BMJ Open

Are COVID-19 age-mortality curves for 2020 flatter in developing countries? Evidence from official death counts and excess deaths estimates.

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2022-061589
Article Type:	Original research
Date Submitted by the Author:	31-Jan-2022
Complete List of Authors:	Demombynes, Gabriel; World Bank, Human Development Global Practice de Walque, Damien; World Bank, Development Research Group Gubbins, Paul; World Bank, Human Development Global Practice Urdinola, Piedad ; Universidad Nacional de Colombia - Sede Bogotá, School of Economics Veillard, Jeremy; World Bank Group, Human Development Global Practice
Keywords:	COVID-19, EPIDEMIOLOGY, PUBLIC HEALTH

Are COVID-19 age-mortality curves for 2020 flatter in developing countries? Evidence from official death counts and excess deaths estimates.

Gabriel Demombynes[1], Damien de Walque[2], Paul Gubbins[1],

B. Piedad Urdinola[3], Jeremy Veillard[1]

Keywords: COVID-19, Pandemic, Developing Countries, Mortality

Corresponding author: Damien de Walque, The World Bank, Development Research Group, The World Bank. ddewalque@worldbank.org

Affiliations

1. The World Bank, Human Development Global Practice
2. The World Bank, Development Research Group
3. School of Economics at Universidad Nacional de Colombia-Bogotá

Abstract

Objectives

Previous studies have found a pattern of flatter COVID-19 age-mortality curves among low- and middle-income countries using only official COVID-19 death counts. This study examines this question by comparing the age gradient of COVID-19 mortality in a broad set of countries using both official COVID-19 death counts and excess mortality estimates for 2020.

Design

The analysis uses official COVID-19 death counts for 64 countries and excess death estimates for 41 countries. A standardized population analysis was conducted to assess the extent to which variation across countries in the age distribution of COVID-19 deaths was driven by variation in the population age distribution.

Results

A higher share of pandemic-related deaths in 2020 were at younger ages in middle-income countries compared to high-income countries. People under age 65 constituted on average (1) 11 percent of both official deaths and excess deaths in high-income countries, (2) 40 percent of official deaths and 37 percent of excess deaths in upper-middle-income countries, and (3) 54 percent of official deaths in lower-middle-income countries. These contrasting profiles are due only in part to differences in population age structure.

Conclusions

These findings are driven by some combination of variation in age patterns of infection rates and infection fatality rates. They indicate that COVID-19 is not just a danger to older people in developing countries, where a large share of victims are people of working age, who are caregivers and breadwinners for their families.

Strengths and limitations of this study

- Nearly all studies of the pandemic's age mortality patterns have used only official COVID-19 death data. However, excess deaths at the aggregate population level during the pandemic exceed officially recognized COVID-19 deaths in most countries. It is thus unclear to what extent that flatter age pattern of mortality found in developing countries may have been driven by data reporting issues.
- This study compares the age gradient of COVID-19 mortality in a broad set of countries using both official COVID-19 death counts and excess mortality estimates for 2020. This is to our knowledge the first study that estimates COVID-19 excess mortality by age for a large group of countries.
- This study shows that the same pattern of flatter age mortality curves for developing countries is found using both official COVID-19 death counts and excess mortality estimates, but the available data does not allow ascertaining to what extend the reported differences in the age-specific mortality rates are driven by differences in age-specific cumulative infection rates or in the age-specific cumulative infection fatality rate or both.
- Because of limitations in available mortality data, the analysis includes a large set of high-and-middle income countries but does not include low-income countries.

Introduction

An important question for understanding the global impact of the COVID-19 pandemic is the disease's age pattern of mortality across countries. Early in the pandemic, case data from COVID-19 patients in mainland China showed that COVID-19 mortality risk increases rapidly with age.[1] This risk profile would tend to limit the death toll in developing countries, which generally have younger populations. But this prediction only holds if the age profile of COVID-19 mortality remains similar across countries.

Our study examines this question by comparing the age gradient of COVID-19 mortality in a broad set of countries using both official COVID-19 death counts and excess mortality estimates for 2020. Vaccine availability was very limited before 2021 and therefore is unlikely to affect the mortality patterns identified in this analysis.

Nearly all studies of the pandemic's age mortality patterns have used only official COVID-19 death data.[2–8] However, excess deaths at the aggregate population level during the pandemic exceed officially recognized COVID-19 deaths in most countries.[9] Other studies have used excess mortality estimates but have mainly focused on estimating changes to life-expectancy without examining the age profile of the COVID-19 impacts on mortality[10-12]. This is to our knowledge the first study that estimates COVID-19 excess mortality by age for a wide swath of countries.

Previous studies have found a pattern of flatter COVID-19 age-mortality curves among low- and middle-income countries (LMICs) using only official COVID-19 death counts.[4,8] It was unclear to what extent that finding may have been driven by data reporting issues. In particular, it is possible that deaths among older people in developing countries have been more likely to be under-attributed to the disease in official COVID-19 death counts. This paper addresses that concern by showing that the same pattern is found using both official COVID-19 death counts and excess mortality estimates.

Methods

Data sources

The analysis employs two main sources of data:

1. Official reported COVID-19 deaths drawn from the COVerAGE database, with death counts aggregated to 5-year age-groups.[13]
2. All-cause deaths by age drawn from national vital statistics records, aggregated in the Short-Term Mortality Fluctuations harmonized data series assembled as part of the Human Mortality Database.[14]

Additional all-cause death data from Colombia, Mexico, Brazil and Peru was obtained from national statistical offices. Population by age figures for each country from 2020 were taken from United Nations estimates.[15] A more detailed description of data sources is provided in an annex.

Standardized population

A standardized population analysis was conducted to assess the extent to which variation across countries in the age distribution of COVID-19 deaths was driven by variation in the population age distribution. First age-specific mortality rates were calculated by dividing the number of deaths attributed to COVID-19 for each age group by the population in each age group. These calculations were conducted for the following age groups: under 45, 45-54, 55-64, 65-74, 75-84, 85 and above. A hypothetical age distribution of deaths for each country was calculated by multiplying the age-specific COVID-19 mortality rates by corresponding population shares from the United States. A parallel calculation was carried out using estimates of excess mortality by age.

Excess mortality calculations

Excess mortality methods compare the number of deaths to the number of expected deaths during a period of interest. Excess mortality is often treated as the "gold standard" in analysis of COVID-19 mortality.[16] However, there are two issues that are often overlooked in the analysis of excess mortality.

The first issue is that estimates are sensitive to the choice of method. Many COVID-19 excess mortality calculations have estimated expected deaths as the mean number of deaths over a corresponding period in previous years. If the number of deaths was trending upward in previous years, this common approach will over-estimate excess mortality.

This issue is illustrated in Figure 1 for five Latin American countries. All five countries show an increase in the number of annual deaths over 2015-19. Excess death estimates based on predicting expected 2020 deaths using estimated 2015-19 linear trends (red lines) are shown as "Excess 1." Alternative excess death estimates using a prediction based on the 2015-19 mean death count (blue lines) are shown as "Excess 2." In all cases, ignoring the increase over time and using the historical mean to calculate expected deaths would result in substantial overestimation of excess deaths.

For the analysis in this paper, expected deaths are estimated using a simple regression using 2015-2019 historical data, run separately by country and age-group, where observed deaths are modeled as a linear function of year and an error term.

The second issue often neglected in COVID-19 excess mortality discussions is that excess mortality represents a combination of effects. Specifically,

Net excess deaths =

[Direct COVID-19 deaths] + *[Indirect COVID-19 deaths]* - *[Averted deaths]*

Direct COVID-19 deaths are those due to infection with the virus. *Indirect COVID-19 deaths* are those due in part to factors such as congestion in the health system, delays in care-seeking, or mental health issues caused by the pandemic. *Averted deaths* are those that would have taken place in the absence of the pandemic but did not occur as a result of pandemic-induced measures. These could include deaths due to other infectious diseases, violence, or traffic injuries that were avoided due to voluntary or mandated social distancing. The possibility of non-zero indirect deaths and averted deaths makes the interpretation of excess deaths more complex than is often recognized.

Slope calculation

The shape of an age-mortality curve can be summarized in terms of the percent rate of increase in probability of death per year of additional age after age 45, calculated by fitting a line to the age-specific mortality rates as follows:

$$\log\left(r(x,i)\right) = \alpha_i + \beta_i x$$

where the age-specific mortality rate is $r(x,i) = \frac{D(x,i)}{N(x,i)}$ for the ten-year age group age x to age x + 9, (x = 45, 55, 65, 75, 85) in country i, $D(x,i)$ is the number of deaths in the age group and $N(x,i)$ is the population of the age group in country i.[1] The x = 85 points correspond to the group consisting of all ages 85 and above.

To take into account the varying age structure across countries within this open interval, an adjustment factor based on indirect standardization was calculated. Following Goldstein and Lee (2020)[17], the indirect standardization was calculated using 2020 both-sex mortality from the United States as the standard mortality schedule ${}_5M_x^s$ by three 5-year age groups consisting of ages 85-89, 90-94, and 95-99. We define the share of each population k for each group $c_{x,k}$ such that $1 = \sum_x c_{y,k}$, summing up over the three 5-year age groups and where the shares for the United States age structure are referred to by $c_{x,R}$. The adjustment for population k is as follows:

$$\frac{\sum_x c_{x,R_5}M_x^s}{\sum_x c_{x,k_5}M_x^s}$$

These adjustment factors were multiplied by the observed age-specific COVID-19 mortality rates (and separately the estimated age-specific excess mortality rates) for the open interval 85+.

The coefficients, β_i , are the rates of increase per year of age in probability of death. This calculation was performed first defining $D(x,i)$ in terms of official COVID-19 counts by age for each country for which data was available. The calculation was also performed for each country defining $D(x,i)$ using excess mortality estimates by age as described in the previous section.[2] These results provide 1) the slope of the COVID-19 age-mortality curve according to official counts, and 2) the slope of the age-mortality curve for excess deaths.

Patient and public involvement

The study presents analysis of secondary data. There was no patient and public involvement.

Results

[1] The slope is fitted starting at age 45 because there are few deaths in most countries below age 45.
[2] In cases for which estimated excess deaths were zero or less, the value was coded as 0.001 in order to calculate logarithms.

The left side of Figure 2 shows the age distribution of officially recorded COVID-19 deaths in 2020 by country and the age distribution of excess deaths. According to official reports, on average across high-income countries, just 11 percent of deaths were among those under age 65.[3] In contrast, people under 65 constituted on average 40 percent of official COVID-19 deaths in upper-middle-income countries and 54 percent of deaths in lower-middle-income countries. The same pattern is observed using the distribution of excess deaths by age, shown on the right side of Figure 2. In high-income countries, those under 65 are also 11 percent of excess deaths. For the upper-middle-income countries for which data is available (Peru, Colombia, and Mexico), the age profiles of excess deaths are similar to those of official COVID-19 deaths, and those under age 65 account for on average 37 percent of excess deaths.[4]

Figure 3 shows the hypothetical age distribution of COVID-19 deaths according to official reports, as well as excess deaths, applying the United States standardized age distribution. This controls for the differing population age distributions across countries. Unsurprisingly in low- and middle-income countries, which have younger populations than the United States, the hypothetical distribution shows an older profile of deaths as compared to the actual distribution. However, the pattern of a younger profile of deaths in less wealthy countries remains, both with official data and with excess mortality data. The numbers shown in Figures 2 and 3 can also be found in Appendix Tables A1 and A2.

Notably the United States has a much younger profile of death—using both official COVID-19 death counts and excess mortality—than countries with similar income levels. This is the case even after controlling for differences in population age distribution. The age distribution of deaths in the United States is roughly similar to that of Chile. In both countries, 27 percent of excess deaths were among those under age 65.

Figure 4 presents a visual representation of all the mortality rates by age group across all countries and economies with available data. The vertical axis represents mortality rates per

[3] Note that all countries in Figure 2 from Chile downward with the exception of Turkey on the figure are classified as high-income countries. Turkey is classified as an upper-middle-income country. Bangladesh, India, the Philippines, Jordan, and Indonesia are lower-middle-income countries. World Bank classifications are based on GNI calculated by the Atlas method while the figure uses GNI calculated with purchasing power parity exchange rates.
[4] Data is also available to produce excess death estimates by age for Brazil, but not with our preferred age group breakdown.

100,000, and it is important to note that the scale varies widely across countries, reflecting the different levels of exposure to the pandemic and to its related mortality across the globe. Overall, mortality rates increase with age, albeit with different gradients. With the excess mortality data, a few deviations from this gradient are likely due to the relatively low mortality as well as the overall small number of deaths (e.g. Iceland). Australia, New Zealand and Taiwan, China have close to zero official COVID-19 deaths and show negative estimates of excess mortality rates, especially for the older age groups, likely reflecting averted deaths due to isolation policies.

Figure 5 shows a more detailed comparison of results for five Latin American countries and the United States, using the same log scale for all countries. To add perspective on the extent of COVID-19 related mortality compared to what might have been the mortality experience in the absence of the COVID-19 pandemic, each figure adds in grey the expected all-cause mortality for 2020, based on levels and trends in the 5 preceding years. For each country, the figure also reports the total cumulative deaths for 2020 using both official COVID-19 deaths and excess mortality. Points for the age group 0-14 are not shown because for that age group official COVID-19 death rates are very low and excess mortality rates are negative for all countries shown.

Official COVID-19 death counts are higher than excess-mortality estimates in many cases. This is the case for most age groups in Brazil, the oldest age group in Chile, all but the oldest age group in Peru, and all age groups in Colombia. These patterns indicate that for these country-age group combinations, the number of deaths averted due to the pandemic exceeds the sum of direct and indirect COVID-19 deaths. This could have occurred, for example, because a decline in driving and exposure to violence during lockdowns and a reduction in transmission of other infectious diseases as a result of pandemic precautions.

In Mexico, the mortality estimates using excess deaths is consistently higher than using the official COVID-19 death count, and the gap between both measures increases with age. In the United States, mortality estimates using excess deaths are also higher than using official COVID-19 deaths, but that difference decreases with age and becomes minimal for older age groups. The especially extreme impact of the pandemic in Peru is evident in Figure 5. Among those ages 45-74, both deaths attributed to COVID-19 and excess deaths exceeded total expected all-cause mortality for 2020.

Another notable pattern evident in Figure 5 is the large gap between the two measures for the United States at younger age groups. For the 15-44 age group, the excess death estimate is four times the official COVID-19 death count. Given that testing of patients with COVID-19 symptoms has been widespread in the United States in all but the early stages of the pandemic, the jump in excess mortality among young people most likely reflects indirect COVID-19 deaths.

Figure 6a explores how the slope of the age-mortality gradient for each country varies with its level of income. More precisely, it shows the exponential rate of increase in mortality by age in percent per year starting at age 45 against 2019 GNI per capita (the numbers for the estimated rates of increase are available in Appendix Table A3). The left panel presents this plot for the 64 countries with official COVID-19 deaths data and the right displays the corresponding plot for the 33 countries with excess deaths estimates available for a consistent set of age-groups as follows: 45-54, 55-64, 65-74,75-84, 85+. Using all available data, we find that the increase in mortality risk with each additional year of age above 45 typically ranges (IQR) from 7.9 to 12.2 percent (median = 10.9) using excess deaths and 6.6 to 12.6 percent (median = 9.2) using official deaths.

Both plots show a positive association between income per capita and the age-mortality gradient, indicating that COVID-19 mortality increases more steeply for older age groups in richer countries. Using official death rate data, across countries the rate of increase of mortality risk per year of age rises by 0.14 percent for each US$1,000 of GNI. Using excess mortality data, it rises by 0.21 percent for each US$1,000 of GNI.

To verify that this observed association is not driven by the composition of both sets of countries/economies, Figure 6b repeats the same exercise with the common set of 25 countries/economies. The conclusions taken from Figures 6a and b are similar: COVID mortality is more concentrated among older individuals in richer countries. With the more limited set of countries the gradient is less steep and more consistent between the methods for estimating mortality. Using official death rate data, across countries the rate of increase of mortality risk per year of age rises by 0.12 percent for each US$1,000 of GNI. Using excess mortality data, it rises by 0.10 percent for each US$1,000 of GNI.

Discussion

The age profile of COVID-19 mortality risk in 2020 was flatter (with relatively higher mortality at younger ages) in countries with lower incomes. This pattern is found using official COVID-19 death data from a large set of countries as well as excess mortality from a smaller set of countries which include high-income countries plus Colombia, Mexico, and Peru. Our analysis concerns the year 2020 and is therefore unaffected by the arrival of COVID-19 vaccines and their unequal distribution across countries.

The findings in this paper can provide the basis for a more comprehensive accounting of the impact of COVID-19. For example, the younger mortality profile in developing countries means that in those countries the pandemic has killed large numbers of people who were of working age, many of whom were their families' breadwinners. Earlier global estimates suggest that more than 1.5 million children have experienced the death of at least one caregiver as a consequence of the pandemic.[18] This raises the concern that long-term impacts via lower investments in human capital of orphaned children will be particularly deep in developing countries. This is highly worrisome given the already massive declines in school enrollment and learning losses generated by the pandemic in developing countries.[19–21]

A full understanding of age-specific patterns of excess mortality will require country-by-country analysis using cause-of-death data, where available, to pull apart estimates of direct COVID-19 deaths, indirect COVID-19 deaths, and averted deaths. A brief comparison of Colombia and the United States highlights how components of excess mortality can vary widely by country. In Colombia, both vehicular and homicide deaths fell during the country's lockdown, reducing its excess mortality count. For 2020 vehicular deaths dropped 18.2 percent, and the number of homicides fell 5.4 percent, causing Colombia's murder rate to reach its lowest level since 1979.[22,23] In contrast, the United States excess mortality estimate for 2020 reflects in part a 7.2 percent increase in motor vehicle deaths, a 29.4 percent increase in homicides, and a 30.0 percent spike in drug overdose deaths.[24–26]

Official COVID-19 death reports and excess mortality estimates show broadly similar age patterns country-by-country. This finding, along with the fact that direct COVID-19 deaths account for the large share of excess mortality, suggests that the flatter profile of excess mortality in lower income countries is driven principally by direct COVID-19 deaths. To consider drivers of the direct COVID-19 age pattern it is useful to note that the age-specific mortality rate is the product of the age-specific cumulative infection rate (*IR*) and the age-specific cumulative infection fatality rate (*IFR*). Using the notation employed earlier and where $I(x,i)$ designates the cumulative number of infections of age group *x* in country *i*, this can be expressed as follows:

$$r(x,i) = \frac{D(x,i)}{N(x,i)} = \frac{I(x,i)}{N(x,i)} * \frac{D(x,i)}{I(x,i)}$$

$$= IR(x,i) * IFR\,(x,i)$$

The greater flatness of direct COVID-19 age-specific mortality rates in lower income countries could result from differing patterns across countries by age of *IR*, *IFR*, or both. A number of studies have documented possible contributing factors to variation across countries in overall COVID-19 mortality and those same factors could generate different patterns in mortality by age.[27–31]

The relative IR of younger vs. older people may vary across countries for many reasons. First, in lower income countries, a large share of the population cannot work remotely.[32] Second, in developing countries, a lower share of older people are long-term care facility residents, who are at high risk for infection and death. One-quarter of recognized COVID-19 deaths during the first few months of the pandemic in the United Kingdom were residents of care facilities, and 31 percent of recognized COVID-19 deaths in the United States as of June 1, 2021 were care facility residents or staff.[33,34] Both of these characteristics of developing countries would tend to increase the relative risk of infection for younger people. On the other hand, in low- and middle-income countries, intergenerational households are more common. This means older people are more exposed to infection risk, particularly because in those countries people are more likely to live in crowded conditions. Roughly 20 percent of households in LMICs have at least one household member under age 20 and one over age 60, as compared to just 5 percent in high-income countries.[35] In 54 LMICs with recent Demographic and Health Surveys, just half of the households have no more than two people per sleeping room.[230]

Among those infected, age-specific IFRs may vary by age due to many different factors. One systematic review found that overall IFRs in developing countries are 1.3-2.5 times higher than in high-income countries.[36] Country-level factors like the profile of comorbidities, differences in health system capacity, quality of care, infection prevention and control practices, and availability of personal protective equipment, could have age-specific effects on the IFR .[31,37] A form of survivor bias may be a factor as well. High quality medical care in wealthier countries keeps many older people alive despite weak health conditions that make them vulnerable to COVID-19. It may be that older people in developing countries are on average healthier than those in wealthier countries because those with ailments would have been at high risk for death at younger ages. If this is the case, older people in developing countries might be more resilient to the disease.

Distinguishing various explanations for the observed age patterns of mortality identified in this paper should be a topic for further research. The analysis in this paper is also a reminder of the value of demographic data and in particular vital statistics as a tool amid the COVID-19 crisis. Excess mortality analysis by age presented here is only possible for countries that have well-functioning vital statistics systems and that have made their data widely available. Investments in vital statistics systems and greater data transparency should be encouraged as a global public good.

Acknowledgments

The authors express appreciation to Joshua Goldstein, Young Eun Kim, Ronald D. Lee, Norman Loayza, Andrew Noymer, Robert Oelrichs, Sharon Piza, and Philip Schellekens for helpful suggestions. The findings, interpretations, and conclusions in this paper are entirely those of the authors. They do not necessarily represent the views of the International Bank for Reconstruction and Development/World Bank and its affiliated organizations, or those of the Executive Directors of the World Bank or the governments they represent and are not intended to make any judgment on the legal or other status of geographic areas, or to prejudice the determination of any claims with respect to such area.

Funding

None

Author information

Affiliations

The World Bank, Human Development Global Practice

Gabriel Demombynes (gdemombynes@worldbank.org), Paul Gubbins (paul.gubbins@gmail.com), Jeremy Veillard (jveillard@worldbank.org)

The World Bank, Development Research Group

Damien de Walque (ddewalque@worldbank.org)

School of Economics at Universidad Nacional de Colombia-Bogotá

B. Piedad Urdinola (bpurdinolac@unal.edu.co)

Data availability statement

The data availability section in the online appendix describes the data sources used for this study. Upon acceptance a link to Github repository will be made available to facilitate replication.

Author Contributions

The study and the methodology were conceived by all authors. GD and PG conducted the formal analysis and validated the results. All authors collaborated on writing the paper.

Ethics Declaration

Ethics approval was not sought as the study presents results of an analysis of secondary data and does not involve human participants.

Competing interests

The authors declare no competing interests.

