteristics shared by all countries at a specific point in time. Our explanatory variables included data for the most recently-available period, and hence country fixed effects were not feasible due to perfect collinearity with these time-invariant variables.

With respect to generic variables, we sourced income and income inequality data from the OECD (OECD, 2021). Our primary income inequality variable is the disposable income Gini coefficient. Some researchers have posited that inequality and (relative) poverty are dependent but distinct measures and that their conjoint use is appropriate (Rambotti, 2015). To address this, in our Full Model we included a bottom-distribution-weighted inequality measure, the percentage of persons with disposable income below 50% of median income, often referred to as relative poverty, which we sourced from the OECD (OECD, 2021). However, the relative poverty variable is highly correlated with the Gini coefficient and so to avoid multicollinearity, we regressed the relative poverty variable on the Gini coefficient variable and used the resulting relative poverty residuals as the relative poverty variable for our regression analysis. For our national income variable, we used median per capita income in USD PPP. We included three variables to capture the effects of the three-stage framework. For the exposure stage we explored two elements: being able to work from home (WFH), for which we calculated the percentage point difference between the top and bottom income quintile estimates of potential WFH based on industrial classifications (Espinoza & Reznikova, 2020) for each 19 of the 22 study countries and predicted estimates for the three remaining countries (Dingel & Neiman, 2020); and residency in a long term care (LTC) home, for which we calculated the percentage of the ≥80 age population in LTC homes (OECD, 2021). For the susceptibility and treatment stages, we were not able to identify internationally-comparable variables to capture intra-national differences in these stages; a study limitation. As an alternative, we used age-stratified age-group-specific Survival Rates calculated from cohort life tables (UN, 2020) as a joint proxy for these two stages.

In summary, our dataset consists of a balanced panel of daily COVID-19 deaths for 273 days for our 22 study countries. To maximize the number of observations and avoid the "small-N″ regression problem (Kim, 2019), while reducing undue variability, we aggregated daily observations into 7-day periods, making 39 weeks, for a balanced panel of 858 country-weeks for each age group. Our explanatory variables include population-wide (Gini coefficient, median income, residual relative poverty and WFH) and age-group-specific (LTC and Survival Rates) pre-pandemic data. For each age group we apply a Poisson multivariate model, using country-level clustered SEs and time fixed effects. We present two models for each age group, for a total of 8 regressions. The Base Model examines the association between mortality rates and the Gini coefficient and median income. The Full Model adds the residual relative poverty, WFH, LTC and Survival Rate variables.

3. Results

Table 1 presents the descriptive statistics and correlation coefficients for all regression variables. The average mortality rates indicate that COVID-19 has a steep age gradient. Table 2 presents the summary results of the 8 regressions for the Base and Full Models for all four age groups, including coefficient point estimates, country-level clustered SEs and the corresponding significance levels and fit statistics.

Table 1
Descriptive Statistics and Correlation Coefficients of key variables of 22 OECD countries.

		Study Period (273 days)		COVID Mortality (/100,000)				Inequality Variables		Control Variables	Exposure Variables		Survival Rates			
		Start Dates	End Dates	15–44	45–64	65–79	≥80	disp.GINI	rel.POV(res)	Median Income	WFH(Q5-1)	LTC%≥80	15–45	45–65	65–80	80–90
Mean		26-Mar-2020	23-Dec-2020	2.7	30.3	181.4	878.3	0.31	0.0%	$27,725	46%	11.9%	98.0%	91.1%	72.7%	42.9%
StandDev		9.2		4.7	48.4	138.2	436.1	0.06	1.7%	$9,198	10%	4.9%	0.9%	2.0%	4.2%	3.2%
Minimum		8-Mar-2020	5-Dec-2020	0.0	2.1	14.3	108.6	0.24	−2.0%	$6,086	17%	0.8%	94.9%	84.5%	59.7%	34.1%
Maximum		18-Apr-2020	15-Jan-2021	22.5	235.4	654.5	1,943.4	0.46	3.4%	$47,469	61%	19.2%	98.8%	93.6%	78.5%	49.4%
Correlation Coefficients	**15–44**		0.58	1.00				0.76	−0.04	−0.60	−0.75		−0.90			
	45–64		0.58	1.00	1.00			0.75	−0.08	−0.62	−0.75			−0.80		
	65–79		0.43	0.88	0.91	1.00		0.70	0.02	−0.64	−0.71				−0.65	
	≥80		−0.13	0.15	0.18	0.54	1.00	0.15	0.35	−0.14	−0.09	0.09				−0.09

Table 2
Poisson regression of COVID-19 mortality rates in 22 OECD countries. Country-level clustered SE in parantheses. p-value significance level codes: ***:0.001, **:0.01, *:0.05, $^{+}$:0.10.