References

1. Verity, R. *et al.* Estimates of the severity of coronavirus disease 2019: a model-based analysis. *Lancet Infect. Dis.* 2020: **20**, 669–677.
2. Sasson, I. Age and COVID-19 mortality: A comparison of Gompertz doubling time across countries and causes of death. *Demogr. Res.* 2021: **44**, 379–396.
3. Sasson, I. Aging and COVID-19 mortality: A demographic perspective. *medRxiv* 2020.
4. Demombynes, G. COVID-19 Age-Mortality Curves Are Flatter in Developing Countries. World Bank Policy Research Working Paper. 2020. 9313.
5. Shapiro, V. COVID-19 Outbreaks and Age Mortality Patterns. 2020.
6. Goldstein, J. R. & Lee, R. D. Demographic perspectives on the mortality of COVID-19 and other epidemics. *Proc. Natl. Acad. Sci.* 2020: **117**, 22035–22041.
7. Sudharsanan, N., Didzun, O., Bärnighausen, T. & Geldsetzer, P. The Contribution of the Age Distribution of Cases to COVID-19 Case Fatality Across Countries: A Nine-Country Demographic Study. *Ann. Intern. Med.* 2020:**173**, 714–720.
8. Chauvin, J. P., Folwer, A. & Herrera, L. N. The Younger Age Profile of Covid-19 Deaths in Developing Countries. 2020. *Washington DC*.
9. Karlinsky, A. & Kobak, D. Tracking excess mortality across countries during the COVID-19 pandemic with the World Mortality Dataset. *Elife* 2021:**10**, e69336.
10. Aburto, J.M., Jonas Schöley, Ilya Kashnitsky, Luyin Zhang, Charles Rahal, Trifon I Missov, Melinda C Mills, Jennifer B Dowd, Ridhi Kashyap, Quantifying impacts of the COVID-19 pandemic through life-expectancy losses: a population-level study of 29 countries, *International Journal of Epidemiology*, 2021,

11. Islam N, Jdanov D A, Shkolnikov V M, Khunti K, Kawachi I, White M et al. Effects of covid-19 pandemic on life expectancy and premature mortality in 2020: time series analysis in 37 countries *BMJ* 2021: 375:e066768

12. Castro, M.C., Gurzenda, S., Turra, C.M. *et al.* Reduction in life expectancy in Brazil after COVID-19. *Nat Med* 2021: **27,** 1629–1635.

13. Riffe, T., Acosta, E., & the COVerAGE-DB team. Data Resource Profile: COVerAGE-DB: a global demographic database of COVID-19 cases and deaths. *Int. J. Epidemiol.* 2021: **50**, 390–390f.

14. Jdanov, D. A. *et al.* The short-term mortality fluctuation data series, monitoring mortality shocks across time and space. *Sci. Data* 2021: **8**, 235.

15. DESA, U. World Population Prospects 2019. United Nations. Department of Economic and Social Affairs. 2019. *World Popul. Prospects 2019*.

16. Beaney, T. *et al.* Excess mortality: the gold standard in measuring the impact of COVID-19 worldwide? *J. R. Soc. Med.* 2020: **113**, 329–334.

17. Goldstein, J. R. & Lee, R. D. Demographic perspectives on the mortality of COVID-19 and other epidemics. *Proc. Natl. Acad. Sci.* 2020: **117**, 22035–22041.

18. Hillis, S. D. *et al.* Global minimum estimates of children affected by COVID-19-associated orphanhood and deaths of caregivers: a modelling study. *The Lancet* 2021: **398**, 391–402.

19. Bundervoet, T., Dávalos, M. E. & Garcia, N. *The Short-Term Impacts of COVID-19 on Households in Developing Countries: An Overview Based on a Harmonized Data Set of High-Frequency Surveys*. The World Bank, 2021. doi:10.1596/1813-9450-9582.

20. Miguel, E. & Mobarak, A. M. The Economics of the COVID-19 Pandemic in Poor Countries. *Annu. Rev. Econ.* 2021 doi:https:// doi.org/10.1146/annurev-economics-051520-025412.

21. Azevedo, J. P., Hasan, A., Goldemberg, D., Geven, K. & Iqbal, S. A. Simulating the potential impacts of COVID-19 school closures on schooling and learning outcomes: A set of global estimates. *World Bank Res. Obs.* 2021: **36**, 1–40.

22. Departamento Administrativo Nacional de Estadística. Cuadros unificados: Defunciones no fetales cifras definitivas 2019. 2020.

23. Departamento Administrativo Nacional de Estadística. Cuadros unificados: Defunciones no fetales acumulado año 2020pr. 2021.

24. National Center for Statistics and Analysis. Early Estimate of Motor Vehicle Traffic Fatalities in 2020. 2021.

25. Krishnakumar, P. Murders rose sharply in 2020 but data is lacking across much of the country. 2021.

26. National Center for Health Statistics. Provisional Drug Overdose Death Counts. 2021.

27. Schellekens, I. G. and P. COVID-19 is a developing country pandemic. *Brookings* https://www.brookings.edu/blog/future-development/2021/05/27/covid-19-is-a-developing-country-pandemic/ (2021).

28. Schellekens, P. & Sourrouille, D. M. COVID-19 Mortality in Rich and Poor Countries: A Tale of Two Pandemics? World Bank Policy Research Working Paper 2020: 9260.

29. Walker, P. G. *et al.* The impact of COVID-19 and strategies for mitigation and suppression in low-and middle-income countries. *Science* 2020: 369, 413–422 2020.

30. Brown, C. S., Ravallion, M. & van de Walle, D. *Can the World's Poor Protect Themselves from the New Coronavirus?* 2020.

31. Ghisolfi, S. *et al.* Predicted COVID-19 fatality rates based on age, sex, comorbidities and health system capacity. *BMJ Glob. Health* 2020: **5**, e003094.

32. Garrote Sanchez, D. *et al.* Who on earth can work from home? 2020.

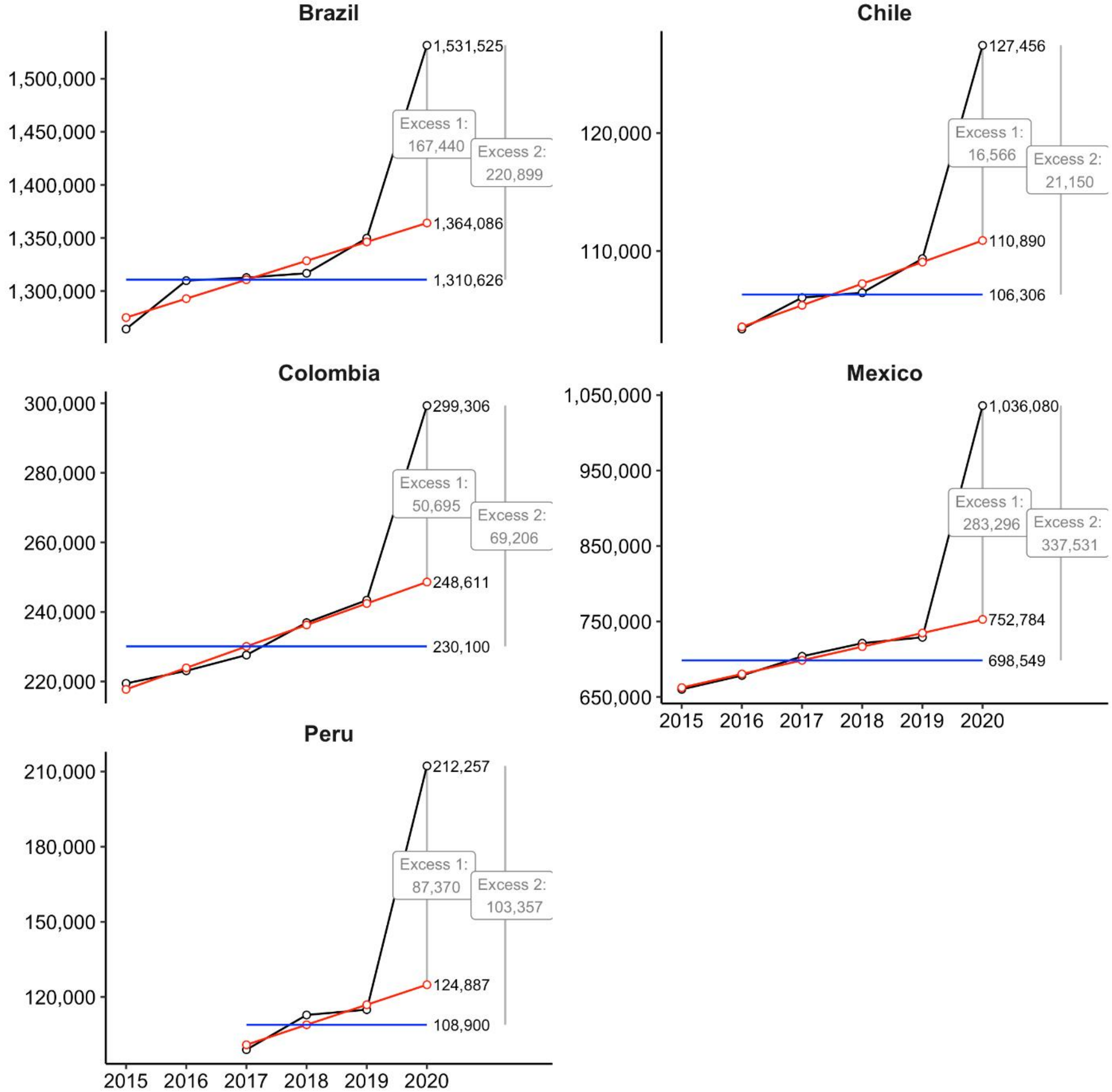
33. Public Health England. *Disparities in the risk and outcomes of COVID-19*. 2020.

34. The New York Times, Nearly One-Third of U.S. Coronavirus Deaths Are Linked to Nursing Homes. *The New York Times*. 2020.

35. Winskill, P. *et al. Report 22: Equity in response to the COVID-19 pandemic: an assessment of the direct and indirect impacts on disadvantaged and vulnerable populations in low-and lower middle-income countries WHO Collaborating Centre for Infectious Disease Modelling MRC Centre for Global Infectious Disease Analysis*. 2020.

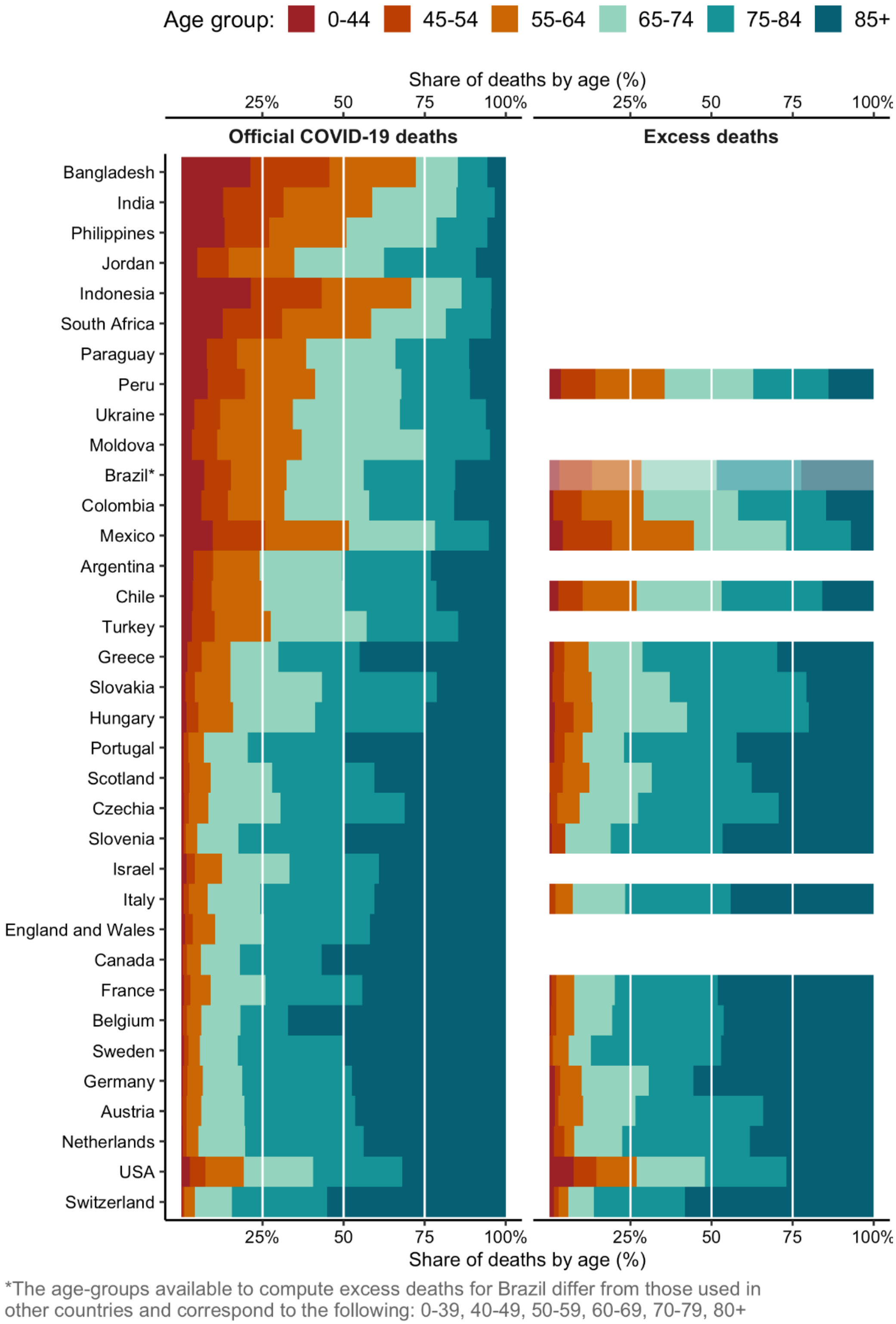
36. Levin, A. *et al.* Assessing the Burden of COVID-19 in Developing Countries: Systematic Review, Meta-Analysis, and Public Policy Implications. *medRxiv* 2021.09.29.21264325 doi:10.1101/2021.09.29.21264325.

37. Nepomuceno, M. R. *et al.* Besides population age structure, health and other demographic factors can contribute to understanding the COVID-19 burden. 2020. *Proc. Natl. Acad. Sci.* **117**, 13881–13883.



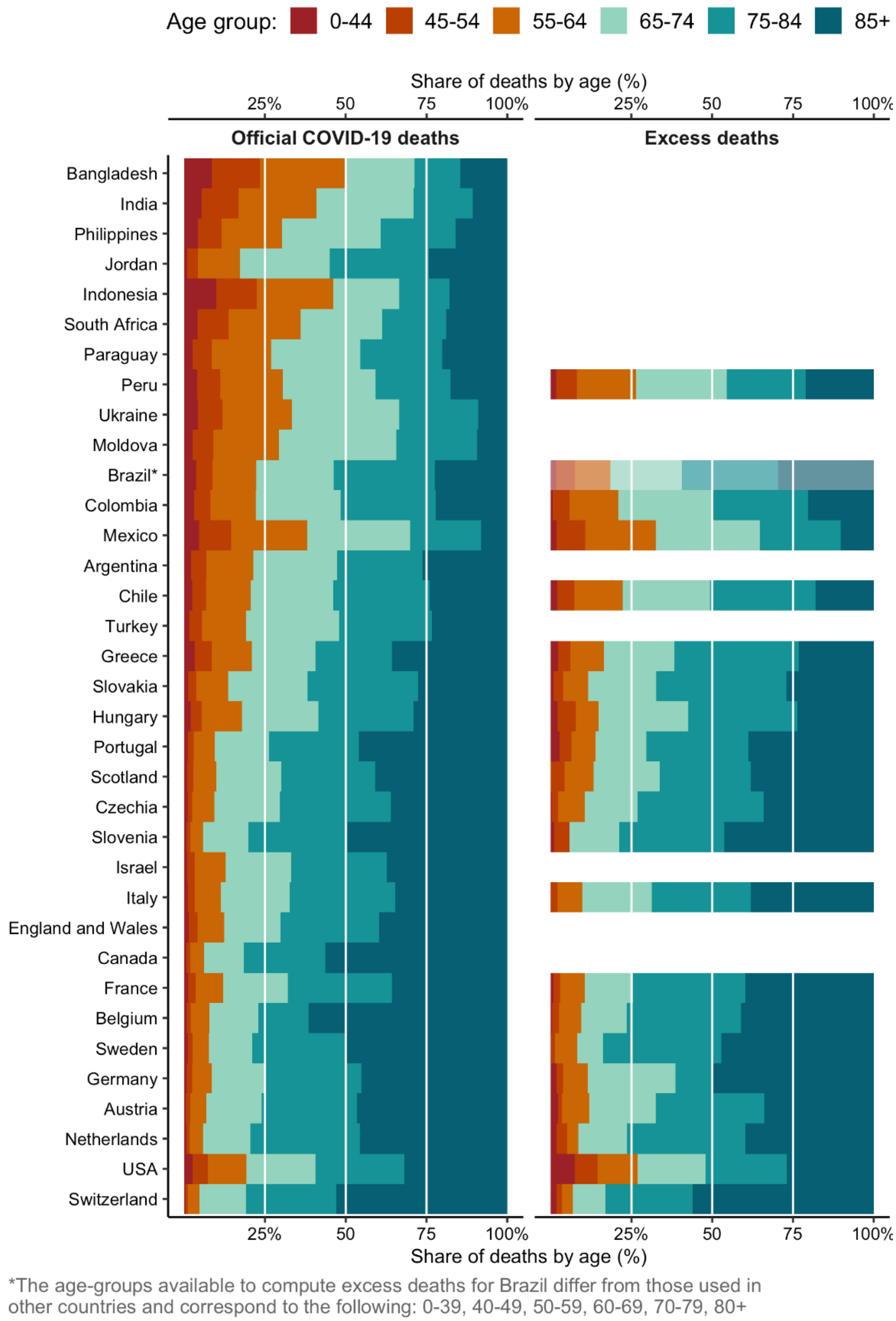
Notes: Actual deaths are shown in black. Predicted deaths based on a linear projection using annual mortality totals 2015-19 are shown in red. Mean deaths 2015-19 are shown in blue.

Figure 1: Actual and predicted total deaths (all causes) by year, select countries



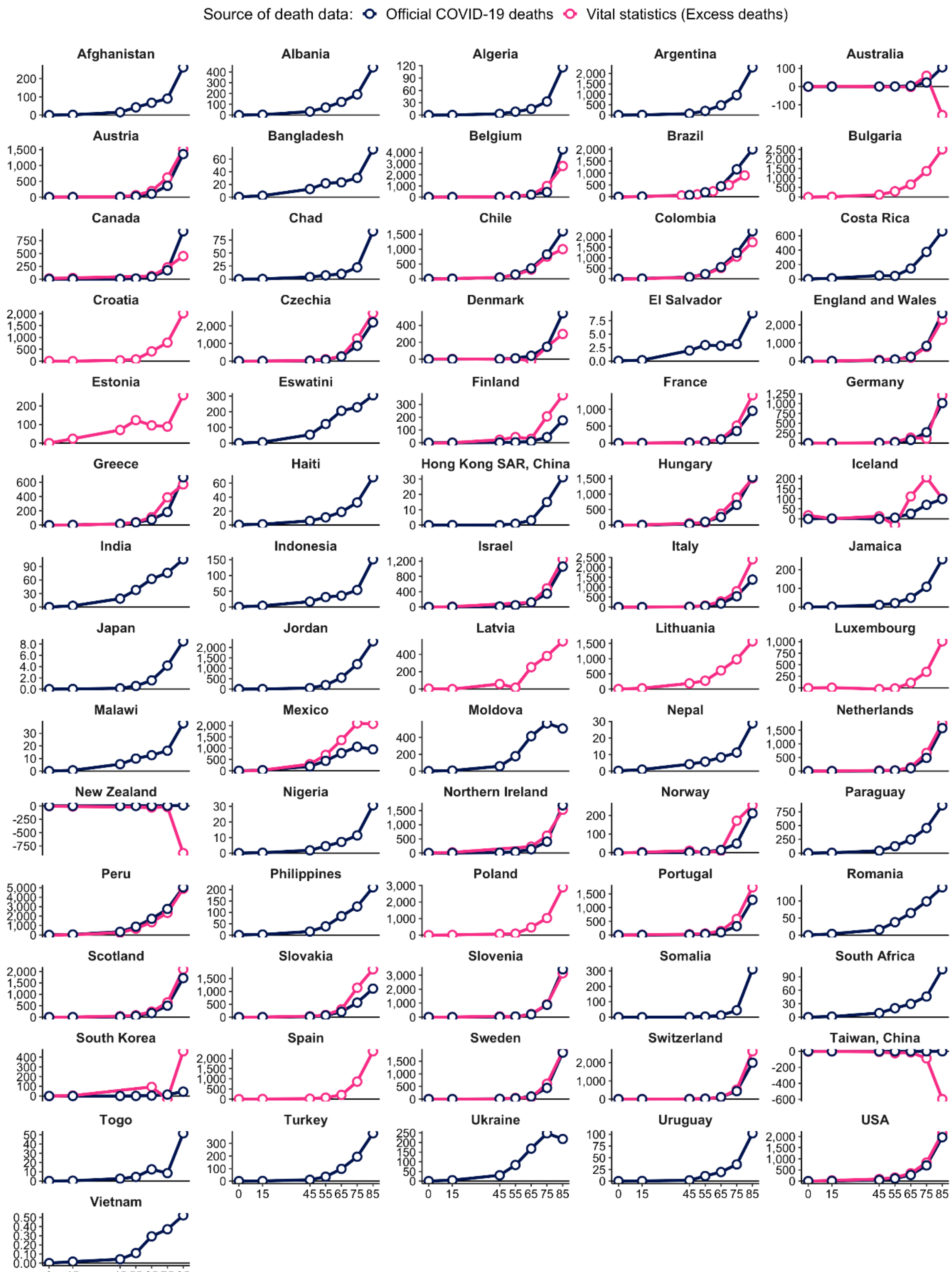
Notes: Countries with fewer than 2000 official COVID-19 deaths are excluded. Country-age group combinations with negative excess deaths are shown as zeroes. Countries are sorted by 2019 GNI per capita (PPP).

Figure 2: Age distribution of official COVID-19 deaths and excess deaths in 2020



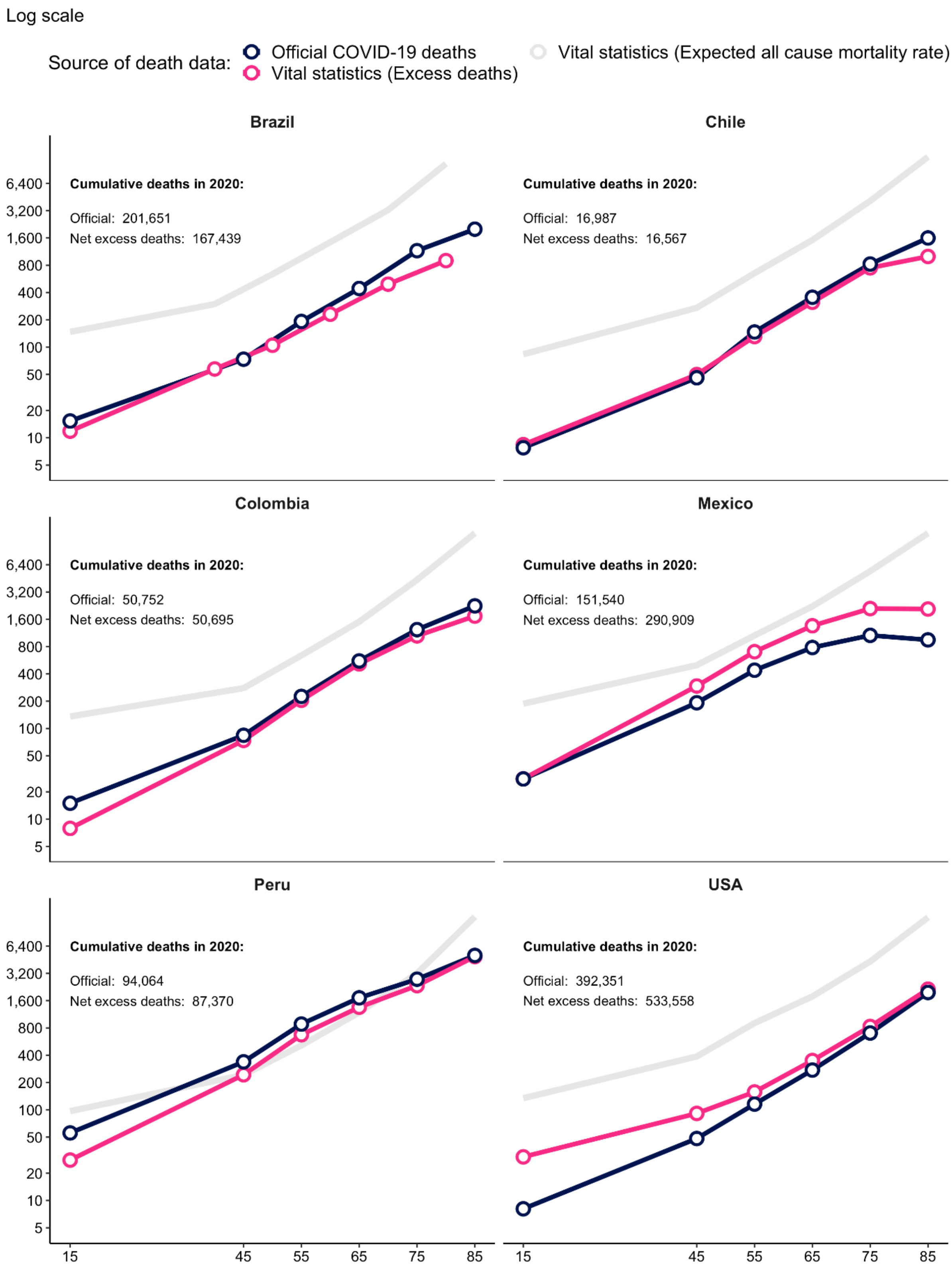
Notes: Countries with fewer than 2000 official COVID-19 deaths are excluded. Country-age group combinations with negative excess deaths are shown as zeroes. Countries are sorted by 2019 GNI per capita (PPP).

Figure 3: Hypothetical age distribution of official COVID-19 and excess deaths in 2020, using country age-specific mortality rates and the US population age distribution



Note: Points are plotted at the start of each age group: 0-14, 15-44,45-54,55-64,65-74,75-84, 85+

Figure 4: Official COVID-19 vs excess deaths by age group (per 100,000 population)



Note: Points are plotted at the start of each age group: 15-44,45-54,55-64,65-74,75-84, 85+.

Figure 5: Official COVID-19 vs excess deaths by age group, select Latin American countries and the United States (per 100,000 population)

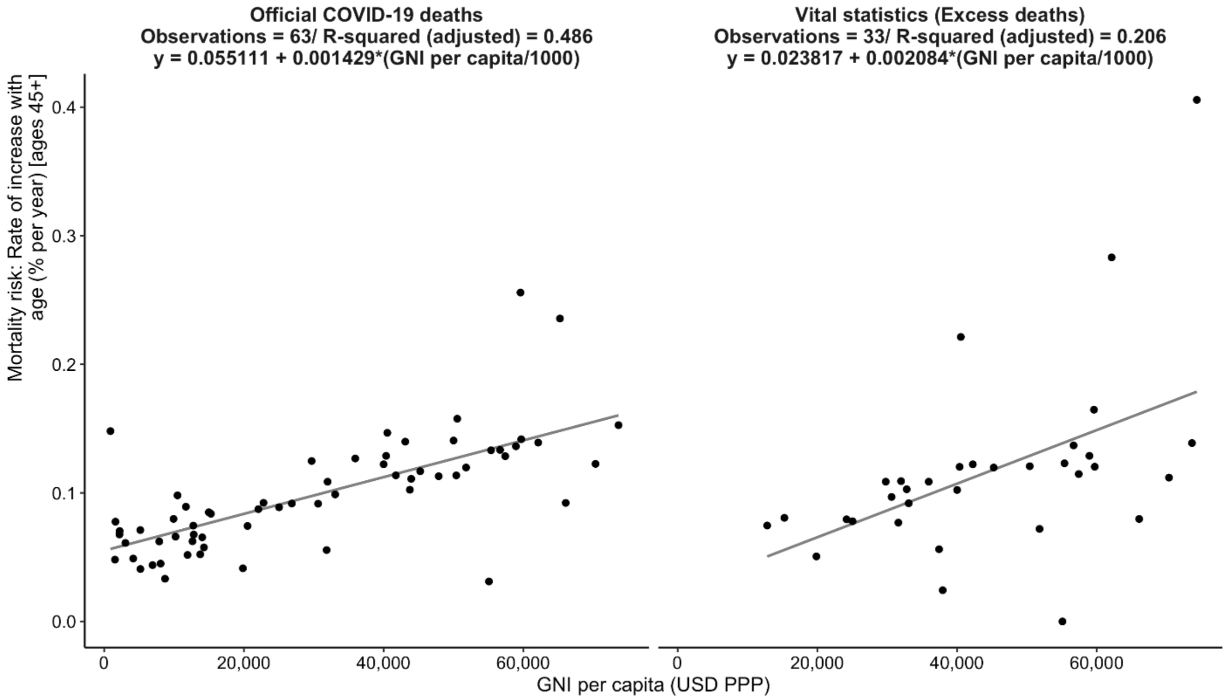


Figure 6: Slope of the age-mortality curve vs GNI per capita, official COVID-19 deaths vs excess deaths, all data

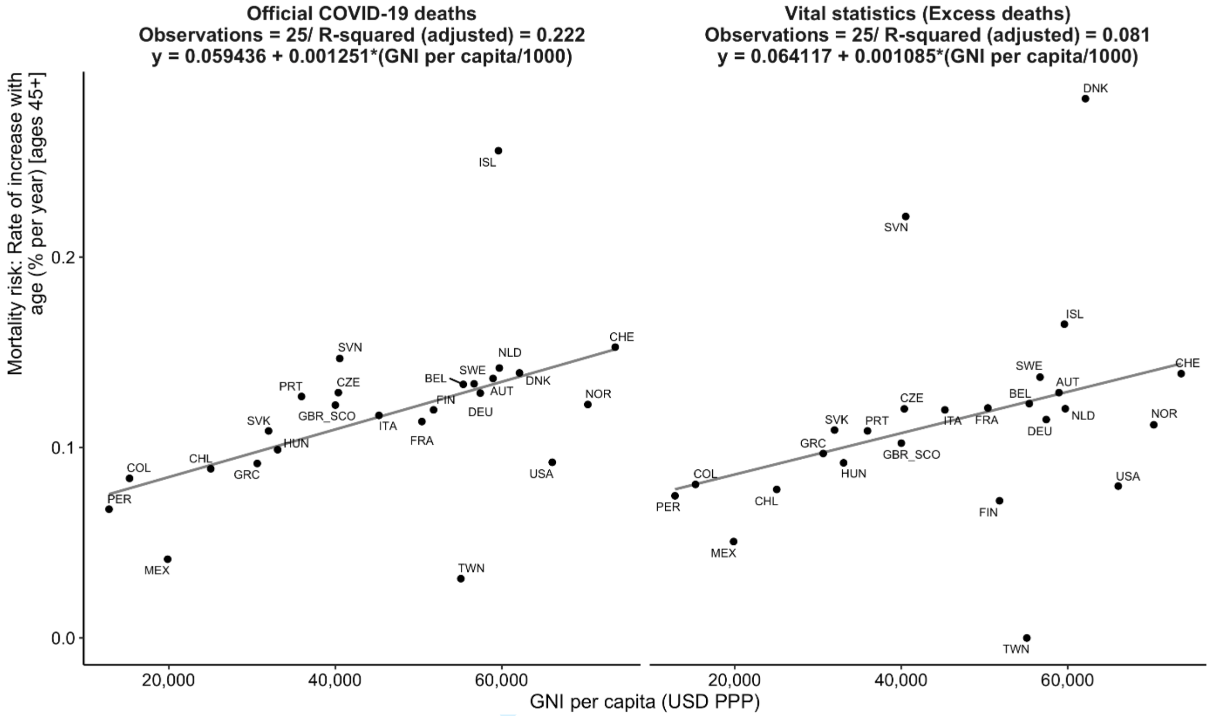


Figure 7: Slope of the age-mortality curve vs GNI per capita, official COVID-19 deaths vs excess deaths, common set of countries/economies

Online Appendix

Data Availability

Data sources

Official reported COVID-19 deaths aggregated in the COVerAGE database For this analysis the output file with death counts aggregated to 5-year age-groups is used.

There are 114 countries in the COVerAGE database (excluding England and United Kingdom). For this analysis, the political units that make up the United Kingdom are treated separately as follows: England and Wales, Scotland, and Northern Ireland.

84 countries have at least one record of cumulative deaths during 2020 or 2021.

64 countries have a record of cumulative deaths that covers at least 6 months since the first case was detected in the country (per case-data derived from Our World in Data). Countries with an "exposure" of less than 6 months as of the end of 2020 are excluded from the analysis.

The following is the set of 64 countries and economies with official reported deaths used in the analysis: Afghanistan; Albania; Algeria; Argentina; Australia; Austria; Bangladesh; Belgium; Brazil; Canada; Chad; Chile; Colombia; Costa Rica; Czechia; Denmark; El Salvador; England and Wales; Eswatini; Finland; France; Germany; Greece; Haiti; Hong Kong SAR, China; Hungary; Iceland; India; Indonesia; Israel; Italy; Jamaica; Japan; Jordan; Malawi; Mexico; Moldova; Nepal; Netherlands; New Zealand; Nigeria; Northern Ireland; Norway; Paraguay; Peru; Philippines; Portugal; Romania; Scotland; Slovak Republic; Slovenia; Somalia; South Africa; Republic of Korea; Spain; Sweden; Switzerland; Taiwan, China; Togo; Turkey; Ukraine; Uruguay; United States; Vietnam.

Excess all-cause deaths from vital statistics records, from the following sources:

Short term mortality fluctuations (STMF) harmonized data series from the Human Mortality Database

- For this analysis; the STMF input files are used. These input files cover 38 countries and economies: Australia; Austria; Belgium; Bulgaria; Canada; Switzerland; Chile; Czech Republic; Germany; Denmark; Spain; Estonia; Finland; France; Northern Ireland;

Scotland; England and Wales; Greece; Croatia; Hungary; Iceland; Israel; Italy; Republic of Korea; Lithuania; Luxembourg; Latvia; Netherlands; Norway; New Zealand; Poland; Portugal; Russian Federation; Slovak Republic; Slovenia; Sweden; Taiwan, China; United States.

- Russia does not have data for 2020.
- Chile and Germany do not have data for 2015.

Colombia vital statistics tabulations (*Defunciones no fetales*) were compiled by DANE. 2019 and 2020 tabulations are preliminary.

Historic (2015-2019) Mexico vital statistics microdata are those compiled (*Defunciones registradas, mortalidad general*) by INEGI, 2020-21 deaths microdata based on death certificates compiled by RENAPO and accessed via the government of Mexico's open data platform.

Peru death certificate microdata were compiled by SINADEF obtained via correspondence with University of Toronto researchers.

Together there are 39 countries and economies with excess death estimates: Austria; Belgium; Bulgaria; Switzerland; Chile; Czech Republic; Germany; Denmark; Spain; Estonia; Finland; France; Scotland; Greece; Croatia; Hungary; Iceland; Italy; Lithuania; Luxembourg; Latvia; Netherlands; Norway; Poland; Portugal; Slovak Republic; Slovenia; Sweden; Taiwan, China; Colombia; Peru; Mexico; England and Wales; United States; Australia; Canada; Israel; Republic of Korea; New Zealand.

Of these, nine do not have corresponding official death records from the coverage database: Bulgaria, Czech Republic, Estonia, Croatia, Lithuania, Luxembourg, Latvia, Poland, Slovak Republic.

The preferred age group categories for the analyses conducted in this paper were as follows: 0-14, 15-44, 45-54, 55-64, 65-74, 75-84, 85+. However, since the reporting of all-cause deaths by age used by the Human Mortality Database is not consistent from country to country (not all countries report death counts tabulated at 5-year intervals or less), successively broader age-groupings are used in cases where the preferred age groups could not be constructed directly from the STMF input data. These countries include the United States, England and Wales, Australia, Canada, New Zealand, Israel, the Republic of Korea, and Northern Ireland. We compute excess mortality rates for all unique country-age group combinations (as shown in Figure 4) but to estimate the age gradient of mortality, we only include countries for which we could construct the preferred age-group categories as described above. Countries for which we could not construct the preferred age-group categories are Brazil, Israel, and New Zealand. To avoid excluding the United States from this analysis, we use mortality data from the CDC which reports deaths for finer age groups for 2015 through 2019.

Annex Table A1: Age Distribution of Official COVID-19 Deaths and Excess Deaths in 2020 (Data Shown in Figure 2)

			Share (%) of official COVID-19 deaths by age group						Share (%) of excess mortality deaths by age group					
Country	**GNI PPP$**	**Group**	0-44	45-54	55-64	65-74	75-84	85+	0-44	45-54	55-64	65-74	75-84	85+
Bangladesh	5190	LMIC	21	24	26	13	9	6						
India	6930	LMIC	13	19	27	26	12	3						
Philippines	10220	LMIC	13	14	24	28	16	6						
Jordan	10500	UMIC	5	10	20	28	28	9						
Indonesia	11940	LMIC	21	22	28	16	9	4						
South Africa	12640	UMIC	13	18	27	23	14	5						
Paraguay	12760	UMIC	8	9	21	27	23	11						
Peru	12820	UMIC	8	11	22	27	21	11	4	11	21	27	23	14
Ukraine	13750	LMIC	4	8	23	33	27	6						
Moldova	14280	LMIC	3	8	26	38	20	5						
Brazil*	14980	UMIC	7	8	17	24	28	16	3	10	15	23	26	22
Colombia	15280	UMIC	6	8	17	26	26	16	1	9	19	29	27	15
Mexico	19860	UMIC	10	16	26	27	17	5	4	15	25	28	20	7
Argentina	22080	HIC	4	6	14	25	28	23						
Chile	25040	HIC	4	6	16	25	29	21	3	7	17	26	31	16
Turkey	26860	UMIC	3	7	17	30	28	15						
Greece	30620	HIC	2	4	9	15	25	45	1	3	7	17	42	30
Slovakia	31980	HIC	1	3	11	28	36	21	1	4	9	24	42	21
Hungary	33070	HIC	2	4	11	25	34	25	2	6	6	29	38	20
Portugal	35940	HIC	1	1	5	14	30	49	2	3	6	13	35	42
Scotland	40000	HIC	1	2	7	19	32	40	0	4	8	19	31	38
Czechia	40360	HIC	1	1	6	22	38	31	0	2	7	18	43	29
Slovenia	40530	HIC	1	1	3	13	33	50	1	4	0	14	34	47
Israel	41750	HIC	1	3	8	21	28	39						
Italy	45240	HIC	1	2	6	16	35	41	0	2	5	16	33	44
England & Wales	47880	HIC	1	3	7	15	33	42	0	0	0	0	0	0
Canada	50010	HIC	0	1	4	12	25	57	0	0	0	0	0	0
France	50400	HIC	1	2	6	17	30	44	1	2	5	12	32	48
Belgium	55370	HIC	0	1	5	12	15	67	0	2	6	12	34	46
Sweden	56670	HIC	1	1	4	12	32	50	0	1	5	7	40	47
Germany	57410	HIC	0	1	5	12	34	47	2	2	7	21	14	56
Austria	58940	HIC	0	1	4	13	34	46	2	1	8	16	39	34
Netherlands	59700	HIC	0	1	4	14	36	44	1	3	3	15	39	38
USA	66060	HIC	3	5	12	21	28	32	7	7	12	21	25	27
Switzerland	73620	HIC	0	1	3	12	29	55	1	1	3	8	28	58

* The age groups available to compute excess deaths for Brazil differ from those used in other countries and correspond to the following: 0-39, 40-49, 50-59, 60-69, 70-79, 80+. GNI is from 2019.

Annex Table A2: Hypothetical Age Distribution of Official COVID-19 and Excess Deaths in 2020, Using Country Age-Specific Mortality Rates and the US Population Age Distribution (Data Shown in Figure 3)

			Share (%) of official COVID-19 deaths by age group						Share (%) of excess mortality deaths by age group					
Country	GNI PPP$	Group	0-44	45-54	55-64	65-74	75-84	85+	0-44	45-54	55-64	65-74	75-84	85+
Bangladesh	5190	LMIC	9	15	26	22	14	15						
India	6930	LMIC	5	11	24	30	18	11						
Philippines	10220	LMIC	4	7	19	31	23	16						
Jordan	10500	UMIC	1	3	13	28	31	24						
Indonesia	11940	LMIC	10	12	24	21	16	18						
South Africa	12640	UMIC	4	10	22	25	20	19						
Paraguay	12760	UMIC	3	6	18	28	25	20						
Peru	12820	UMIC	4	7	19	29	23	18	2	6	18	28	24	21
Ukraine	13750	LMIC	4	8	22	33	25	9						
Moldova	14280	LMIC	3	6	20	36	25	9						
Brazil*	14980	UMIC	4	5	14	24	31	22	2	6	11	22	30	30
Colombia	15280	UMIC	3	5	14	26	29	22	1	5	15	29	30	20
Mexico	19860	UMIC	5	10	24	32	22	8	2	9	22	32	25	10
Argentina	22080	HIC	2	5	14	26	27	26						
Chile	25040	HIC	2	4	14	26	30	24	2	5	15	27	33	18
Turkey	26860	UMIC	2	4	14	29	29	23						
Greece	30620	HIC	3	5	12	20	24	36	2	4	10	22	38	23
Slovakia	31980	HIC	1	2	10	25	34	28	1	3	8	21	40	27
Hungary	33070	HIC	2	3	13	24	30	29	2	6	7	28	34	24
Portugal	35940	HIC	1	2	7	17	28	46	3	4	7	16	32	39
Scotland	40000	HIC	1	2	7	20	29	41	0	4	9	21	28	38
Czechia	40360	HIC	1	1	7	20	34	36	0	2	8	16	39	34
Slovenia	40530	HIC	1	1	4	14	31	49	1	5	0	15	33	46
Israel	41750	HIC	1	2	10	20	30	37						
Italy	45240	HIC	1	2	8	21	33	35	0	2	8	22	31	38
England & Wales	47880	HIC	1	3	8	17	30	40						
Canada	50010	HIC	1	1	4	12	25	56						
France	50400	HIC	1	2	9	20	32	36	1	2	8	15	35	40
Belgium	55370	HIC	1	1	6	15	16	62	0	2	7	14	35	41
Sweden	56670	HIC	1	2	5	13	29	50	0	1	7	8	37	47
Germany	57410	HIC	1	2	6	17	30	45	2	2	8	27	11	50
Austria	58940	HIC	0	1	5	17	29	47	2	1	9	21	34	34
Netherlands	59700	HIC	1	1	4	15	34	46	2	3	3	15	37	40
USA	66060	HIC	3	5	12	21	28	32	7	7	12	21	25	27
Switzerland	73620	HIC	0	1	4	14	28	53	2	2	3	10	27	56

* The age groups available to compute excess deaths for Brazil differ from those used in other countries and correspond to the following: 0-39, 40-49, 50-59, 60-69, 70-79, 80+. GNI is from 2019.

Annex Table A3: Rate of Increase in Risk of Death by Age and Ratio of Mortality Risk Between Age Groups

Country/economy	Official deaths: Exponential rate of increase in risk of death for each year of age	Official deaths: Ratio (MR 75-84/ MR 45-*54*)	Excess deaths: Exponential rate of increase in risk of death for each year of age	Excess deaths: Ratio (MR 75-84/ MR 45-54)
Afghanistan	0.07	6	--	
Albania	0.07	6	--	
Algeria	0.09	11	--	
Argentina	0.09	14	--	
Australia	0.16	104	--	
Austria	0.14	58	0.13	76
Bangladesh	0.04	2	--	
Belgium	0.13	29	0.12	43
Brazil	0.08	16	--	
Bulgaria	--		0.08	12
Canada	0.14	53	--	
Chad	0.08	6	--	
Chile	0.09	18	0.08	15
Colombia	0.08	15	0.08	14
Costa Rica	0.07	8	--	
Croatia	--		0.11	24
Czechia	0.13	62	0.12	49
Denmark	0.14	75	0.28	-
El Salvador	0.03	2	--	
England and Wales	0.11	28	--	
Estonia	--		0.02	1
Eswatini	0.05	4	--	
Finland	0.12	27	0.07	9
France	0.11	34	0.12	43
Germany	0.13	45	0.11	14
Greece	0.09	11	0.10	26
Haiti	0.06	5	--	
Hong Kong SAR, China	0.24	-	--	
Hungary	0.10	22	0.09	15
Iceland	0.26	-	0.16	16
India	0.04	4	--	
Indonesia	0.05	3	--	
Israel	0.11	33	--	
Italy	0.12	40	0.12	39
Jamaica	0.08	9	--	
Japan	0.10	30	--	

Jordan	0.10	24	--	
Latvia	--		0.08	6
Lithuania	--		0.06	5
Luxembourg	--		0.41	-
Malawi	0.05	3	--	
Mexico	0.04	6	0.05	7
Moldova	0.06	10	--	
Nepal	0.05	3	--	
Netherlands	0.14	74	0.12	28
New Zealand	0.11	28	--	
Nigeria	0.07	6	--	
Northern Ireland	0.12	36	--	
Norway	0.12	32	0.11	17
Paraguay	0.07	11	--	
Peru	0.07	8	0.07	10
Philippines	0.07	8	--	
Poland	--		0.10	16
Portugal	0.13	39	0.11	21
Romania	0.06	6	--	
Scotland	0.12	38	0.10	17
Slovak Republic	0.11	34	0.11	34
Slovenia	0.15	81	0.22	18
Somalia	0.15	57	--	
South Africa	0.06	5	--	
Korea, Rep.	0.14	80	--	
Spain	0.12	37	0.12	45
Sweden	0.13	47	0.14	78
Switzerland	0.15	97	0.14	43
Taiwan, China	0.03	1	0.00	15
Togo	0.07	3	--	
Turkey	0.09	18	--	
Ukraine	0.05	8	--	
Uruguay	0.09	20	--	
United States	0.09	15	0.08	9
Vietnam	0.06	9	--	

BMJ Open

Are COVID-19 age-mortality curves for 2020 flatter in developing countries? Evidence from an observational study of official death counts and excess deaths estimates.

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2022-061589.R1
Article Type:	Original research
Date Submitted by the Author:	09-Jun-2022
Complete List of Authors:	Demombynes, Gabriel; World Bank, Human Development Global Practice de Walque, Damien; World Bank, Development Research Group Gubbins, Paul; World Bank, Human Development Global Practice Urdinola, Piedad ; Universidad Nacional de Colombia - Sede Bogotá, School of Economics Veillard, Jeremy; World Bank Group, Human Development Global Practice
Primary Subject Heading:	Infectious diseases
Secondary Subject Heading:	Epidemiology
Keywords:	COVID-19, EPIDEMIOLOGY, PUBLIC HEALTH

Are COVID-19 age-mortality curves for 2020 flatter in developing countries? Evidence from an observational study of official death counts and excess deaths estimates.