Dependent Variable:	Base Model				Full Model			
COVID-19 mortality rate (by age group, years)	**15–44**	**45–64**	**65–79**	**≥80**	**15–44**	**45–64**	**65–79**	**≥80**
Regression #	#1	#2	#3	#4	#5	#6	#7	#8
Variables								
Disposable Income GINI	0.130**	0.101**	0.042^{+}	0.008	0.054**	0.065***	0.030^{+}	0.040^{+}
	(0.040)	(0.034)	(0.023)	(0.021)	(0.019)	(0.015)	(0.017)	(0.022)
Median Income (US$PPP)	−0.019	−0.030	−0.026^{+}	−0.005	−0.048**	−0.034*	−0.028	−0.050**
	(0.027)	(0.023)	(0.015)	(0.011)	(0.017)	(0.018)	(0.017)	(0.017)
Relative Poverty (res. to GINI)					0.179***	0.125*	0.121	0.177*
					(0.054)	(0.057)	(0.078)	(0.077)
Work From Home (differentials)					0.019	0.013	0.006	0.019
					(0.021)	(0.023)	(0.021)	(0.017)
% LTC beds of ≥80 age group								0.085**
								(0.032)
Survival Rates					−0.539***	−0.207***	−0.052	−0.049
					(0.098)	(0.059)	(0.033)	(0.032)
Time Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fit Statistics:								
Pseudo R^2	0.227	0.366	0.345	0.417	0.261	0.416	0.368	0.479
AIC	384	1,598	5,636	19,606	376	1,486	5,446	17,558
Observations	858	858	858	858	858	858	858	858

The Base Model shows a positive and statistically significant association between inequality and mortality rate for the 15–44, 45–64 and 65–79 age groups, with 1%, 1% and 10% significance levels, respectively. The size of the disposable income Gini coefficient declines with age, consistent with the results for all-cause mortality (Kim, 2017; Torre & Myrskylä, 2014).

Table 2 shows that adding the residual relative poverty and three-stage framework variables in the Full Model generally reduces the size of the Gini coefficient point estimates, but it remains positive and is now statistically significant for all age groups, including for the ≥80 age group, with 1%, 0.1%, 10% and 10% significance levels, respectively. The national income variable is negative and statistically significant for three of the age groups, suggesting that higher national income is associated with lower COVID-19 mortality rates. The residual relative poverty variable is positive and significant for three age groups, indicating that higher-than-predicted relative poverty, given a country's Gini coefficient, is associated with higher mortality. This result confirms the observation that (relative) poverty and inequality are distinct measures, and that including both variables in our analysis can provide a more comprehensive understanding of the drivers of COVID-19 mortality (Rambotti, 2015). The WFH variable is positive for all age groups but not statistically significant for any, the LTC coefficient is positive and

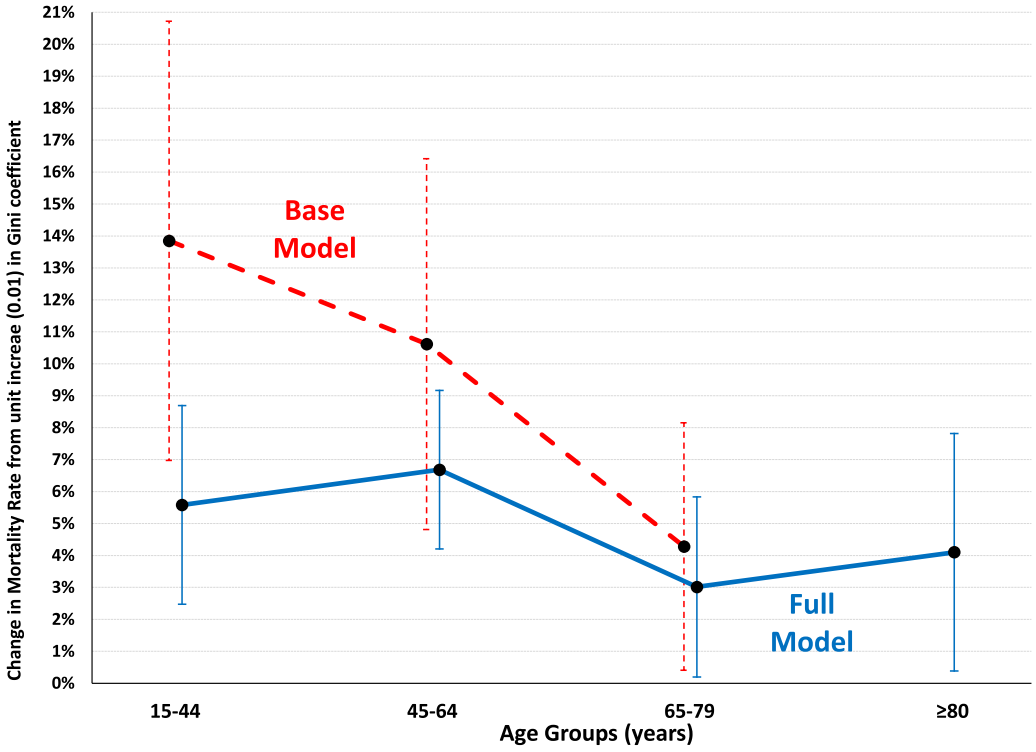

Fig. 2. Base and Full Model regression results for disposable income Gini coefficient estimates at p-value ≤10% statistical significance, by age cohort, transformed values. Error bars represent 90% confidence intervals based on country-level clustered SEs.

significant for the ≥80 age group and the Survival Rates coefficients are negative and statistically significant for the 15–44 and 45–64 age groups.

To be interpretable in unit/percentage impact terms, the coefficient estimates in Table 2 may be transformed using the (Exp(coefficient-1)* 100) formula, which for the Gini coefficient results in the estimates presented in Fig. 2; for the Full Model, a unit (0.01) increase in the Gini coefficient is associated with an average COVID-19 mortality rate increase of 6.1% for the 15–44 and 45–64 age groups and an average increase of 3.6% for the 65–79 and ≥ 80 age groups.

3.1. Robustness, sensitivities and limitations

We undertook a series of robustness checks and sensitivities for our regression results to assess possible data quality or statistical limitations.

We assessed a number of specifications to control for possible heteroskedasticity and autocorrelation. Our initial specification employed time-fixed effects with heteroskedasticity-robust SEs and resulted in the same coefficient values, but with lower SEs, compared to our final specification in Table 2. Most importantly, our key variable, the Gini coefficient, remained significant for the same seven out of eight models (four age groups across Base and Full Models) for both specifications, albeit at different significance levels: five at 0.1% and two at 1% for the initial specification, and one at 0.1% and three at both 1% and 10% for the final specification. Both these specifications support our conclusions. Ideally, the choice between these specifications would take into account the results of an appropriate test; however, we were not able to identify an autocorrelation test for the Poisson model. In the absence of such results, and with the objective of applying the more stringent specification to ensure robust results, we selected the clustered SE as our final specification, as presented in Table 2. To assess period-related robustness, we varied the days aggregated from the base 7-day period to 21- and 273-day periods. The results show the same coefficient values, but with larger SE, consistent with the reduced observations. Noting the study limitation of 15 excluded OECD countries, and to assess country selection robustness, we ran regressions on subsamples of 11 and 16 of the 22 study countries, ranked by inequality and mortality, with the results providing us with reasonable statistical comfort that, were it possible, the inclusion of the excluded 15 countries would not likely alter our general results. With respect to the study period (1–39 weeks) robustness, we ran regressions for weeks 1–13 and weeks 1–26; the Gini coefficient remained positive and significant for all age groups. To check for omitted variables, we undertook numerous sensitivities, including regressions with pandemic-contemporaneous "average period" and/or "early first wave" public health (PH) variables (Fotiou & Lagerborg, 2021; IMF, 2021) as measured by the Containment and Health Index (CHI) from the Oxford COVID-19 Government Response Tracker (OxCGRT) (Hale et al., 2021); the Gini coefficient remained positive for all age groups and was significant for the majority of the sensitivity results. To assess the results without age-stratifying, we pooled the entire population; the Gini coefficient remained positive for both the Base and Full Models, but was not statistically significant for either, highlighting the importance of age-stratification for COVID-19 analysis. Lastly, to test regression model robustness, we ran both Models using ordinary least square (OLS) regression, rather than Poisson regression; the Gini coefficients remained positive and significant.

4. Discussion

Our study of 22 OECD countries revealed important structural variables that were associated with COVID-19 mortality. Most importantly, for our full regression model we found that income inequality is significantly associated with higher COVID-19 mortality ***for all four age groups***, after controlling for a number of variables.