Gabriel Demombynes[1], Damien de Walque[2], Paul Gubbins[1],

B. Piedad Urdinola[3], Jeremy Veillard[1]

Keywords: COVID-19, Pandemic, Developing Countries, Mortality

Corresponding author: Damien de Walque, The World Bank, Development Research Group, The World Bank. ddewalque@worldbank.org

Affiliations

1. The World Bank, Human Development Global Practice
2. The World Bank, Development Research Group
3. School of Economics at Universidad Nacional de Colombia-Bogotá

Abstract

Objectives

Previous studies have found a pattern of flatter COVID-19 age-mortality curves among low- and middle-income countries using only official COVID-19 death counts. This study examines this question by comparing the age gradient of COVID-19 mortality in a broad set of countries using both official COVID-19 death counts and excess mortality estimates for 2020.

Design

This observational study uses official COVID-19 death counts for 76 countries and excess death estimates for 42 countries. A standardized population analysis was conducted to assess the extent to which variation across countries in the age distribution of COVID-19 deaths was driven by variation in the population age distribution.

Setting and primary outcomes

Official reported COVID-19 deaths and excess deaths for 2020 for all countries where such data was available in the COVerAGE database and the Short-Term Mortality Fluctuations (STMF) harmonized data series, respectively.

Results

A higher share of pandemic-related deaths in 2020 occurred at younger ages in middle-income countries compared to high-income countries. People under age 65 constituted on average (1) 10 percent of official deaths and 11 percent of excess deaths in high-income countries, (2) 34 percent of official deaths and 33 percent of excess deaths in upper-middle-income countries, and (3) 54 percent of official deaths in lower-middle-income countries. These contrasting profiles are due only in part to differences in population age structure.

Conclusions

These findings are driven by some combination of variation in age patterns of infection rates and infection fatality rates. They indicate that COVID-19 is not just a danger to older people in developing countries, where a large share of victims are people of working age, who are caregivers and breadwinners for their families.

Strengths and limitations of this study

- Nearly all studies of the pandemic's age mortality patterns have used only official COVID-19 death data. However, excess deaths at the aggregate population level during the pandemic exceed officially recognized COVID-19 deaths in most countries.
- This study compares the age gradient of COVID-19 mortality in a broad set of countries using both official COVID-19 death counts and excess mortality estimates for 2020.
- Using a standardized population analysis, this study assesses the extent to which variation across countries in the age distribution of COVID-19 deaths was driven by variation in the population age distribution.
- The available data does not allow ascertaining to what extend the reported differences in the age-specific mortality rates are driven by differences in age-specific cumulative infection rates or in the age-specific cumulative infection fatality rate or both.
- Because of limitations in available mortality data, the analysis includes a large set of high-and-middle income countries but does not include many low-income countries.

Introduction

An important question for understanding the global impact of the COVID-19 pandemic is the disease's age pattern of mortality across countries. Early in the pandemic, case data from COVID-19 patients in mainland China showed that COVID-19 mortality risk increases rapidly with age.[1] This risk profile would tend to limit the death toll in developing countries, which generally have younger populations. But this prediction only holds if the age profile of COVID-19 mortality remains similar across countries.

Our study examines this question by comparing the age gradient of COVID-19 mortality in a broad set of countries using both official COVID-19 death counts and excess mortality estimates for 2020. Vaccine availability was very limited before 2021 and therefore is unlikely to affect the mortality patterns identified in this analysis.

Nearly all studies of the pandemic's age mortality patterns have used only official COVID-19 death data.[2–7] Some of these studies have found a pattern of flatter COVID-19 age-mortality curves among low- and middle-income countries (LMICs) using only official COVID-19 death counts.[4],[7] However, excess deaths at the aggregate population level during the pandemic exceed officially recognized COVID-19 deaths in most countries.[8-10] Other studies have used excess mortality estimates but have mainly focused on estimating changes to life-expectancy without examining the age profile of the COVID-19 impacts on mortality.[11-13] This is to our knowledge the first study that estimates COVID-19 excess mortality by age for a wide swath of countries.

Several studies have highlighted possible contributing factors to variation across countries in overall COVID-19 mortality, including age structure of the population and preexisting health conditions and those same factors could generate different patterns in mortality by age. [14–19] When using only official death counts, it is unclear to what extent the finding of flatter COVID-19 age-mortality curves among low- and middle-income countries (LMICs) may have been driven by data reporting issues. In particular, it is possible that deaths among older people in developing countries have been more likely to be under-attributed to the disease in official COVID-19 death counts. This paper addresses that concern and examines this question by comparing the age gradient of COVID-19 mortality in a broad set of countries using both official COVID-19 death counts and excess mortality estimates for 2020.

Methods

Data sources

The analysis employs two main sources of data:

1. Official reported COVID-19 deaths drawn from the COVerAGE database, with death counts aggregated to 5-year age-groups, downloaded May 16, 2022.[20] 76 countries have a record of cumulative deaths that satisfies the inclusion criteria of covering at least 6 months since the first case was detected in the country (per case-data derived from Our World in Data[21]).
2. All-cause deaths by age drawn from national vital statistics records, aggregated in the Short-Term Mortality Fluctuations harmonized data series assembled as part of the Human Mortality Database, downloaded February 18, 2022 (38 countries).[22], [23]

Additional all-cause death data from Colombia, Mexico, Brazil, Peru and the United States was obtained from national statistical offices. [24-27] Contrary to other COVID mortality estimates such as those released by the World Health Organization, this study does not use modelled data. [9],[10] Population by age figures for each country from 2020 were taken from United Nations estimates.[28] A more detailed description of data sources is provided in an annex.

Standardized population

A standardized population analysis was conducted to assess the extent to which variation across countries in the age distribution of COVID-19 deaths was driven by variation in the population age distribution. First age-specific mortality rates were calculated by dividing the number of deaths attributed to COVID-19 for each age group by the population in each age group. These calculations were conducted for the following age groups: under 45, 45-54, 55-64, 65-74, 75-84, 85 and above. A hypothetical age distribution of deaths for each country was calculated by multiplying the age-specific COVID-19 mortality rates by corresponding population shares from the United States. A parallel calculation was carried out using estimates of excess mortality by age.

Excess mortality calculations

Excess mortality methods compare the number of deaths to the number of expected deaths during a period of interest. Excess mortality is often treated as the "gold standard" in analysis of COVID-19 mortality.[29] However, there are two issues that are often overlooked in the analysis of excess mortality.

The first issue is that estimates are sensitive to the choice of method. Many COVID-19 excess mortality calculations have estimated expected deaths as the mean number of deaths over a corresponding period in previous years. If the number of deaths was trending upward in previous years, this common approach will over-estimate excess mortality. [30], [31]

This issue is illustrated in Figure 1 for five Latin American countries. All five countries show an increase in the number of annual deaths over 2015-19. Excess death estimates based on predicting expected 2020 deaths using estimated 2015-19 linear trends (red lines) are shown as "Excess 1." Alternative excess death estimates using a prediction based on the 2015-19 mean death count (blue lines) are shown as "Excess 2." In all cases, ignoring the increase over time and using the historical mean to calculate expected deaths would result in substantial overestimation of excess deaths.

For the analysis in this paper, expected deaths are estimated using a simple regression using 2015-2019 historical data, run separately by country and age-group, where observed deaths are modeled as a linear function of year and an error term.

The second issue often neglected in COVID-19 excess mortality discussions is that excess mortality represents a combination of effects. Specifically,

Net excess deaths =

[Direct COVID-19 deaths] + [Indirect COVID-19 deaths] - [Averted deaths]

Direct COVID-19 deaths are those due to infection with the virus. *Indirect COVID-19 deaths* are those due in part to factors such as congestion in the health system, delays in care-seeking, or mental health issues caused by the pandemic. *Averted deaths* are those that would have taken place in the absence of the pandemic but did not occur as a result of pandemic-induced measures. These could include deaths due to other infectious diseases, violence, or traffic injuries that were avoided due to voluntary or mandated social distancing. The possibility of non-zero indirect deaths and averted deaths makes the interpretation of excess deaths more complex than is often recognized.

Slope calculation

The shape of an age-mortality curve can be summarized in terms of the percent rate of increase in the mortality rate per year of additional age after age 45, calculated by running a Poisson regression using deaths as response variable and exposures as an offset, fitting a Gompertz (1825) model to the data. [32, 33]

$$D_{x,\ i} \sim Poisson(u_i \theta_i)\ where\ \theta_i = \exp\,(\alpha_i + \ \beta_i X_i)$$

where the age-specific number of deaths is $D_{x,\,i}$ for the ten-year age group age x to age x + 9, (x = 45, 55, 65, 75, 85) in country i. The x = 85 points correspond to the group consisting of all ages 85 and above. To interpret death counts relative to person-years, an exposure term u_i is introduced as an offset in the model as $\log(u_i)$.

The coefficients, β_i , are the rates of increase per year of age in the mortality rate. This calculation was performed first defining $D(x,i)$ in terms of official COVID-19 counts by age for each country for which data was available. The calculation was also performed for each country defining $D(x,i)$ using excess mortality estimates by age as described in the previous section.[1] These results provide 1) the slope of the COVID-19 age-mortality curve according to official counts, and 2) the slope of the age-mortality curve for excess deaths.

Patient and public involvement

The study presents analysis of secondary data. There was no patient and public involvement.

Results

The left side of Figure 2 shows the age distribution of officially recorded COVID-19 deaths in 2020 by country and the age distribution of excess deaths. According to official reports, on

[1] When estimated excess deaths were zero or less, a weight of zero was assigned to such cases.

average across high-income countries, just 10 percent of deaths were among those under age 65.[2] In contrast, people under 65 constituted on average 34 percent of official COVID-19 deaths in upper-middle-income countries and 54 percent of deaths in lower-middle-income countries. The same pattern is observed using the distribution of excess deaths by age, shown on the right side of Figure 2. In high-income countries, those under 65 are 11 percent of excess deaths. For the upper-middle-income countries for which data is available (Peru, Colombia, and Mexico), the age profiles of excess deaths are similar to those of official COVID-19 deaths, and those under age 65 account for on average 33 percent of excess deaths.[3]

Figure 3 shows the hypothetical age distribution of COVID-19 deaths according to official reports, as well as excess deaths, applying the United States standardized age distribution. This controls for the differing population age distributions across countries. Unsurprisingly in low- and middle-income countries, which have younger populations than the United States, the hypothetical distribution shows an older profile of deaths as compared to the actual distribution. However, the pattern of a younger profile of deaths in less wealthy countries remains, both with official data and with excess mortality data. The numbers shown in Figures 2 and 3 can also be found in Appendix Tables A1 and A2.

Notably the United States has a much younger profile of death—using both official COVID-19 death counts and excess mortality—than countries with similar income levels. This is the case even after controlling for differences in population age distribution. The age distribution of deaths in the United States is roughly similar to that of Chile. In both countries, 27 percent of excess deaths were among those under age 65.

Figure 4 presents a visual representation of all the mortality rates by age group across all countries and economies with available data. The vertical axis represents mortality rates per 100,000 on a log scale, and it is important to note that the scale varies across countries, reflecting the different levels of exposure to the pandemic and to its related mortality across the globe.

[2] Note that all countries in Figure 2 from Chile downward with the exception of Turkey on the figure are classified as high-income countries. Turkey is classified as an upper-middle-income country. Bangladesh, India, the Philippines, Jordan, and Indonesia are lower-middle-income countries. World Bank classifications are based on GNI calculated by the Atlas method while the figure uses GNI calculated with purchasing power parity exchange rates.

[3] Data is also available to produce excess death estimates by age for Brazil, but not with our preferred age group breakdown.

Overall, mortality rates increase with age, albeit with different gradients. With the excess mortality data, a few deviations from this gradient are likely due to the relatively low mortality as well as the overall small number of deaths (e.g., Iceland). Australia, New Zealand and Taiwan, China have close to zero official COVID-19 deaths and show negative estimates of excess mortality rates, especially for the older age groups, likely reflecting averted deaths due to isolation policies.

Figure 5 shows a more detailed comparison of results for five Latin American countries and the United States, using the same log scale for all countries. To add perspective on the extent of COVID-19 related mortality compared to what might have been the mortality experience in the absence of the COVID-19 pandemic, each figure adds in grey the expected all-cause mortality for 2020, based on levels and trends in the 5 preceding years. For each country, the figure also reports the total cumulative deaths for 2020 using both official COVID-19 deaths and excess mortality.

Official COVID-19 death counts are higher than excess-mortality estimates in some cases. These patterns indicate that for these country-age group combinations, the number of deaths averted due to the pandemic exceeds indirect COVID-19 deaths. This could have occurred, for example, because a decline in driving and exposure to violence during lockdowns and a reduction in transmission of other infectious diseases as a result of pandemic precautions. Similar to our estimates, dos Santo et al (2021) [34] find for Brazil that total estimated excess mortality in 2020 was below the official COVID-19 death count, reflecting drops in deaths due to violence as well as cardiovascular and infectious diseases.

In Mexico, the mortality estimates using excess deaths is consistently higher than using the official COVID-19 death count, and the gap between both measures increases with age. In the United States, mortality estimates using excess deaths are also higher than using official COVID-19 deaths, but that difference decreases with age and becomes minimal for older age groups. The especially extreme impact of the pandemic in Peru is evident in Figure 5. Among those ages 45-74, both deaths attributed to COVID-19 and excess deaths exceeded total expected all-cause mortality for 2020.

Another notable pattern evident in Figure 5 is the large gap between the two measures for the United States at younger age groups. For the 15-44 age group, the excess death estimate is four times the official COVID-19 death count. Given that testing of patients with COVID-19 symptoms has been widespread in the United States in all but the early stages of the pandemic, the jump in excess mortality among young people most likely reflects indirect COVID-19 deaths.

Figure 6 explores how the slope of the age-mortality gradient for each country varies with its level of income. More precisely, it shows the exponential rate of increase in mortality by age in percent per year against 2019 GNI per capita (the numbers for the estimated rates of increase are available in Appendix Table A3). The right panel presents this plot for the 76 countries with official COVID-19 deaths data and the right displays the corresponding plot for the 34 countries with excess deaths estimates available for a consistent set of age-groups as follows: 45-54, 55-64, 65-74,75-84, 85+. Using all available data, we find that the increase in mortality risk with each additional year of age typically ranges (IQR) from 6.3 to 11.7 percent (median = 9.8) using excess deaths and 5.9 to 11.1 percent (median = 7.6) using official deaths.

Both plots show a positive association between income per capita and the age-mortality gradient, indicating that COVID-19 mortality increases more steeply for older age groups in richer countries. Using official death rate data, across countries the rate of increase of mortality risk per year of age rises by 0.11 percent for each US$1,000 of GNI. Using excess mortality data, it rises by 0.03 percent for each US$1,000 of GNI.

To verify that this observed association is not driven by the composition of both sets of countries/economies, Figure 7 repeats the same exercise with the common set of 28 countries/economies. The conclusions taken from Figures 6 and 7 are similar: COVID mortality is more concentrated among older individuals in richer countries. Using official death rate data, across countries the rate of increase of mortality risk per year of age rises by 0.13 percent for each US$1,000 of GNI. Using excess mortality data, it rises by 0.05 percent for each US$1,000 of GNI.

Discussion

The age profile of COVID-19 mortality risk in 2020 was flatter (with relatively higher mortality at younger ages) in countries with lower incomes. This pattern is found using official COVID-19 death data from a large set of countries as well as excess mortality from a smaller set of countries which include high-income countries plus Colombia, Mexico, and Peru. Our analysis concerns the year 2020 and is therefore unaffected by the arrival of COVID-19 vaccines and their unequal distribution across countries.

One limitation of this study is that the available data does not allow ascertaining to what extent the reported differences in the age-specific mortality rates are driven by differences in age-specific cumulative infection rates or in the age-specific cumulative infection fatality rate or both. Further, because of limitations in available mortality data, the analysis includes a large set of high-and-middle income countries but does not include many low-income countries. Finally, we acknowledge that, even as we used excess mortality measures to address the concern of under-reporting of official COVID-19 deaths, all causes mortality itself could also be underreported in some countries and that the extent of underreporting might vary across countries. This would however affect our analysis only to the extent that the underreporting of all causes mortality was affected by the COVID pandemic.

The findings in this paper can provide the basis for a more comprehensive accounting of the impact of COVID-19. For example, the younger mortality profile in developing countries means that in those countries the pandemic has killed large numbers of people who were of working age, many of whom were their families' breadwinners. Earlier global estimates suggest that more than 1.5 million children have experienced the death of at least one caregiver as a consequence of the pandemic.[35] This raises the concern that long-term impacts via lower investments in human capital of orphaned children will be particularly deep in developing countries. This is highly worrisome given the already massive declines in school enrollment and learning losses generated by the pandemic in developing countries.[36–38]

A full understanding of age-specific patterns of excess mortality will require country-by-country analysis using cause-of-death data, where available, to pull apart estimates of direct COVID-19 deaths, indirect COVID-19 deaths, and averted deaths. A brief comparison of Colombia and the United States highlights how components of excess mortality can vary widely by country. In Colombia, both vehicular and homicide deaths fell during the country's lockdown, reducing its excess mortality count. For 2020 vehicular deaths dropped 18.2 percent, and the number of homicides fell 5.4 percent, causing Colombia's murder rate to reach its lowest level since 1979.[39,40] In contrast, the United States excess mortality estimate for 2020 reflects in part a 7.2

percent increase in motor vehicle deaths, a 29.4 percent increase in homicides, and a 30.0 percent spike in drug overdose deaths.[41–43]

Official COVID-19 death reports and excess mortality estimates show broadly similar age patterns country-by-country. This finding, along with the fact that direct COVID-19 deaths account for the large share of excess mortality, suggests that the flatter profile of excess mortality in lower income countries is driven principally by direct COVID-19 deaths. To consider drivers of the direct COVID-19 age pattern it is useful to note that the age-specific mortality rate is the product of the age-specific cumulative infection rate (*IR*) and the age-specific cumulative infection fatality rate (*IFR*). Using a notation where $N(x,i)$ is the population of the age group in country *I*, $D(x,i)$ is the number of deaths in the age group, and $I(x,i)$ designates the cumulative number of infections of age group *x* in country *i*, this can be expressed as follows:

$$r(x,i) = \frac{D(x,i)}{N(x,i)} = \frac{I(x,i)}{N(x,i)} * \frac{D(x,i)}{I(x,i)}$$

$$= IR(x,i) * IFR\,(x,i)$$

The greater flatness of direct COVID-19 age-specific mortality rates in lower income countries could result from differing patterns across countries by age of *IR*, *IFR*, or both. A number of studies have documented possible contributing factors to variation across countries in overall COVID-19 mortality and those same factors could generate different patterns in mortality by age.[14–18]

The relative IR of younger vs. older people may vary across countries for many reasons. First, in lower income countries, a large share of the population cannot work remotely.[44] Second, in developing countries, a lower share of older people are long-term care facility residents, who are at high risk for infection and death. One-quarter of recognized COVID-19 deaths during the first few months of the pandemic in the United Kingdom were residents of care facilities, and 31 percent of recognized COVID-19 deaths in the United States as of June 1, 2021 were care facility residents or staff.[45,46] Both of these characteristics of developing countries would tend to increase the relative risk of infection for younger people. On the other hand, in low- and middle-income countries, intergenerational households are more common. This means older people are more exposed to infection risk, particularly because in those countries people are more likely to live in crowded conditions. Roughly 20 percent of households in LMICs have at least one household member under age 20 and one over age 60, as compared to just 5 percent in high-income countries.[47] In 54 LMICs with recent Demographic and Health Surveys, just half of the households have no more than two people per sleeping room.[17]

Among those infected, age-specific IFRs may vary by age due to many different factors. One systematic review found that age-specific IFRs in developing countries were roughly 2 times higher than in high-income countries.[48] Country-level factors like the profile of comorbidities, differences in health system capacity, quality of care, infection prevention and control practices, and availability of personal protective equipment, could have age-specific effects on the IFR.[18,49] A form of survivor bias may be a factor as well. High quality medical care in wealthier countries keeps many older people alive despite weak health conditions that make them vulnerable to COVID-19. It may be that older people in developing countries are on average healthier than those in wealthier countries because those with ailments would have been at high risk for death at younger ages. If this is the case, older people in developing countries might be more resilient to the disease.

Distinguishing various explanations for the observed age patterns of mortality identified in this paper should be a topic for further research. The analysis in this paper is also a reminder of the value of demographic data and in particular vital statistics as a tool amid the COVID-19 crisis. Excess mortality analysis by age presented here is only possible for countries that have well-functioning vital statistics systems and that have made their data widely available. Investments in vital statistics systems and greater data transparency should be encouraged as a global public good.

Acknowledgments

The authors express appreciation to Joshua Goldstein, Young Eun Kim, Ronald D. Lee, Norman Loayza, Andrew Noymer, Robert Oelrichs, Sharon Piza, and Philip Schellekens for helpful suggestions. The findings, interpretations, and conclusions in this paper are entirely those of the authors. They do not necessarily represent the views of the International Bank for Reconstruction and Development/World Bank and its affiliated organizations, or those of the Executive Directors of the World Bank or the governments they represent and are not intended to make any judgment on the legal or other status of geographic areas, or to prejudice the determination of any claims with respect to such area.

Funding

None

Author information

Affiliations

The World Bank, Human Development Global Practice

Gabriel Demombynes (gdemombynes@worldbank.org), Paul Gubbins (paul.gubbins@gmail.com), Jeremy Veillard (jveillard@worldbank.org)

The World Bank, Development Research Group

Damien de Walque (ddewalque@worldbank.org)

School of Economics at Universidad Nacional de Colombia-Bogotá

B. Piedad Urdinola (bpurdinolac@unal.edu.co)

Data availability statement

The data availability section in the online appendix describes the data sources used for this study. Upon acceptance a link to Github repository will be made available to facilitate replication.

Author Contributions

The study and the methodology were conceived by GD, DdW, PG, BPU and JV. GD and PG conducted the formal analysis and validated the results. GD, DdW, PG, BPU and JV collaborated on writing the paper.

Ethics Declaration

Ethics approval was not sought as the study presents results of an analysis of secondary data and does not involve human participants.

Competing interests

The authors declare no competing interests.

References

1. Verity, R. *et al.* Estimates of the severity of coronavirus disease 2019: a model-based analysis. *Lancet Infect. Dis.* 2020: **20**, 669–677.
2. Sasson, I. Age and COVID-19 mortality: A comparison of Gompertz doubling time across countries and causes of death. *Demogr. Res.* 2021: **44**, 379–396.
3. Demombynes, G. COVID-19 Age-Mortality Curves Are Flatter in Developing Countries. World Bank Policy Research Working Paper. 2020. 9313.
4. Shapiro, V. COVID-19 Outbreaks and Age Mortality Patterns. 2020.
5. Goldstein, J. R. & Lee, R. D. Demographic perspectives on the mortality of COVID-19 and other epidemics. *Proc. Natl. Acad. Sci.* 2020: **117**, 22035–22041.
6. Sudharsanan, N., Didzun, O., Bärnighausen, T. & Geldsetzer, P. The Contribution of the Age Distribution of Cases to COVID-19 Case Fatality Across Countries: A Nine-Country Demographic Study. *Ann. Intern. Med.* 2020:**173**, 714–720.
7. Chauvin, J. P., Folwer, A. & Herrera, L. N. The Younger Age Profile of Covid-19 Deaths in Developing Countries. 2020. *Washington DC*.
8. Karlinsky, A. & Kobak, D. Tracking excess mortality across countries during the COVID-19 pandemic with the World Mortality Dataset. *Elife* 2021:**10**, e69336.
9. World Health Organization. Global excess deaths associated with COVID-19 (modelled estimates). May 5, 2022 Update. https://www.who.int/data/sets/global-excess-deaths-associated-with-covid-19-modelled-estimates
10. Knutson, V., Aleshin-Guendel, S., Karlinsky, A., Msemburi, W. and Wakefield, J., 2022. Estimating Global and Country-Specific Excess Mortality During the COVID-19 Pandemic. *arXiv preprint arXiv:2205.09081*.

11. Aburto, J.M., Jonas Schöley, Ilya Kashnitsky, Luyin Zhang, Charles Rahal, Trifon I Missov, Melinda C Mills, Jennifer B Dowd, Ridhi Kashyap, Quantifying impacts of the COVID-19 pandemic through life-expectancy losses: a population-level study of 29 countries, *International Journal of Epidemiology*, 2021,

12. Islam N, Jdanov D A, Shkolnikov V M, Khunti K, Kawachi I, White M et al. Effects of covid-19 pandemic on life expectancy and premature mortality in 2020: time series analysis in 37 countries *BMJ* 2021: 375:e066768

13. Castro, M.C., Gurzenda, S., Turra, C.M. *et al.* Reduction in life expectancy in Brazil after COVID-19. *Nat Med* 2021: **27,** 1629–1635.

14. Schellekens, I. G. and P. COVID-19 is a developing country pandemic. *Brookings* https://www.brookings.edu/blog/future-development/2021/05/27/covid-19-is-a-developing-country-pandemic/ (2021).

15. Schellekens, P. & Sourrouille, D. M. COVID-19 Mortality in Rich and Poor Countries: A Tale of Two Pandemics? World Bank Policy Research Working Paper 2020: 9260.

16. Walker, P. G. *et al.* The impact of COVID-19 and strategies for mitigation and suppression in low-and middle-income countries. *Science* 2020: 369, 413–422 2020.

17. Brown, C. S., Ravallion, M. & van de Walle, D. *Can the World's Poor Protect Themselves from the New Coronavirus?* 2020.

18. Ghisolfi, S. *et al.* Predicted COVID-19 fatality rates based on age, sex, comorbidities and health system capacity. *BMJ Glob. Health* 2020: **5**, e003094.

19. Ashton M Verdery, PhD, Lauren Newmyer, MA, Brandon Wagner, PhD, Rachel Margolis, PhD, National Profiles of Coronavirus Disease 2019 Mortality Risks by Age Structure and

Preexisting Health Conditions, *The Gerontologist*, Volume 61, Issue 1, February 2021, Pages 71–77, https://doi.org/10.1093/geront/gnaa152

[dataset] 20. Riffe, T., Acosta, E., & the COVerAGE-DB team. Data Resource Profile: COVerAGE-DB: a global demographic database of COVID-19 cases and deaths. *Int. J. Epidemiol.* 2021: **50**, 390–390f. https://doi.org/10.1093/ije/dyab027

21. Hannah Ritchie, Edouard Mathieu, Lucas Rodés-Guirao, Cameron Appel, Charlie Giattino, Esteban Ortiz-Ospina, Joe Hasell, Bobbie Macdonald, Diana Beltekian and Max Roser (2020) - "Coronavirus Pandemic (COVID-19)". *Published online at OurWorldInData.org.* Retrieved from: 'https://ourworldindata.org/coronavirus' [Online Resource]

22. Jdanov, D. A. *et al.* The short-term mortality fluctuation data series, monitoring mortality shocks across time and space. *Sci. Data* 2021: **8**, 235.

[dataset] 23. Human Mortality Database. University of California, Berkeley (USA), and Max Planck Institute for Demographic Research (Germany). Available at www.mortality.org or www.humanmortality.de (data downloaded on February 18, 2022).

[dataset] 24. DANE. 2022. Defunciones No Fetales. Dirreción Nacional de Estadistidica, Bogota, Colombia. https://www.dane.gov.co/index.php/estadisticas-por-tema/salud/nacimientos-y-defunciones/defunciones-no-fetales (data downloaded on February 18, 2022).

[dataset] 25. INEGI. 2022. Defunciones Registrada mortalidad general. Instituto Nacional de Estadística, Geografía e Informática (INEGI), Aguascalientes, Mexico. https://www.inegi.org.mx/programas/mortalidad/#Microdatos (data downloaded on February 18, 2022).

[dataset] 26. SINADEF. 2022. Certificado Defunciones. Sistema Informato de Defunciones. Lima, Peru: https://www.datosabiertos.gob.pe/dataset/sinadef-certificado-

defunciones/resource/fef60d30-c135-4b51-82e1-a642ef29fe79 (data downloaded on February 18, 2022).

[dataset] 27. Ministério da Saúde. 2022. Mortalidada – Brasil. Ministério da Saúde, Brazilia, Brazil. http://tabnet.datasus.gov.br/cgi/deftohtm.exe?sim/cnv/obt10uf.def (data downloaded on February 18, 2022).

28. DESA, U. World Population Prospects 2019. United Nations. Department of Economic and Social Affairs. 2019. *World Popul. Prospects 2019*.

29. Beaney, T. *et al.* Excess mortality: the gold standard in measuring the impact of COVID-19 worldwide? *J. R. Soc. Med.* 2020: **113**, 329–334.

30. Nepomuceno, M.R., Klimkin, I., Jdanov, D.A., Alustiza-Galarza, A. and Shkolnikov, V.M. (2022). Sensitivity Analysis of Excess Mortality due to the COVID-19 Pandemic. Population and Development Review. https://doi.org/10.1111/padr.12475

31. Schöley, J. (2021). Robustness and bias of European excess death estimates in 2020 under varying model specifications. MedRxiv. https://doi.org/10.1101/2021.06.04.21258353

32. Brillinger, D. R. (1986). A biometrics invited paper with discussion: The natural variability of vital rates and associated statistics. Biometrics, 42(4):693–734.

33. Gompertz, B. (1825). On the nature of the function expressive of the law of human mortality, and on a new mode of determining the value of life contingencies. Philosophical Transactions of the Royal Society of London, 115:513–583.

34. Santos, A. M. dos, Souza, B. F. de, Carvalho, C. A. de, Campos, M. A. G., Oliveira, B. L. C. A. de, Diniz, E. M., Branco, M. dos R. F. C. ., Queiroz, R. C. de S. ., Carvalho, V. A. de, Araújo, W. R. M., & Silva, A. A. M. da. (2021). Excess deaths from all causes and by

COVID-19 in Brazil in 2020. *Revista De Saúde Pública*, *55*, 71. https://doi.org/10.11606/s1518-8787.2021055004137

35. Hillis, S. D. *et al.* Global minimum estimates of children affected by COVID-19-associated orphanhood and deaths of caregivers: a modelling study. *The Lancet* 2021: **398**, 391–402.

36. Bundervoet, T., Dávalos, M. E. & Garcia, N. *The Short-Term Impacts of COVID-19 on Households in Developing Countries: An Overview Based on a Harmonized Data Set of High-Frequency Surveys*. The World Bank, 2021. doi:10.1596/1813-9450-9582.

37. Miguel, E. & Mobarak, A. M. The Economics of the COVID-19 Pandemic in Poor Countries. *Annu. Rev. Econ.* 2021 doi:https:// doi.org/10.1146/annurev-economics-051520-025412.

38. Azevedo, J. P., Hasan, A., Goldemberg, D., Geven, K. & Iqbal, S. A. Simulating the potential impacts of COVID-19 school closures on schooling and learning outcomes: A set of global estimates. *World Bank Res. Obs.* 2021: **36**, 1–40.

39. Departamento Administrativo Nacional de Estadística. Cuadros unificados: Defunciones no fetales cifras definitivas 2019. 2020.

40. Departamento Administrativo Nacional de Estadística. Cuadros unificados: Defunciones no fetales acumulado año 2020pr. 2021.

41. National Center for Statistics and Analysis. Early Estimate of Motor Vehicle Traffic Fatalities in 2020. 2021.

42. Krishnakumar, P. Murders rose sharply in 2020 but data is lacking across much of the country. 2021.

43. National Center for Health Statistics. Provisional Drug Overdose Death Counts. 2021.

44. Garrote Sanchez, D. *et al.* Who on earth can work from home? 2020.

45. Public Health England. *Disparities in the risk and outcomes of COVID-19*. 2020.

46. The New York Times, Nearly One-Third of U.S. Coronavirus Deaths Are Linked to Nursing Homes. *The New York Times*. 2020.

47. Winskill, P. *et al. Report 22: Equity in response to the COVID-19 pandemic: an assessment of the direct and indirect impacts on disadvantaged and vulnerable populations in low-and lower middle-income countries WHO Collaborating Centre for Infectious Disease Modelling MRC Centre for Global Infectious Disease Analysis*. 2020.

48. Levin AT, Owusu-Boaitey N, Pugh S*, et al*. Assessing the burden of COVID-19 in developing countries: systematic review, meta-analysis and public policy implications *BMJ Global Health* 2022;**7:**e008477.

49. Nepomuceno, M. R. *et al.* Besides population age structure, health and other demographic factors can contribute to understanding the COVID-19 burden. 2020. *Proc. Natl. Acad. Sci.* **117**, 13881–13883.

Figures Legend/Caption

Figure 1: Actual and predicted total deaths (all causes) by year, select countries in LAC

Figure 2: Age distribution of official COVID-19 deaths and excess deaths in 2020

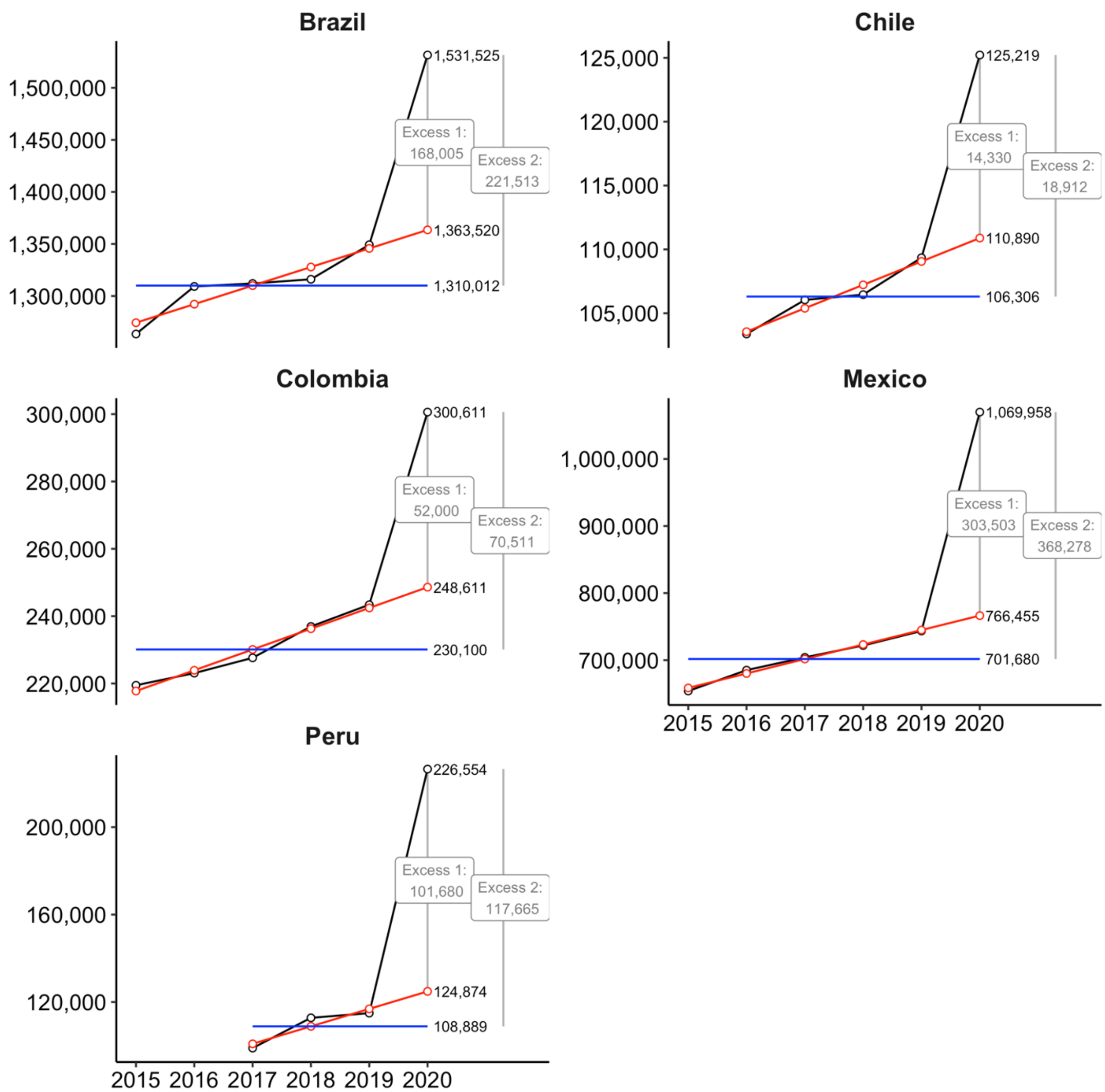
Figure 3: Hypothetical age distribution of official COVID-19 and excess deaths in 2020, using country age-specific mortality rates and the US population age distribution

Figure 4: Official COVID-19 vs excess deaths by age group (per 100,000 population) [log scale]

Figure 5: Official COVID-19 vs excess deaths by age group, select Latin American countries and the United States (per 100,000 population)

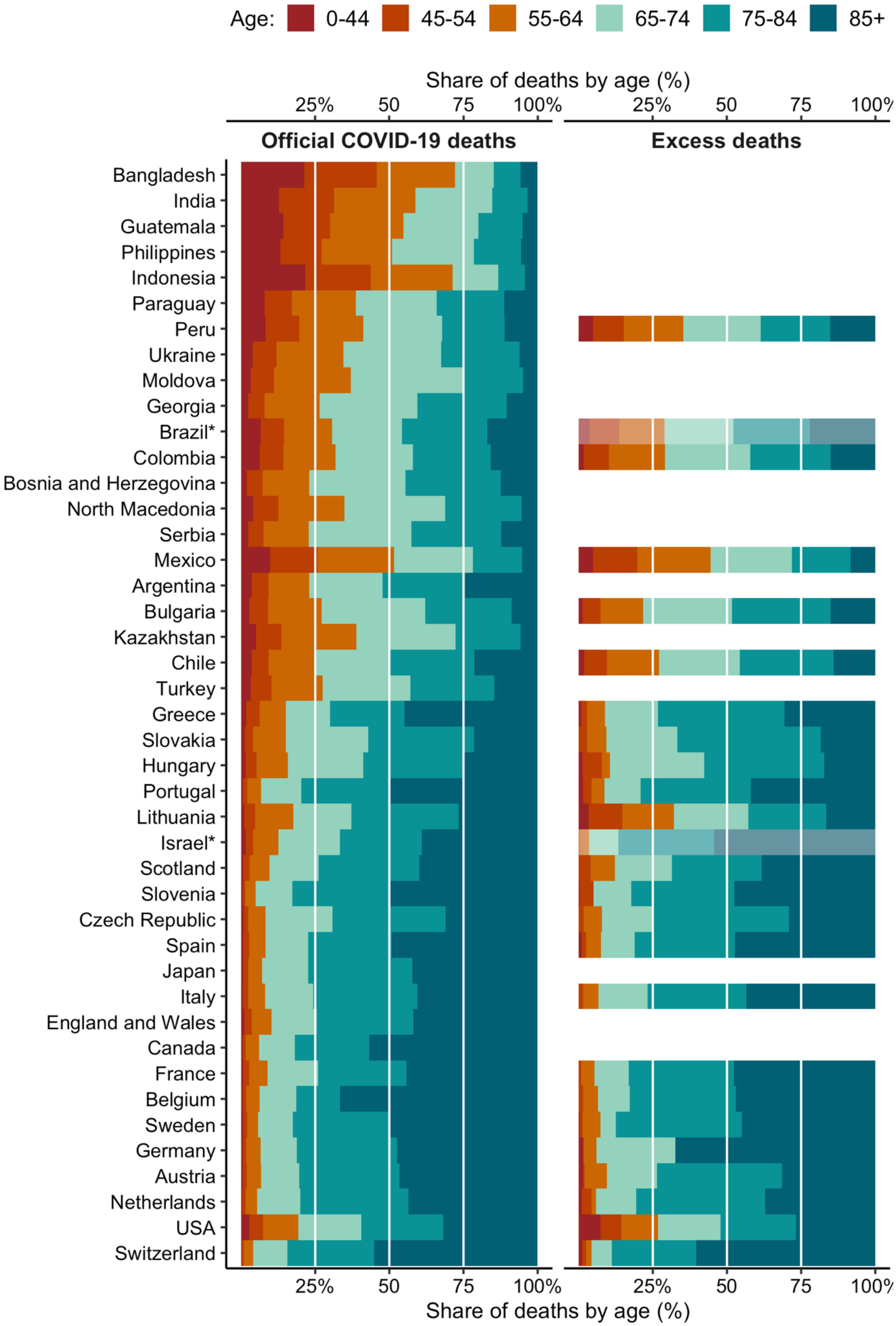
Figure 6: Slope of the age-mortality curve vs GNI per capita, official COVID-19 deaths vs excess deaths, all data Poisson model (estimates use all age group and deaths recoded to 0 where they are negative)

Figure 7: Slope of the age-mortality curve vs GNI per capita, official COVID-19 deaths vs excess deaths common set of countries/economies. Poisson model (estimates use all age group and deaths recoded to 0 where they are negative)



Notes: Actual deaths are shown in black. Predicted deaths based on a linear projection using annual mortality totals 2015-19 are shown in red. Mean deaths 2015-19 are shown in blue.

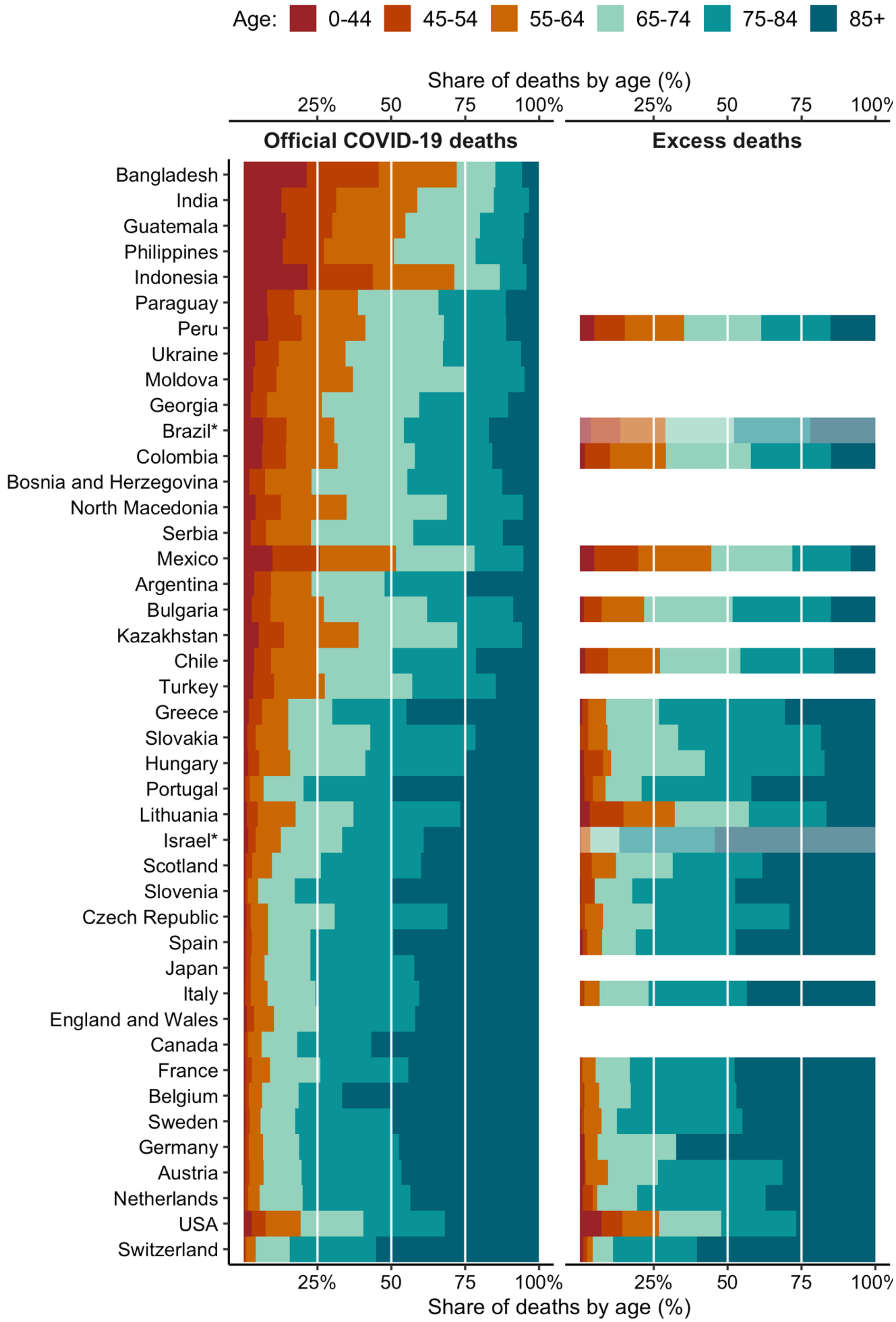
Figure 1: Actual and predicted total deaths (all causes) by year, select countries in LAC



Age: 0-44 45-54 55-64 65-74 75-84 85+
Share of deaths by age (%)
25% 50 75 100%
Official COVID-19 deaths
Excess deaths
Bangladesh
India
Guatemala
Philippines
Indonesia
Paraguay
Peru
Ukraine
Moldova
Georgia
Brazil*
Colombia
Bosnia and Herzegovina
North Macedonia
Serbia
Mexico
Argentina
Bulgaria
Kazakhstan
Chile
Turkey
Greece
Slovakia
Hungary
Portugal
Lithuania
Israel*
Scotland
Slovenia
Czech Republic
Spain
Japan
Italy
England and Wales
Canada
France
Belgium
Sweden
Germany
Austria
Netherlands
USA
Switzerland