With respect to understanding these results, we consider it unlikely that it is due to data quality issues or statistical modelling limitations. We used variables from the same sources to limit data quality problems. We conducted extensive robustness checks, and controlled for heteroskedasticity and autocorrelation in our statistical model. It is unlikely that our results are due to cross-national differences in relative poverty or age structure, because we controlled for both these in the analysis. We conducted sensitivity analyses, including for average period and/or early first wave public health (PH) variables as measured by the CHI from OxCGRT, to help assess whether such PH measures could explain our results. We found that both PH variables were positively correlated with the Gini coefficient, suggesting that factors other than inequality are primarily driving cross-national variation in PH measures. For instance, one study found that countries with past experience with SARS or MERS outbreaks were more likely to implement successful early first wave PH measures (Fotiou & Lagerborg, 2021). To summarize, it is unlikely that differential contemporaneous PH measures can explain our finding of a statistically significant and positive association between income inequality and COVID-19 mortality.

A credible explanation for our results is that inequality is acting through generic processes and the three-stage framework to produce a more pronounced negative COVID-19 SES gradient in higher inequality countries. In other words, it is possible that a larger proportion of the population in higher inequality countries is at a higher risk of COVID-19 mortality due to higher poverty, higher exposure, more comorbidities, and/or poorer access to treatment. Other research suggests that income inequality may be primarily acting via the exposure stage and secondarily via the susceptibility and treatment stages (Brown & Ravallion, 2020; IMF, 2021).

For the three-stage framework we analyzed the role of two structural exposure elements. Our study found that higher variation in being able to work from home was associated with higher COVID-19 mortality, however these results are not statistically significant. Other studies have shown how essential workers and others who work in sectors that cannot be done from the home are at increased risk of COVID-19 (Dingel & Neiman, 2020). It is possible that this variable, based on potential WFH, was not a good proxy for actual WFH differentials for the 22 study countries during the pandemic, suggesting that contemporaneous cross-national data may be necessary to better capture this effect.

Our study found a statistically significant and positive association between the percentage of the ≥80 age population living in LTC homes and COVID-19 mortality. This finding is consistent with prior research that LTC homes were a major source of mortality (Sepulveda et al., 2020). While the Gini coefficient was not significant in the Base Model, controlling for the proportion of the ≥80 age group that lives in LTC homes made the inequality/COVID-19 mortality association statistically significant for that age group, suggesting that the association was being obscured by the high mortality rates of LTC residents.

For those who have been exposed to the COVID-19 virus, the two other aspects of the three-stage framework are susceptibility and treatment. Higher inequality countries may have a larger proportion of their population at higher risk of COVID-19 mortality due to underlying health conditions that are associated with higher COVID-19 mortality (Ssentongo et al., 2020) and/or who are not able to access quality treatment for COVID-19 (Kanter et al., 2020). Our study indicates that our proxy for the susceptibility and treatment elements, Survival Rates, was significantly associated with lower COVID-19 mortality for the 15–44 and 45–64 age groups.

Our results are based on aggregate national data, and therefore, we cannot assess individual-level associations between inequality and COVID-19 mortality (Gravelle et al., 2002). This is a study limitation that has been noted by other researchers using aggregate data (Oronce et al., 2020; Torre & Myrskylä, 2014; Wildman, 2021). While cross-nationally comparable individual-level income and COVID-19 mortality data are a long-term objective, more granular aggregate data, including cross-nationally comparable SES-stratified COVID-19 data, may be available in the short or medium term. Access to such data would allow researchers, for example, to assess our results and explore

whether higher rates of COVID-19 mortality in higher inequality countries may be explained mostly by proportionately higher mortality across the entire SES ladder, or mostly due to a disproportionately higher mortality rates in lower-SES groups.

5. Conclusion

This study shows the association between a series of structural variables and COVID-19 mortality rates. Consistent with a growing body of research, we find that income inequality, as measured by the disposable income Gini coefficient, is significantly and positively associated with COVID-19 mortality for all four age groups. Our results suggest that it is likely that inequality increases COVID-19 mortality via a more pronounced negative COVID-19 SES gradient in higher inequality countries, possibly because a larger proportion of the population in those countries is at higher risk due to higher poverty, higher exposure, more comorbidities, and/or poorer access to treatment.

For policy analysts and decision-makers the implications of this study are clear; income inequality is associated with higher COVID-19 mortality, and other health conditions. In addition, there are other known deleterious effects of higher income inequality, such as lower economic growth (Ostry et al., 2019), lower educational attainment (IMF, 2021), and lower intergenerational mobility (Corak, 2013).

Declaration of interest statement

The Authors declare no Interest.

Ethical statement

The study is based on publicly available data, and as such it did not require ethical approval.

CRediT authorship contribution statement

Edgardo R. Sepulveda: Conceptualization, Methodology, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration. **Ann-Sylvia Brooker:** Methodology, Resources, Writing – original draft, Writing – review & editing.

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