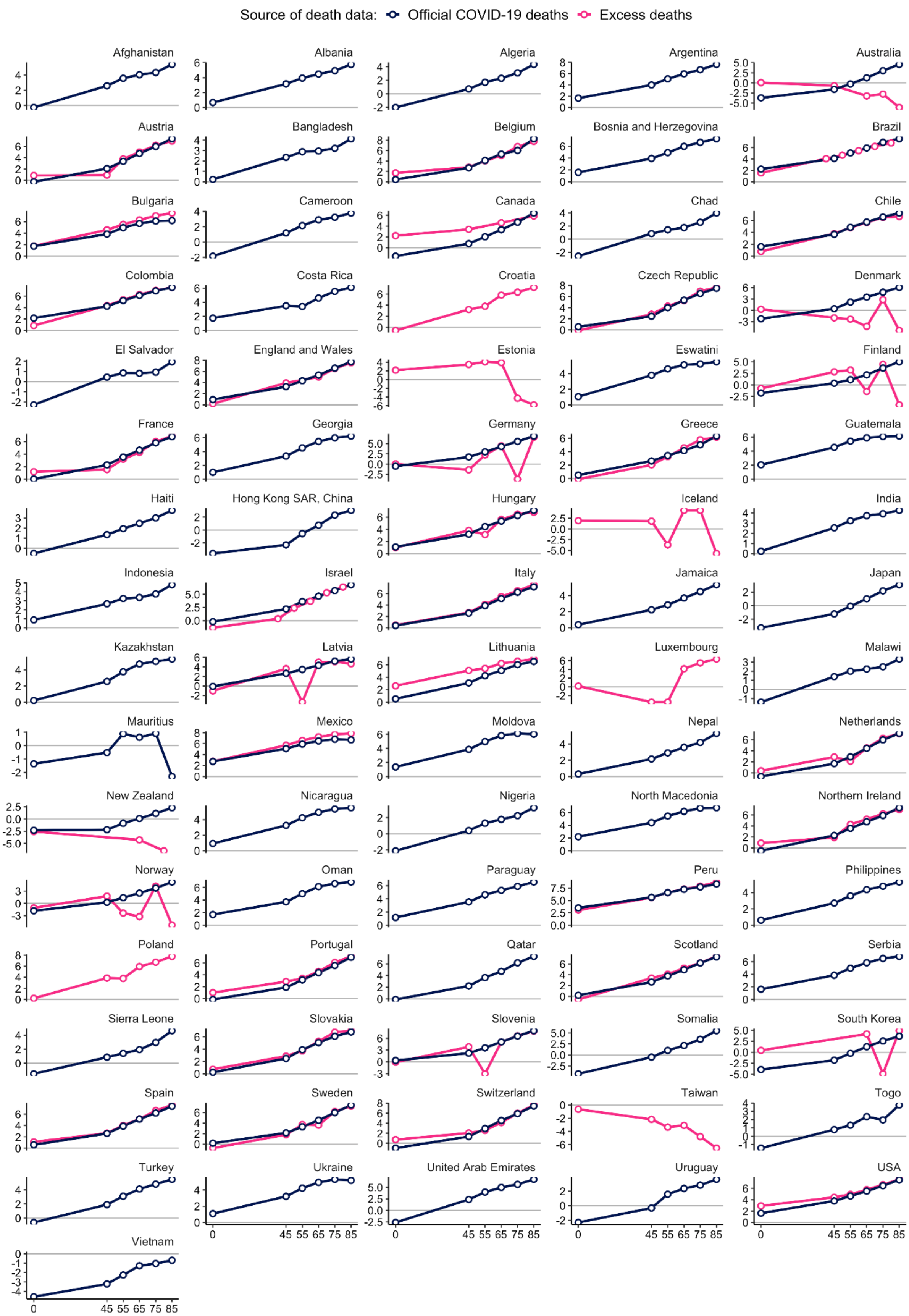
Notes: Countries with fewer than 2000 official COVID-19 deaths are excluded. The age-groups available to compute excess deaths for Brazil and Israel differ from those available in other countries. For Brazil and Israel, the age groups are: 0-39, 40-49, 50-59, 60-69, 70-79, 80+. Negative excess deaths estimated in the Philippines (age-groups 0-44 75-84 and 85+), Slovenia (55-64) and Scotland (0-44) are re-coded to zero. Countries are sorted by 2019 GNI per capita (PPP).

Figure 2: Age distribution of official COVID-19 deaths and excess deaths in 2020


Age: 0-44 45-54 55-64 65-74 75-84 85+
Share of deaths by age (%)
25% 50 75 100%
Official COVID-19 deaths
Excess deaths
Bangladesh
India
Guatemala
Philippines
Indonesia
Paraguay
Peru
Ukraine
Moldova
Georgia
Brazil*
Colombia
Bosnia and Herzegovina
North Macedonia
Serbia
Mexico
Argentina
Bulgaria
Kazakhstan
Chile
Turkey
Greece
Slovakia
Hungary
Portugal
Lithuania
Israel*
Scotland
Slovenia
Czech Republic
Spain
Japan
Italy
England and Wales
Canada
France
Belgium
Sweden
Germany
Austria
Netherlands
USA
Switzerland

Notes: Countries with fewer than 2000 official COVID-19 deaths are excluded. The age-groups available to compute excess deaths for Brazil and Israel differ from those available in other countries. For Brazil and Israel, the age groups are: 0-39, 40-49, 50-59, 60-69, 70-79, 80+; Negative excess deaths estimated in the Philippines (age-groups 0-44 75-84 and 85+), Slovenia (55-64) and Scotland (0-44) are re-coded to zero. Countries are sorted by 2019 GNI per capita (PPP).

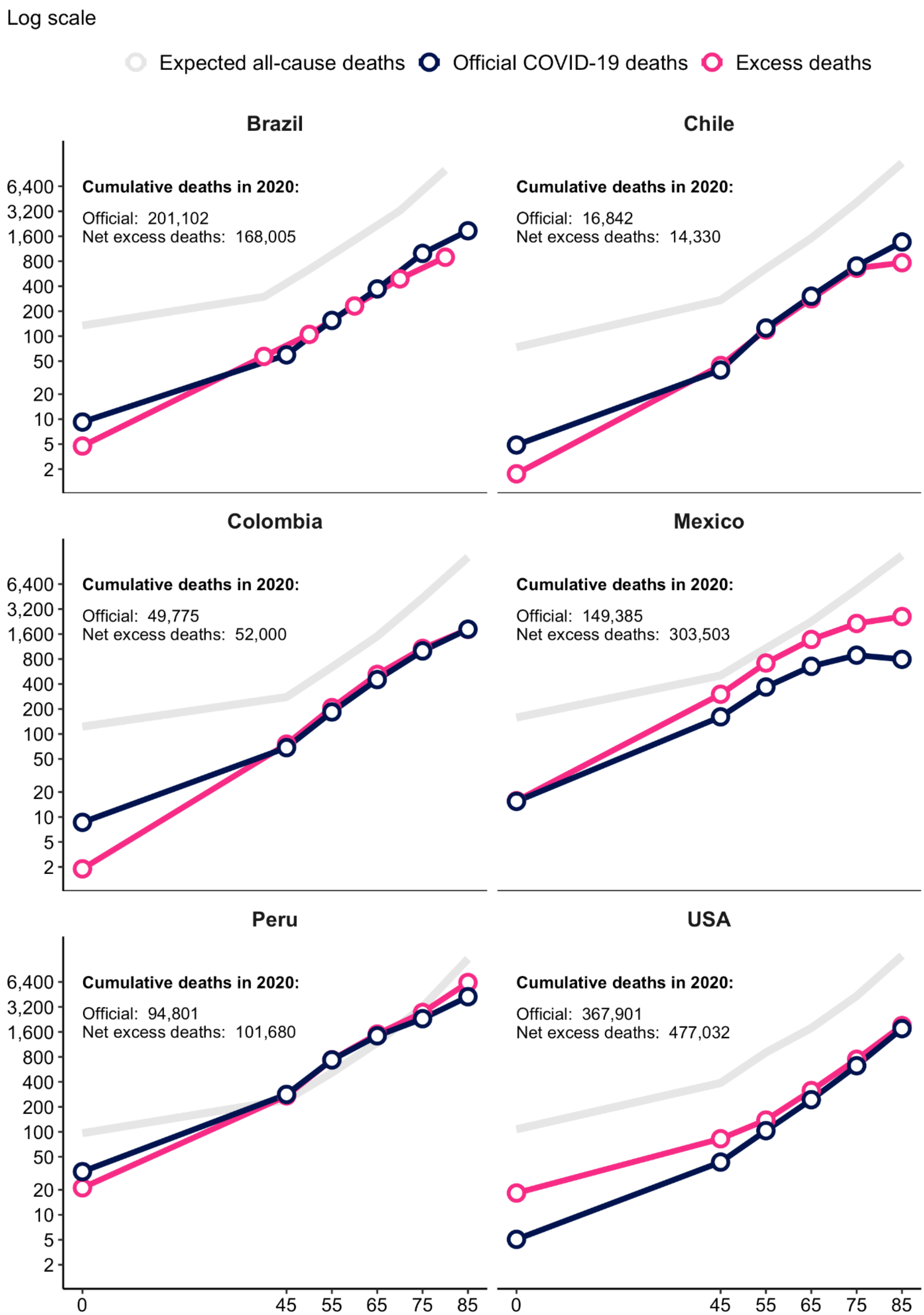
Figure 3: Hypothetical age distribution of official COVID-19 and excess deaths in 2020, using country age-specific mortality rates and the US population age distribution



Source of death data: Official COVID-19 deaths Excess deaths
Afghanistan
Albania
Algeria
Argentina
Australia
Austria
Bangladesh
Belgium
Bosnia and Herzegovina
Brazil
Bulgaria
Cameroon
Canada
Chad
Chile
Colombia
Costa Rica
Croatia
Czech Republic
Denmark
El Salvador
England and Wales
Estonia
Eswatini
Finland
France
Georgia
Germany
Greece
Guatemala
Haiti
Hong Kong SAR, China
Hungary
Iceland
India
Indonesia
Israel
Italy
Jamaica
Japan
Kazakhstan
Latvia
Lithuania
Luxembourg
Malawi
Mauritius
Mexico
Moldova
Nepal
Netherlands
New Zealand
Nicaragua
Nigeria
North Macedonia
Northern Ireland
Norway
Oman
Paraguay
Peru
Philippines
Poland
Portugal
Qatar
Scotland
Serbia
Sierra Leone
Slovakia
Slovenia
Somalia
South Korea
Spain
Sweden
Switzerland
Taiwan
Togo
Turkey
Ukraine
United Arab Emirates
Uruguay
USA
Vietnam
0
45 55 65 75 85

Note: Points are plotted at the start of each age group: 0-44,45-54,55-64,65-74,75-84, 85+
Vertical axis labels are expressed as log (deaths/100,000 population).

Figure 4: Official COVID-19 vs excess deaths by age group (per 100,000 population) [log scale]


Log scale
Expected all-cause deaths
Official COVID-19 deaths
Excess deaths
Brazil
Cumulative deaths in 2020:
Official: 201,102
Net excess deaths: 168,005
Chile
Cumulative deaths in 2020:
Official: 16,842
Net excess deaths: 14,330
Colombia
Cumulative deaths in 2020:
Official: 49,775
Net excess deaths: 52,000
Mexico
Cumulative deaths in 2020:
Official: 149,385
Net excess deaths: 303,503
Peru
Cumulative deaths in 2020:
Official: 94,801
Net excess deaths: 101,680
USA
Cumulative deaths in 2020:
Official: 367,901
Net excess deaths: 477,032
6,400
3,200
1,600
800
400
200
100
50
20
10
5
2
0
45
55
65
75
85

Note: Points are plotted at the start of each age group: 0-44,45-54,55-64,65-74,75-84, 85+. Brazil has different age group categories. The excess mortality calculation for Chile is based on the first 52 weeks of the ISO calendar year and thus excludes the last 4 days of the calendar year.

Figure 5: Official COVID-19 vs excess deaths by age group, select Latin American countries and the United States (per 100,000 population)

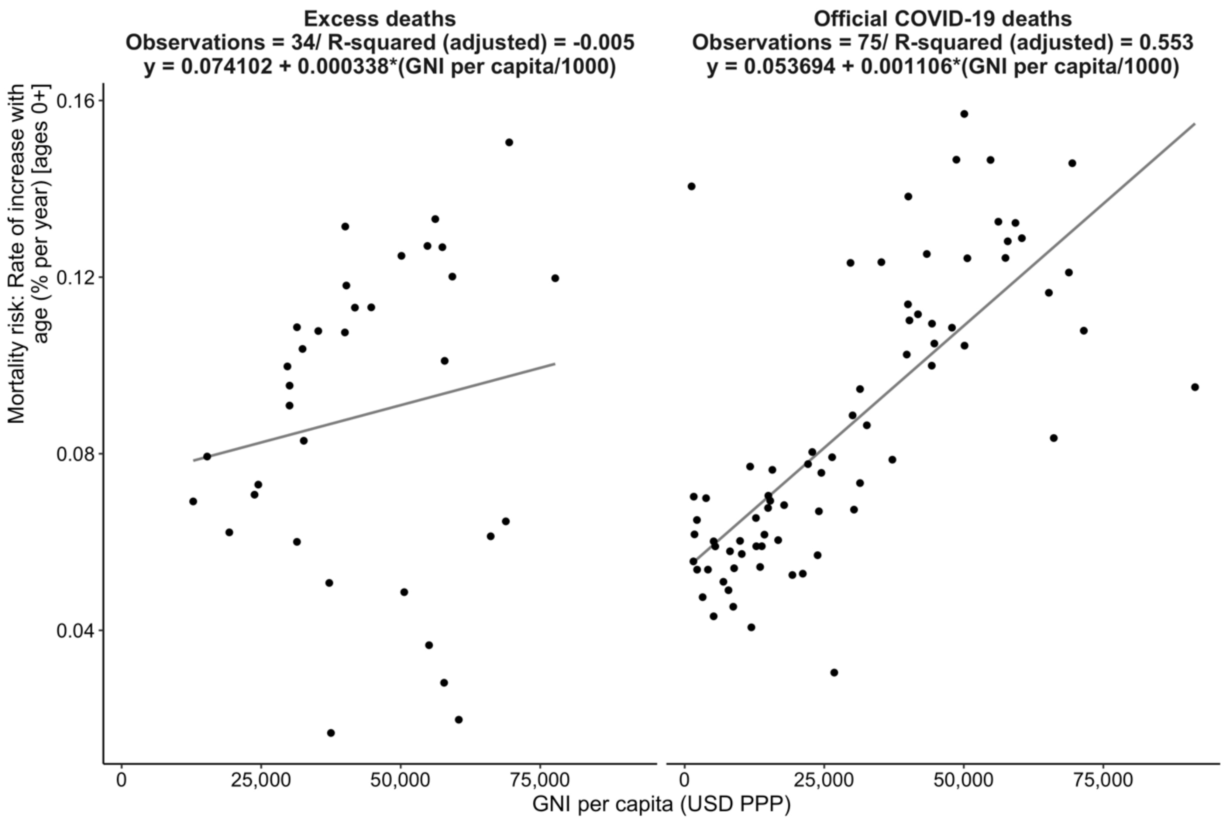


Figure 6: Slope of the age-mortality curve vs GNI per capita, official COVID-19 deaths vs excess deaths, all data Poisson model (estimates use all age group and deaths recoded to 0 where they are negative)

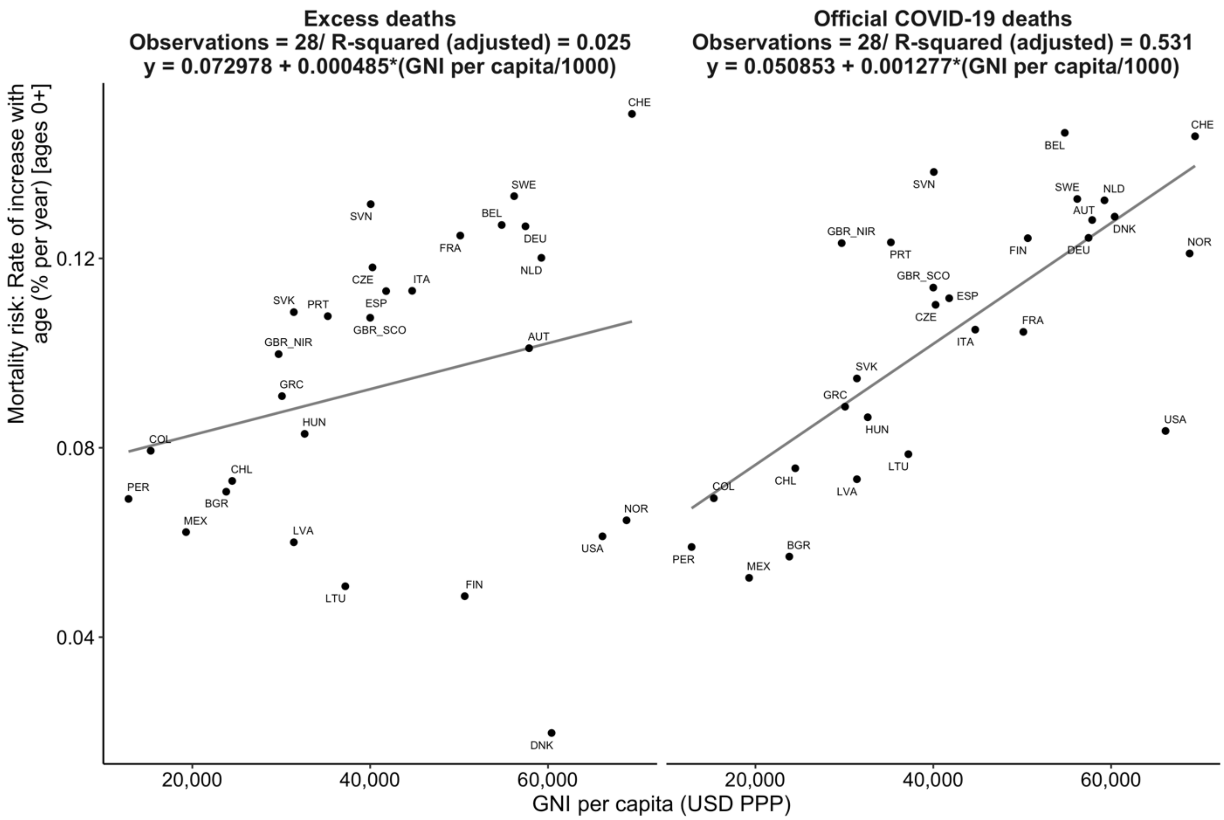


Figure 7: Slope of the age-mortality curve vs GNI per capita, official COVID-19 deaths vs excess deaths common set of countries/economies. Poisson model (estimates use all age group and deaths recoded to 0 where they are negative)

Online Appendix

Data Availability

Data sources

Official reported COVID-19 deaths aggregated in the COVerAGE database (Output_5.zip Version 395 downloaded May 16, 2022 from https://osf.io/7tnfh/. For this analysis the output file with death counts aggregated to 5-year age-groups is used [20].

There are 125 countries in the COVerAGE database (excluding England and United Kingdom). For this analysis, the political units that make up the United Kingdom are treated separately as follows: England and Wales, Scotland, and Northern Ireland.

85 countries have at least one record of cumulative deaths during 2020.

76 countries have a record of cumulative deaths that covers at least 6 months since the first case was detected in the country (per case-data derived from Our World in Data). Countries with an "exposure" of less than 6 months as of the end of 2020 are excluded from the analysis.

The following is the set of 76 countries and economies with official reported deaths used in the analysis: Afghanistan; Albania; Algeria; Argentina; Australia; Austria; Bangladesh; Belgium; Bosnia and Herzegovina; Brazil; Bulgaria; Cameroon; Canada; Chad; Chile; Colombia; Costa Rica; Czech Republic; Denmark; El Salvador; England and Wales; Eswatini; Finland; France; Georgia; Germany; Greece; Guatemala; Haiti; Hong Kong SAR, China; Hungary; India; Indonesia; Israel; Italy; Jamaica; Japan; Jordan; Kazakhstan; Latvia; Lithuania; Malawi; Mauritius; Mexico; Moldova; Nepal; Netherlands; New Zealand; Nicaragua; Nigeria; North Macedonia; Northern Ireland; Norway; Oman; Paraguay; Peru; Philippines; Portugal;; Qatar; Scotland; Serbia; Sierra Leone; Slovak Republic; Slovenia; Somalia; Republic of Korea; Spain; Sweden; Switzerland; Togo; Turkey; Ukraine; United Arab Emirates; Uruguay; United States; Vietnam.

Excess all-cause deaths from vital statistics records, from the following sources:

Short term mortality fluctuations (STMF) harmonized data series from the Human Mortality Database [23], downloaded February 18, 2022 from https://www.mortality.org

For Colombia, Peru, Mexico, Brazil and the USA all cause death data are sources from national statistical authorities.

- For this analysis, the STMF input files are used. These input files cover 38 countries and economies: Australia; Austria; Belgium; Bulgaria; Canada; Switzerland; Chile; Czech Republic; Germany; Denmark; Spain; Estonia; Finland; France; Northern Ireland; Scotland; England and Wales; Greece; Croatia; Hungary; Iceland; Israel; Italy; Republic of Korea; Lithuania; Luxembourg; Latvia; Netherlands; Norway; New Zealand; Poland; Portugal; Russian Federation; Slovak Republic; Slovenia; Sweden; Taiwan, China; United States.
- Russia does not have data for 2020.
- Chile and Germany do not have data for 2015.

Colombia vital statistics tabulations (*Defunciones no fetales*) were compiled by DANE. 2019 and 2020 tabulations are preliminary [24].

Mexico vital statistics microdata are those compiled by INEGI (*Defunciones registradas, mortalidad general*) and cover 2015-2020 [25].

Peru death certificate microdata were compiled by SINADEF [26] obtained through the government's open data portal. These data cover 2017-2021.

Brazil vital statistics tabulations are obtained from the Ministry of Health's Sistema de Informação sobre Mortalidade (SIM) data portal [27] http://tabnet.datasus.gov.br/cgi/deftohtm.exe?sim/cnv/obt10uf.def

Together there are 41 countries and economies with excess death estimates: Austria; Belgium; Brazil; Bulgaria; Switzerland; Chile; Czech Republic; Germany; Denmark; Spain; Estonia; Finland; France; Scotland; Greece; Croatia; Hungary; Iceland; Italy; Lithuania; Luxembourg; Latvia; Netherlands; Norway; Poland; Portugal; Slovak Republic; Slovenia; Sweden; Taiwan, Colombia; Peru; Mexico; England and Wales; United States; Australia; Canada; Israel; Republic of Korea; New Zealand.

Of these, four do not have corresponding official death records from the coverage database: Estonia, Croatia, Luxembourg, and Poland.

For all countries, the official COVID-19 death data is drawn from the COVerAGE database and the figures correspond to calendar year 2020. The excess mortality estimates are based principally on all-cause data compiled in the Short Term Mortality Fluctuations (SMTF) database and reported in terms of deaths by week, using weeks as defined by the International Organization for Standardization (ISO) weeks. All ISO weeks start on a Monday and end on a Sunday and thus do not conform precisely to the calendar year. There are 52 ISO weeks in most years but 53 ISO weeks in 2015 and 2020. Including all 53 ISO weeks for 2020 in the excess mortality calculations would result in an overestimate of excess mortality. In order to ensure that the excess mortality calculations are based on an identical number of days in each year, we use the first 52 weeks of each year, excluding week 53 from the calculations for 2015 and 2020 for all cases where the data comes from SMTF. The 52-week ISO year for 2020 thus starts December 30, 2019, and ends December 27, 2020. For the Brazil, Colombia, Mexico, Peru and United States excess mortality estimates, which are based on data sourced directly to national statistical agencies, we use the full calendar year.

The preferred age group categories for the analyses conducted in this paper were as follows: 0-14, 15-44, 45-54, 55-64, 65-74, 75-84, 85+. However, since the reporting of all-cause deaths by age used by the Human Mortality Database is not consistent from country to country (not all countries report death counts tabulated at 5-year intervals or less), successively broader age-groupings are used in cases where the preferred age groups could not be constructed directly from the STMF input data. These countries include the United States, England and Wales, Australia, Canada, New Zealand, Israel and the Republic of Korea. We compute excess mortality rates for all unique country-age group combinations (as shown in Figure 4) but to estimate the age gradient of mortality, we only include countries for which we could construct the preferred age-group categories as described above. Countries for which we could not construct the preferred age-group categories are Brazil, Israel, and New Zealand. To avoid excluding the United States from this analysis, we use mortality data from the CDC which reports deaths for consistent age groups for 2015 through 2020.

Annex Table A1: Age Distribution of Official COVID-19 Deaths and Excess Deaths in 2020 (Data Shown in Figure 2)

			Share (%) of official COVID-19 deaths by age group						Share (%) of excess mortality deaths by age group					
Country	GNI per capita (PPP)	World Bank Income Group	0-44	45-54	55-64	65-74	75-84	85+	0-44	45-54	55-64	65-74	75-84	85+
Bangladesh	5,180	LMIC	21	25	27	13	9	6						
India	6,930	LMIC	13	19	27	26	12	3						
Guatemala	8,850	UMIC	14	16	25	25	15	5						
Philippines	10,220	LMIC	13	14	24	28	16	6						
Indonesia	11,940	LMIC	22	22	28	15	9	4						
Paraguay	12,760	UMIC	8	9	22	27	23	11						
Peru	12,820	UMIC	8	11	22	27	21	11	5	10	20	26	23	15
Ukraine	13,510	LMIC	4	8	23	33	26	6						
Moldova	14,280	LMIC	3	8	26	38	20	5						
Georgia	14,930	UMIC	2	6	19	33	30	10						
Brazil*	14,980	UMIC	7	8	16	24	29	17	4	10	15	23	26	22
Colombia	15,320	UMIC	6	8	18	26	26	16	2	9	19	29	27	15
Bosnia and Herzegovina	15,700	UMIC	2	5	16	32	32	13						
North Macedonia	16,740	UMIC	4	9	22	34	26	6						
Serbia	17,810	UMIC	2	5	15	35	30	12						
Mexico	19,290	UMIC	10	16	26	27	17	5	5	15	25	28	20	8
Argentina	22,090	UMIC	4	6	14	25	28	25						
Bulgaria	23,810	UMIC	3	6	18	35	29	9	1	6	14	30	33	15
Kazakhstan	24,040	UMIC	5	9	25	34	22	6						
Chile	24,480	HIC	4	6	16	25	29	21	2	8	18	27	32	14
Turkey	26,410	UMIC	3	7	17	30	28	15						
Greece	30,080	HIC	2	5	9	15	25	45	1	2	6	18	43	31
Slovakia	31,410	HIC	1	3	11	28	36	22	0	3	6	24	48	19
Hungary	32,630	HIC	2	4	11	25	34	25	1	7	3	32	40	17
Portugal	35,230	HIC	1	2	5	14	30	50	1	3	4	12	37	42

Lithuania	37,200	HIC	1	4	13	20	36	27	3	11	17	25	26	17
Israel*	39,780	HIC	2	3	8	21	28	39	0	1	3	10	32	54
Scotland	40,000	HIC	1	2	7	17	34	40	0	4	8	19	30	38
Slovenia	40,060	HIC	1	1	3	12	33	50	0	5	0	13	35	48
Czech Republic	40,260	HIC	1	2	6	23	38	31	0	2	6	17	46	29
Spain	41,790	HIC	1	2	6	14	28	49	1	2	5	11	34	47
Japan	44,260	HIC	1	2	5	16	35	42						
Italy	44,720	HIC	1	2	6	16	35	41	0	1	5	17	33	43
England and Wales	47,880	HIC	1	3	7	15	33	42						
Canada	48,670	HIC	1	1	4	12	25	57						
France	50,130	HIC	1	2	6	17	30	44	0	1	4	12	35	48
Belgium	54,790	HIC	1	1	5	12	15	67	0	2	5	11	36	47
Sweden	56,190	HIC	1	1	4	12	32	50	0	1	6	5	43	45
Germany	57,460	HIC	1	1	5	12	34	47	2	0	4	27	0	67
Austria	57,870	HIC	1	1	5	13	34	47	2	0	8	17	42	31
Netherlands	59,250	HIC	0	1	4	15	37	44	1	3	2	14	43	37
USA	66,120	HIC	3	5	12	21	28	32	7	7	12	21	25	27
Switzerland	69,440	HIC	0	1	3	12	29	55	1	1	2	7	29	60

* The age groups available to compute excess deaths for Brazil differ from those used in other countries and correspond to the following: 0-39, 40-49, 50-59, 60-69, 70-79, 80+. GNI is from 2019.

Annex Table A2: Hypothetical Age Distribution of Official COVID-19 and Excess Deaths in 2020, Using Country Age-Specific Mortality Rates and the US Population Age Distribution (Data Shown in Figure 3)

			Share (%) of official COVID-19 deaths by age group						Share (%) of excess mortality deaths by age group					
Country	GNI per capita (PPP)	World Bank Income Group	0-44	45-54	55-64	65-74	75-84	85+	0-44	45-54	55-64	65-74	75-84	85+
Bangladesh	5,180	LMIC	21	25	27	13	9	6						
India	6,930	LMIC	13	19	27	26	12	3						
Guatemala	8,850	UMIC	14	16	25	25	15	5						
Philippines	10,220	LMIC	13	14	24	28	16	6						
Indonesia	11,940	LMIC	22	22	28	15	9	4						
Paraguay	12,760	UMIC	8	9	22	27	23	11						
Peru	12,820	UMIC	8	11	22	27	21	11	5	10	20	26	23	15
Ukraine	13,510	LMIC	4	8	23	33	26	6						
Moldova	14,280	LMIC	3	8	26	38	20	5						
Georgia	14,930	UMIC	2	6	19	33	30	10						
Brazil*	14,980	UMIC	7	8	16	24	29	17	4	10	15	23	26	22
Colombia	15,320	UMIC	6	8	18	26	26	16	2	9	19	29	27	15
Bosnia and Herzegovina	15,700	UMIC	2	5	16	32	32	13						
North Macedonia	16,740	UMIC	4	9	22	34	26	6						
Serbia	17,810	UMIC	2	5	15	35	30	12						
Mexico	19,290	UMIC	10	16	26	27	17	5	5	15	25	28	20	8
Argentina	22,090	UMIC	4	6	14	25	28	25						
Bulgaria	23,810	UMIC	3	6	18	35	29	9	1	6	14	30	33	15
Kazakhstan	24,040	UMIC	5	9	25	34	22	6						
Chile	24,480	HIC	4	6	16	25	29	21	2	8	18	27	32	14
Turkey	26,410	UMIC	3	7	17	30	28	15						
Greece	30,080	HIC	2	5	9	15	25	45	1	2	6	18	43	31
Slovakia	31,410	HIC	1	3	11	28	36	22	0	3	6	24	48	19

Hungary	32,630	HIC	2	4	11	25	34	25	1	7	3	32	40	17
Portugal	35,230	HIC	1	2	5	14	30	50	1	3	4	12	37	42
Lithuania	37,200	HIC	1	4	13	20	36	27	3	11	17	25	26	17
Israel*	39,780	HIC	2	3	8	21	28	39	0	1	3	10	32	54
Scotland	40,000	HIC	1	2	7	17	34	40	0	4	8	19	30	38
Slovenia	40,060	HIC	1	1	3	12	33	50	0	5	0	13	35	48
Czech Republic	40,260	HIC	1	2	6	23	38	31	0	2	6	17	46	29
Spain	41,790	HIC	1	2	6	14	28	49	1	2	5	11	34	47
Japan	44,260	HIC	1	2	5	16	35	42						
Italy	44,720	HIC	1	2	6	16	35	41	0	1	5	17	33	43
England and Wales	47,880	HIC	1	3	7	15	33	42						
Canada	48,670	HIC	1	1	4	12	25	57						
France	50,130	HIC	1	2	6	17	30	44	0	1	4	12	35	48
Belgium	54,790	HIC	1	1	5	12	15	67	0	2	5	11	36	47
Sweden	56,190	HIC	1	1	4	12	32	50	0	1	6	5	43	45
Germany	57,460	HIC	1	1	5	12	34	47	2	0	4	27	0	67
Austria	57,870	HIC	1	1	5	13	34	47	2	0	8	17	42	31
Netherlands	59,250	HIC	0	1	4	15	37	44	1	3	2	14	43	37
USA	66,120	HIC	3	5	12	21	28	32	7	7	12	21	25	27
Switzerland	69,440	HIC	0	1	3	12	29	55	1	1	2	7	29	60

* The age groups available to compute excess deaths for Brazil differ from those used in other countries and correspond to the following: 0-39, 40-49, 50-59, 60-69, 70-79, 80+. GNI is from 2019.

Annex Table A3: Rate of Increase in Risk of Death by Age and Ratio of Mortality Risk Between Age Groups

	Official deaths		Excess deaths	
Country	Exponential rate of increase in risk of death for each year of age	Ratio (MR 75-84/ MR 45-54)	Exponential rate of increase in risk of death for each year of age	Ratio (MR 75-84/ MR 45-54)
Afghanistan	0.06	5.74		
Albania	0.06	5.88		
Algeria	0.08	10.72		
Argentina	0.08	14.89		
Australia	0.16	103.71		
Austria	0.13	50.11	0.10	195.28
Bangladesh	0.04	2.39		
Belgium	0.15	28.08	0.13	52.81
Bosnia and Herzegovina	0.08	15.22		
Brazil	0.07	16.70		
Bulgaria	0.06	9.59	0.07	11.48
Cameroon	0.07	7.73		
Cada	0.15	52.78		
Chad	0.07	5.58		
Chile	0.08	17.96	0.07	14.85
Colombia	0.07	14.63	0.08	14.24
Costa Rica	0.05	7.67		
Croatia			0.10	22.54
Czech Republic	0.11	61.17	0.12	64.18
Denmark	0.13	78.46	0.02	-2.31
El Salvador	0.05	1.62		
England and Wales	0.11	27.90		
Estonia			0.02	-2.26
Eswatini	0.06	4.26		
Finland	0.12	26.90	0.05	5.10
France	0.10	34.25	0.12	87.28
Georgia	0.07	14.21		
Germany	0.12	44.66	0.13	-164.35
Greece	0.09	11.09	0.09	41.67
Guatemala	0.05	4.66		
Haiti	0.05	5.29		
Hong Kong SAR, China	0.12			
Hungary	0.09	21.90	0.08	14.44
Iceland			0.03	12.27
India	0.05	4.03		

Indonesia	0.04	3.02		
Israel	0.10	32.91		
Italy	0.10	39.76	0.11	46.03
Jamaica	0.06	9.42		
Japan	0.10	29.85		
Kazakhstan	0.07	12.00		
Latvia	0.07	12.95	0.06	4.29
Lithuania	0.08	18.85	0.05	4.42
Luxembourg			0.12	-7.52
Malawi	0.06	2.93		
Mauritius	0.03	4.19		
Mexico	0.05	5.53	0.06	7.13
Moldova	0.06	9.75		
Nepal	0.05	7.62		
Netherlands	0.13	72.86	0.12	29.32
New Zealand	0.11	28.02		
Nicaragua	0.06	8.32		
Nigeria	0.06	6.32		
North Macedonia	0.06	9.73		
Northern Ireland	0.12	37.00	0.10	74.72
Norway	0.12	32.03	0.06	11.47
Oman	0.07	18.21		
Paraguay	0.07	10.69		
Peru	0.06	8.17	0.07	10.09
Philippines	0.06	7.94		
Poland			0.10	17.50
Portugal	0.12	39.63	0.11	24.73
Qatar	0.10	52.10		
Scotland	0.11	34.29	0.11	16.75
Serbia	0.07	14.42		
Sierra Leone	0.06	8.29		
Slovakia	0.09	36.46	0.11	48.40
Slovenia	0.14	78.16	0.13	16.23
Somalia	0.14	56.77		
South Korea	0.13	78.62		
Spain	0.11	36.59	0.11	54.12
Sweden	0.13	47.08	0.13	79.55
Switzerland	0.15	96.99	0.15	51.80
Taiwan			0.04	13.73
Togo	0.05	3.22		
Turkey	0.08	18.27		
Ukraine	0.05	8.09		
United Arab Emirates	0.11	26.72		
Uruguay	0.08	23.17		
USA	0.08	14.50	0.06	9.07
Vietnam	0.05	8.74		

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract **Yes, in title**
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found. **Yes, in abstract**
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported. **P. 3**
Objectives	3	State specific objectives, including any prespecified hypotheses. **P. 3**
Methods		
Study design	4	Present key elements of study design early in the paper. **P 3-4**
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection **P. 4**
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants **P. 4**
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable **P 4-5.**
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group **P. 4**
Bias	9	Describe any efforts to address potential sources of bias **P. 4-5**
Study size	10	Explain how the study size was arrived at **P 4.**
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why **P. 4-6**
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding P. 4-6
		(*b*) Describe any methods used to examine subgroups and interactions **P. 4-6**
		(*c*) Explain how missing data were addressed
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy **P. 6**
		(<u>*e*</u>) Describe any sensitivity analyses. **Figure 3, Figure 7, P. 7 and 9.**

Continued on next page

Results		
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed. **Not applicable as the unit of analysis is the country.**
		(b) Give reasons for non-participation at each stage
		(c) Consider use of a flow diagram
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders. **Countries are classified by income level.**
		(b) Indicate number of participants with missing data for each variable of interest
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount) N.A.
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time
		Case-control study—Report numbers in each exposure category, or summary measures of exposure
		Cross-sectional study—Report numbers of outcome events or summary measures **P. 6-9.**
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included. Figures 2 and 3.
		(*b*) Report category boundaries when continuous variables were categorized
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses **Figure 3, Figure 7, P. 7 and 9.**
Discussion		
Key results	18	Summarise key results with reference to study objectives **P. 9-10**
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias **P. 10**
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence **P. 10-12**
Generalisability	21	Discuss the generalisability (external validity) of the study results **P. 10**
Other information		
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based. **No funding to report.**

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

BMJ Open

Are COVID-19 age-mortality curves for 2020 flatter in developing countries? Evidence from a cross-sectional observational study of population-level official death counts and excess deaths estimates.

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2022-061589.R2
Article Type:	Original research
Date Submitted by the Author:	29-Aug-2022
Complete List of Authors:	Demombynes, Gabriel; World Bank, Human Development Global Practice de Walque, Damien; World Bank, Development Research Group Gubbins, Paul; World Bank, Human Development Global Practice Urdinola, Piedad ; Universidad Nacional de Colombia - Sede Bogotá, School of Economics Veillard, Jeremy; World Bank Group, Human Development Global Practice
Primary Subject Heading:	Infectious diseases
Secondary Subject Heading:	Epidemiology
Keywords:	COVID-19, EPIDEMIOLOGY, PUBLIC HEALTH

Are COVID-19 age-mortality curves for 2020 flatter in developing countries? Evidence from a cross-sectional observational study of population-level official death counts and excess deaths estimates.

Gabriel Demombynes[1], Damien de Walque[2], Paul Gubbins[1],

B. Piedad Urdinola[3], Jeremy Veillard[1]

Keywords: COVID-19, Pandemic, Developing Countries, Mortality

Corresponding author: Damien de Walque, The World Bank, Development Research Group, The World Bank. ddewalque@worldbank.org

Affiliations

1. The World Bank, Human Development Global Practice
2. The World Bank, Development Research Group
3. School of Economics at Universidad Nacional de Colombia-Bogotá

Abstract

Objectives

Previous studies have found a pattern of flatter COVID-19 age-mortality curves among low- and middle-income countries using only official COVID-19 death counts. This study examines this question by comparing the age gradient of COVID-19 mortality in a broad set of countries using both official COVID-19 death counts and excess mortality estimates for 2020.

Design

This observational study uses official COVID-19 death counts for 76 countries and excess death estimates for 42 countries. A standardized population analysis was conducted to assess the extent to which variation across countries in the age distribution of COVID-19 deaths was driven by variation in the population age distribution.

Setting and primary outcomes

Official reported COVID-19 deaths and excess deaths for 2020 for all countries where such data was available in the COVerAGE database and the Short-Term Mortality Fluctuations (STMF) harmonized data series, respectively.

Results

A higher share of pandemic-related deaths in 2020 occurred at younger ages in middle-income countries compared to high-income countries. People under age 65 constituted on average (1) 10 percent of official deaths and 11 percent of excess deaths in high-income countries, (2) 34 percent of official deaths and 33 percent of excess deaths in upper-middle-income countries, and (3) 54 percent of official deaths in lower-middle-income countries. These contrasting profiles are due only in part to differences in population age structure.

Conclusions

These findings are driven by some combination of variation in age patterns of infection rates and infection fatality rates. They indicate that COVID-19 is not just a danger to older people in developing countries, where a large share of victims are people of working age, who are caregivers and breadwinners for their families.

Strengths and limitations of this study

- This study compares the age gradient of COVID-19 mortality in a broad set of countries using both official COVID-19 death counts and excess mortality estimates for 2020.
- This represents a methodological contribution because nearly all studies of the pandemic's age mortality patterns have used only official COVID-19 death data. However, excess deaths at the aggregate population level during the pandemic exceed officially recognized COVID-19 deaths in most countries.
- Using a standardized population analysis, this study assesses the extent to which variation across countries in the age distribution of COVID-19 deaths was driven by variation in the population age distribution.
- The available data for this study does not allow ascertaining to what extent the reported differences in the age-specific mortality rates are driven by differences in age-specific cumulative infection rates or in the age-specific cumulative infection fatality rate or both.
- Because of limitations in available mortality data, the analysis includes a large set of high-and-middle income countries but does not include many low-income countries.

Introduction

An important question for understanding the global impact of the COVID-19 pandemic is the disease's age pattern of mortality across countries. Early in the pandemic, case data from COVID-19 patients in mainland China showed that COVID-19 mortality risk increases rapidly with age.[1] This risk profile would tend to limit the death toll in developing countries, which generally have younger populations. But this prediction only holds if the age profile of COVID-19 mortality remains similar across countries.

Our study examines this question by comparing the age gradient of COVID-19 mortality in a broad set of countries using both official COVID-19 death counts and excess mortality estimates for 2020. Vaccine availability was very limited before 2021 and therefore is unlikely to affect the mortality patterns identified in this analysis.

Nearly all studies of the pandemic's age mortality patterns have used only official COVID-19 death data.[2–7] Some of these studies have found a pattern of flatter COVID-19 age-mortality curves among low- and middle-income countries (LMICs) using only official COVID-19 death counts.[4],[7] However, excess deaths at the aggregate population level during the pandemic exceed officially recognized COVID-19 deaths in most countries.[8-10] Other studies have used excess mortality estimates but have mainly focused on estimating changes to life-expectancy without examining the age profile of the COVID-19 impacts on mortality.[11-13] This is to our knowledge the first study that estimates COVID-19 excess mortality by age for a wide swath of countries.

Several studies have highlighted possible contributing factors to variation across countries in overall COVID-19 mortality, including age structure of the population and preexisting health conditions and those same factors could generate different patterns in mortality by age. [14–19] When using only official death counts, it is unclear to what extent the finding of flatter COVID-19 age-mortality curves among low- and middle-income countries (LMICs) may have been driven by data reporting issues. In particular, it is possible that deaths among older people in developing countries have been more likely to be under-attributed to the disease in official COVID-19 death counts. This paper addresses that concern and examines this question by comparing the age gradient of COVID-19 mortality in a broad set of countries using both official COVID-19 death counts and excess mortality estimates for 2020.

Methods

Data sources

The analysis employs two main sources of data:

1. Official reported COVID-19 deaths drawn from the COVerAGE database, with death counts aggregated to 5-year age-groups, downloaded May 16, 2022.[20] 76 countries have a record of cumulative deaths that satisfies the inclusion criteria of covering at least 6 months since the first case was detected in the country (per case-data derived from Our World in Data[21]).
2. All-cause deaths by age drawn from national vital statistics records, aggregated in the Short-Term Mortality Fluctuations harmonized data series assembled as part of the Human Mortality Database, downloaded February 18, 2022 (38 countries).[22], [23]

Additional all-cause death data from Colombia, Mexico, Brazil, Peru and the United States was obtained from national statistical offices. [24-27] Contrary to other COVID mortality estimates such as those released by the World Health Organization, this study does not use modelled data. [9],[10] Population by age figures for each country from 2020 were taken from United Nations estimates.[28] A more detailed description of data sources is provided in an annex.

Standardized population

A standardized population analysis was conducted to assess the extent to which variation across countries in the age distribution of COVID-19 deaths was driven by variation in the population age distribution. First age-specific mortality rates were calculated by dividing the number of deaths attributed to COVID-19 for each age group by the population in each age group. These calculations were conducted for the following age groups: under 45, 45-54, 55-64, 65-74, 75-84, 85 and above. A hypothetical age distribution of deaths for each country was calculated by multiplying the age-specific COVID-19 mortality rates by corresponding population shares from the United States. A parallel calculation was carried out using estimates of excess mortality by age.

Excess mortality calculations

Excess mortality methods compare the number of deaths to the number of expected deaths during a period of interest. Excess mortality is often treated as the “gold standard” in analysis of COVID-19 mortality.[29] However, there are two issues that are often overlooked in the analysis of excess mortality.

The first issue is that estimates are sensitive to the choice of method. Many COVID-19 excess mortality calculations have estimated expected deaths as the mean number of deaths over a corresponding period in previous years. If the number of deaths was trending upward in previous years, this common approach will over-estimate excess mortality. [30], [31]

This issue is illustrated in Figure 1 for five Latin American countries. All five countries show an increase in the number of annual deaths over 2015-19. Excess death estimates based on predicting expected 2020 deaths using estimated 2015-19 linear trends (red lines) are shown as “Excess 1.” Alternative excess death estimates using a prediction based on the 2015-19 mean death count (blue lines) are shown as “Excess 2.” In all cases, ignoring the increase over time and using the historical mean to calculate expected deaths would result in substantial overestimation of excess deaths.

For the analysis in this paper, expected deaths are estimated using a simple regression using 2015-2019 historical data, run separately by country and age-group, where observed deaths are modeled as a linear function of year and an error term.

The second issue often neglected in COVID-19 excess mortality discussions is that excess mortality represents a combination of effects. Specifically,

Net excess deaths =

[Direct COVID-19 deaths] + [Indirect COVID-19 deaths] - [Averted deaths]

Direct COVID-19 deaths are those due to infection with the virus. *Indirect COVID-19 deaths* are those due in part to factors such as congestion in the health system, delays in care-seeking, or mental health issues caused by the pandemic. *Averted deaths* are those that would have taken place in the absence of the pandemic but did not occur as a result of pandemic-induced measures. These could include deaths due to other infectious diseases, violence, or traffic injuries that were avoided due to voluntary or mandated social distancing. The possibility of non-zero indirect deaths and averted deaths makes the interpretation of excess deaths more complex than is often recognized.

Slope calculation

The shape of an age-mortality curve can be summarized in terms of the percent rate of increase in the mortality rate per year of additional age after age 45, calculated by running a Poisson regression using deaths as response variable and exposures as an offset, fitting a Gompertz (1825) model to the data. [32, 33]

$$D_{x,\ i} \sim Poisson(u_i\theta_i) \ where \ \theta_i = \exp\left(\alpha_i + \ \beta_i X_i\right)$$

where the age-specific number of deaths is $D_{x,\,i}$ for the ten-year age group age x to age $x + 9$, ($x = 45, 55, 65, 75, 85$) in country i. The $x = 85$ points correspond to the group consisting of all ages 85 and above. To interpret death counts relative to person-years, an exposure term u_i is introduced as an offset in the model as $\log(u_i)$.

The coefficients, β_i, are the rates of increase per year of age in the mortality rate. This calculation was performed first defining $D(x,i)$ in terms of official COVID-19 counts by age for each country for which data was available. The calculation was also performed for each country defining $D(x,i)$ using excess mortality estimates by age as described in the previous section.[1] These results provide 1) the slope of the COVID-19 age-mortality curve according to official counts, and 2) the slope of the age-mortality curve for excess deaths.

Patient and public involvement

The study presents analysis of secondary data. There was no patient and public involvement.

Results

The left side of Figure 2 shows the age distribution of officially recorded COVID-19 deaths in 2020 by country and the age distribution of excess deaths. According to official reports, on

[1] When estimated excess deaths were zero or less, a weight of zero was assigned to such cases.

average across high-income countries, just 10 percent of deaths were among those under age 65.[2] In contrast, people under 65 constituted on average 34 percent of official COVID-19 deaths in upper-middle-income countries and 54 percent of deaths in lower-middle-income countries. The same pattern is observed using the distribution of excess deaths by age, shown on the right side of Figure 2. In high-income countries, those under 65 are 11 percent of excess deaths. For the upper-middle-income countries for which data is available (Peru, Colombia, and Mexico), the age profiles of excess deaths are similar to those of official COVID-19 deaths, and those under age 65 account for on average 33 percent of excess deaths.[3]

Figure 3 shows the hypothetical age distribution of COVID-19 deaths according to official reports, as well as excess deaths, applying the United States standardized age distribution. This controls for the differing population age distributions across countries. Unsurprisingly in low- and middle-income countries, which have younger populations than the United States, the hypothetical distribution shows an older profile of deaths as compared to the actual distribution. However, the pattern of a younger profile of deaths in less wealthy countries remains, both with official data and with excess mortality data. The numbers shown in Figures 2 and 3 can also be found in Appendix Tables A1 and A2.

Notably the United States has a much younger profile of death—using both official COVID-19 death counts and excess mortality—than countries with similar income levels. This is the case even after controlling for differences in population age distribution. The age distribution of deaths in the United States is roughly similar to that of Chile. In both countries, 27 percent of excess deaths were among those under age 65.

Figure 4 presents a visual representation of all the mortality rates by age group across all countries and economies with available data. The vertical axis represents mortality rates per 100,000 on a log scale, and it is important to note that the scale varies across countries, reflecting the different levels of exposure to the pandemic and to its related mortality across the globe.

---

[2] Note that all countries in Figure 2 from Chile downward with the exception of Turkey on the figure are classified as high-income countries. Turkey is classified as an upper-middle-income country. Bangladesh, India, the Philippines, Jordan, and Indonesia are lower-middle-income countries. World Bank classifications are based on GNI calculated by the Atlas method while the figure uses GNI calculated with purchasing power parity exchange rates.
[3] Data is also available to produce excess death estimates by age for Brazil, but not with our preferred age group breakdown.

Overall, mortality rates increase with age, albeit with different gradients. With the excess mortality data, a few deviations from this gradient are likely due to the relatively low mortality as well as the overall small number of deaths (e.g., Iceland). Australia, New Zealand and Taiwan, China have close to zero official COVID-19 deaths and show negative estimates of excess mortality rates, especially for the older age groups, likely reflecting averted deaths due to isolation policies.

Figure 5 shows a more detailed comparison of results for five Latin American countries and the United States, using the same log scale for all countries. To add perspective on the extent of COVID-19 related mortality compared to what might have been the mortality experience in the absence of the COVID-19 pandemic, each figure adds in grey the expected all-cause mortality for 2020, based on levels and trends in the 5 preceding years. For each country, the figure also reports the total cumulative deaths for 2020 using both official COVID-19 deaths and excess mortality.

Official COVID-19 death counts are higher than excess-mortality estimates in some cases. These patterns indicate that for these country-age group combinations, the number of deaths averted due to the pandemic exceeds indirect COVID-19 deaths. This could have occurred, for example, because a decline in driving and exposure to violence during lockdowns and a reduction in transmission of other infectious diseases as a result of pandemic precautions. Similar to our estimates, dos Santo et al (2021) [34] find for Brazil that total estimated excess mortality in 2020 was below the official COVID-19 death count, reflecting drops in deaths due to violence as well as cardiovascular and infectious diseases.

In Mexico, the mortality estimates using excess deaths is consistently higher than using the official COVID-19 death count, and the gap between both measures increases with age. In the United States, mortality estimates using excess deaths are also higher than using official COVID-19 deaths, but that difference decreases with age and becomes minimal for older age groups. The especially extreme impact of the pandemic in Peru is evident in Figure 5. Among those ages 45-74, both deaths attributed to COVID-19 and excess deaths exceeded total expected all-cause mortality for 2020.

Another notable pattern evident in Figure 5 is the large gap between the two measures for the United States at younger age groups. For the 15-44 age group, the excess death estimate is four times the official COVID-19 death count. Given that testing of patients with COVID-19 symptoms has been widespread in the United States in all but the early stages of the pandemic, the jump in excess mortality among young people most likely reflects indirect COVID-19 deaths.

Figure 6 explores how the slope of the age-mortality gradient for each country varies with its level of income. More precisely, it shows the exponential rate of increase in mortality by age in percent per year against 2019 GNI per capita (the numbers for the estimated rates of increase are available in Appendix Table A3). The right panel presents this plot for the 76 countries with official COVID-19 deaths data and the right displays the corresponding plot for the 34 countries with excess deaths estimates available for a consistent set of age-groups as follows: 45-54, 55-64, 65-74,75-84, 85+. Using all available data, we find that the increase in mortality risk with each additional year of age typically ranges (IQR) from 6.3 to 11.7 percent (median = 9.8) using excess deaths and 5.9 to 11.1 percent (median = 7.6) using official deaths.

Both plots show a positive association between income per capita and the age-mortality gradient, indicating that COVID-19 mortality increases more steeply for older age groups in richer countries. Using official death rate data, across countries the rate of increase of mortality risk per year of age rises by 0.11 percent for each US$1,000 of GNI. Using excess mortality data, it rises by 0.03 percent for each US$1,000 of GNI.

To verify that this observed association is not driven by the composition of both sets of countries/economies, Figure 7 repeats the same exercise with the common set of 28 countries/economies. The conclusions taken from Figures 6 and 7 are similar: COVID mortality is more concentrated among older individuals in richer countries. Using official death rate data, across countries the rate of increase of mortality risk per year of age rises by 0.13 percent for each US$1,000 of GNI. Using excess mortality data, it rises by 0.05 percent for each US$1,000 of GNI.

Discussion

The age profile of COVID-19 mortality risk in 2020 was flatter (with relatively higher mortality at younger ages) in countries with lower incomes. This pattern is found using official COVID-19 death data from a large set of countries as well as excess mortality from a smaller set of countries which include high-income countries plus Colombia, Mexico, and Peru. Our analysis concerns the year 2020 and is therefore unaffected by the arrival of COVID-19 vaccines and their unequal distribution across countries.

One limitation of this study is that the available data does not allow ascertaining to what extent the reported differences in the age-specific mortality rates are driven by differences in age-specific cumulative infection rates or in the age-specific cumulative infection fatality rate or both. Further, because of limitations in available mortality data, the analysis includes a large set of high-and-middle income countries but does not include many low-income countries. Finally, we acknowledge that, even as we used excess mortality measures to address the concern of under-reporting of official COVID-19 deaths, all causes mortality itself could also be underreported in some countries and that the extent of underreporting might vary across countries. This would however affect our analysis only to the extent that the underreporting of all causes mortality was affected by the COVID pandemic.

The findings in this paper can provide the basis for a more comprehensive accounting of the impact of COVID-19. For example, the younger mortality profile in developing countries means that in those countries the pandemic has killed large numbers of people who were of working age, many of whom were their families' breadwinners. Earlier global estimates suggest that more than 1.5 million children have experienced the death of at least one caregiver as a consequence of the pandemic.[35] This raises the concern that long-term impacts via lower investments in human capital of orphaned children will be particularly deep in developing countries. This is highly worrisome given the already massive declines in school enrollment and learning losses generated by the pandemic in developing countries.[36–38]

A full understanding of age-specific patterns of excess mortality will require country-by-country analysis using cause-of-death data, where available, to pull apart estimates of direct COVID-19 deaths, indirect COVID-19 deaths, and averted deaths. A brief comparison of Colombia and the United States highlights how components of excess mortality can vary widely by country. In Colombia, both vehicular and homicide deaths fell during the country's lockdown, reducing its excess mortality count. For 2020 vehicular deaths dropped 18.2 percent, and the number of homicides fell 5.4 percent, causing Colombia's murder rate to reach its lowest level since 1979.[39,40] In contrast, the United States excess mortality estimate for 2020 reflects in part a 7.2

percent increase in motor vehicle deaths, a 29.4 percent increase in homicides, and a 30.0 percent spike in drug overdose deaths.[41–43]

Official COVID-19 death reports and excess mortality estimates show broadly similar age patterns country-by-country. This finding, along with the fact that direct COVID-19 deaths account for the large share of excess mortality, suggests that the flatter profile of excess mortality in lower income countries is driven principally by direct COVID-19 deaths. To consider drivers of the direct COVID-19 age pattern it is useful to note that the age-specific mortality rate is the product of the age-specific cumulative infection rate (*IR*) and the age-specific cumulative infection fatality rate (*IFR*). Using a notation where $N(x,i)$ is the population of the age group in country *I*, $D(x,i)$ is the number of deaths in the age group, and $I(x,i)$ designates the cumulative number of infections of age group *x* in country *i*, this can be expressed as follows:

$$r(x,i) = \frac{D(x,i)}{N(x,i)} = \frac{I(x,i)}{N(x,i)} * \frac{D(x,i)}{I(x,i)}$$

$$= IR(x,i) * IFR\,(x,i)$$

The greater flatness of direct COVID-19 age-specific mortality rates in lower income countries could result from differing patterns across countries by age of *IR*, *IFR*, or both. A number of studies have documented possible contributing factors to variation across countries in overall COVID-19 mortality and those same factors could generate different patterns in mortality by age.[14–18]

The relative IR of younger vs. older people may vary across countries for many reasons. First, in lower income countries, a large share of the population cannot work remotely.[44] Second, in developing countries, a lower share of older people are long-term care facility residents, who are at high risk for infection and death. One-quarter of recognized COVID-19 deaths during the first few months of the pandemic in the United Kingdom were residents of care facilities, and 31 percent of recognized COVID-19 deaths in the United States as of June 1, 2021 were care facility residents or staff.[45,46] Both of these characteristics of developing countries would tend to increase the relative risk of infection for younger people. On the other hand, in low- and middle-income countries, intergenerational households are more common. This means older people are more exposed to infection risk, particularly because in those countries people are more likely to live in crowded conditions. Roughly 20 percent of households in LMICs have at least one household member under age 20 and one over age 60, as compared to just 5 percent in high-income countries.[47] In 54 LMICs with recent Demographic and Health Surveys, just half of the households have no more than two people per sleeping room.[17]

Among those infected, age-specific IFRs may vary by age due to many different factors. One systematic review found that age-specific IFRs in developing countries were roughly 2 times higher than in high-income countries.[48] Country-level factors like the profile of comorbidities, differences in health system capacity, quality of care, infection prevention and control practices, and availability of personal protective equipment, could have age-specific effects on the IFR.[18,49] A form of survivor bias may be a factor as well. High quality medical care in wealthier countries keeps many older people alive despite weak health conditions that make them vulnerable to COVID-19. It may be that older people in developing countries are on average healthier than those in wealthier countries because those with ailments would have been at high risk for death at younger ages. If this is the case, older people in developing countries might be more resilient to the disease.

Distinguishing various explanations for the observed age patterns of mortality identified in this paper should be a topic for further research. The analysis in this paper is also a reminder of the value of demographic data and in particular vital statistics as a tool amid the COVID-19 crisis. Excess mortality analysis by age presented here is only possible for countries that have well-functioning vital statistics systems and that have made their data widely available. Investments in vital statistics systems and greater data transparency should be encouraged as a global public good.

Acknowledgments

The authors express appreciation to Joshua Goldstein, Young Eun Kim, Ronald D. Lee, Norman Loayza, Andrew Noymer, Robert Oelrichs, Sharon Piza, and Philip Schellekens for helpful suggestions. The findings, interpretations, and conclusions in this paper are entirely those of the authors. They do not necessarily represent the views of the International Bank for Reconstruction and Development/World Bank and its affiliated organizations, or those of the Executive Directors of the World Bank or the governments they represent and are not intended to make any judgment on the legal or other status of geographic areas, or to prejudice the determination of any claims with respect to such area.

Funding

None

Author information

Affiliations

The World Bank, Human Development Global Practice

Gabriel Demombynes (gdemombynes@worldbank.org), Paul Gubbins (paul.gubbins@gmail.com), Jeremy Veillard (jveillard@worldbank.org)

The World Bank, Development Research Group

Damien de Walque (ddewalque@worldbank.org)

School of Economics at Universidad Nacional de Colombia-Bogotá

B. Piedad Urdinola (bpurdinolac@unal.edu.co)

Data availability statement

The data availability section in the online appendix describes the data sources used for this study. Upon acceptance a link to Github repository will be made available to facilitate replication.

Author Contributions

The study and the methodology were conceived by GD, DdW, PG, BPU and JV. GD and PG conducted the formal analysis and validated the results. GD, DdW, PG, BPU and JV collaborated on writing the paper.

Ethics Declaration

Ethics approval was not sought as the study presents results of an analysis of secondary data and does not involve human participants.

Competing interests

The authors declare no competing interests.

References

1. Verity, R. *et al.* Estimates of the severity of coronavirus disease 2019: a model-based analysis. *Lancet Infect. Dis.* 2020: **20**, 669–677.
2. Sasson, I. Age and COVID-19 mortality: A comparison of Gompertz doubling time across countries and causes of death. *Demogr. Res.* 2021: **44**, 379–396.
3. Demombynes, G. COVID-19 Age-Mortality Curves Are Flatter in Developing Countries. World Bank Policy Research Working Paper. 2020. 9313.
4. Shapiro, V. COVID-19 Outbreaks and Age Mortality Patterns. 2020.
5. Goldstein, J. R. & Lee, R. D. Demographic perspectives on the mortality of COVID-19 and other epidemics. *Proc. Natl. Acad. Sci.* 2020: **117**, 22035–22041.
6. Sudharsanan, N., Didzun, O., Bärnighausen, T. & Geldsetzer, P. The Contribution of the Age Distribution of Cases to COVID-19 Case Fatality Across Countries: A Nine-Country Demographic Study. *Ann. Intern. Med.* 2020:**173**, 714–720.
7. Chauvin, J. P., Folwer, A. & Herrera, L. N. The Younger Age Profile of Covid-19 Deaths in Developing Countries. 2020. *Washington DC*.
8. Karlinsky, A. & Kobak, D. Tracking excess mortality across countries during the COVID-19 pandemic with the World Mortality Dataset. *Elife* 2021:**10**, e69336.
9. World Health Organization. Global excess deaths associated with COVID-19 (modelled estimates). May 5, 2022 Update. https://www.who.int/data/sets/global-excess-deaths-associated-with-covid-19-modelled-estimates
10. Knutson, V., Aleshin-Guendel, S., Karlinsky, A., Msemburi, W. and Wakefield, J., 2022. Estimating Global and Country-Specific Excess Mortality During the COVID-19 Pandemic. *arXiv preprint arXiv:2205.09081*.

11. Aburto, J.M., Jonas Schöley, Ilya Kashnitsky, Luyin Zhang, Charles Rahal, Trifon I Missov, Melinda C Mills, Jennifer B Dowd, Ridhi Kashyap, Quantifying impacts of the COVID-19 pandemic through life-expectancy losses: a population-level study of 29 countries, *International Journal of Epidemiology*, 2021,

12. Islam N, Jdanov D A, Shkolnikov V M, Khunti K, Kawachi I, White M et al. Effects of covid-19 pandemic on life expectancy and premature mortality in 2020: time series analysis in 37 countries *BMJ* 2021: 375:e066768

13. Castro, M.C., Gurzenda, S., Turra, C.M. *et al.* Reduction in life expectancy in Brazil after COVID-19. *Nat Med* 2021: **27,** 1629–1635.

14. Schellekens, I. G. and P. COVID-19 is a developing country pandemic. *Brookings* https://www.brookings.edu/blog/future-development/2021/05/27/covid-19-is-a-developing-country-pandemic/ (2021).

15. Schellekens, P. & Sourrouille, D. M. COVID-19 Mortality in Rich and Poor Countries: A Tale of Two Pandemics? World Bank Policy Research Working Paper 2020: 9260.

16. Walker, P. G. *et al.* The impact of COVID-19 and strategies for mitigation and suppression in low-and middle-income countries. *Science* 2020: 369, 413–422 2020.

17. Brown, C. S., Ravallion, M. & van de Walle, D. *Can the World's Poor Protect Themselves from the New Coronavirus?* 2020.

18. Ghisolfi, S. *et al.* Predicted COVID-19 fatality rates based on age, sex, comorbidities and health system capacity. *BMJ Glob. Health* 2020: **5**, e003094.

19. Ashton M Verdery, PhD, Lauren Newmyer, MA, Brandon Wagner, PhD, Rachel Margolis, PhD, National Profiles of Coronavirus Disease 2019 Mortality Risks by Age Structure and

Preexisting Health Conditions, *The Gerontologist*, Volume 61, Issue 1, February 2021, Pages 71–77, https://doi.org/10.1093/geront/gnaa152

[dataset] 20. Riffe, T., Acosta, E., & the COVerAGE-DB team. Data Resource Profile: COVerAGE-DB: a global demographic database of COVID-19 cases and deaths. *Int. J. Epidemiol.* 2021: **50**, 390–390f. https://doi.org/10.1093/ije/dyab027

21. Hannah Ritchie, Edouard Mathieu, Lucas Rodés-Guirao, Cameron Appel, Charlie Giattino, Esteban Ortiz-Ospina, Joe Hasell, Bobbie Macdonald, Diana Beltekian and Max Roser (2020) - "Coronavirus Pandemic (COVID-19)". *Published online at OurWorldInData.org.* Retrieved from: 'https://ourworldindata.org/coronavirus' [Online Resource]

22. Jdanov, D. A. *et al.* The short-term mortality fluctuation data series, monitoring mortality shocks across time and space. *Sci. Data* 2021: **8**, 235.

[dataset] 23. Human Mortality Database. University of California, Berkeley (USA), and Max Planck Institute for Demographic Research (Germany). Available at www.mortality.org or www.humanmortality.de (data downloaded on February 18, 2022).

[dataset] 24. DANE. 2022. Defunciones No Fetales. Dirreción Nacional de Estadistidica, Bogota, Colombia. https://www.dane.gov.co/index.php/estadisticas-por-tema/salud/nacimientos-y-defunciones/defunciones-no-fetales (data downloaded on February 18, 2022).

[dataset] 25. INEGI. 2022. Defunciones Registrada mortalidad general. Instituto Nacional de Estadística, Geografía e Informática (INEGI), Aguascalientes, Mexico. https://www.inegi.org.mx/programas/mortalidad/#Microdatos (data downloaded on February 18, 2022).

[dataset] 26. SINADEF. 2022. Certificado Defunciones. Sistema Informato de Defunciones. Lima, Peru: https://www.datosabiertos.gob.pe/dataset/sinadef-certificado-

defunciones/resource/fef60d30-c135-4b51-82e1-a642ef29fe79 (data downloaded on February 18, 2022).

[dataset] 27. Ministério da Saúde. 2022. Mortalidada – Brasil. Ministério da Saúde, Brazilia, Brazil. http://tabnet.datasus.gov.br/cgi/deftohtm.exe?sim/cnv/obt10uf.def (data downloaded on February 18, 2022).

28. DESA, U. World Population Prospects 2019. United Nations. Department of Economic and Social Affairs. 2019. *World Popul. Prospects 2019*.

29. Beaney, T. *et al.* Excess mortality: the gold standard in measuring the impact of COVID-19 worldwide? *J. R. Soc. Med.* 2020: **113**, 329–334.

30. Nepomuceno, M.R., Klimkin, I., Jdanov, D.A., Alustiza-Galarza, A. and Shkolnikov, V.M. (2022). Sensitivity Analysis of Excess Mortality due to the COVID-19 Pandemic. Population and Development Review. https://doi.org/10.1111/padr.12475

31. Schöley, J. (2021). Robustness and bias of European excess death estimates in 2020 under varying model specifications. MedRxiv. https://doi.org/10.1101/2021.06.04.21258353

32. Brillinger, D. R. (1986). A biometrics invited paper with discussion: The natural variability of vital rates and associated statistics. Biometrics, 42(4):693–734.

33. Gompertz, B. (1825). On the nature of the function expressive of the law of human mortality, and on a new mode of determining the value of life contingencies. Philosophical Transactions of the Royal Society of London, 115:513–583.

34. Santos, A. M. dos, Souza, B. F. de, Carvalho, C. A. de, Campos, M. A. G., Oliveira, B. L. C. A. de, Diniz, E. M., Branco, M. dos R. F. C. ., Queiroz, R. C. de S. ., Carvalho, V. A. de, Araújo, W. R. M., & Silva, A. A. M. da. (2021). Excess deaths from all causes and by

COVID-19 in Brazil in 2020. *Revista De Saúde Pública*, *55*, 71. https://doi.org/10.11606/s1518-8787.2021055004137

35. Hillis, S. D. *et al.* Global minimum estimates of children affected by COVID-19-associated orphanhood and deaths of caregivers: a modelling study. *The Lancet* 2021: **398**, 391–402.

36. Bundervoet, T., Dávalos, M. E. & Garcia, N. *The Short-Term Impacts of COVID-19 on Households in Developing Countries: An Overview Based on a Harmonized Data Set of High-Frequency Surveys*. The World Bank, 2021. doi:10.1596/1813-9450-9582.

37. Miguel, E. & Mobarak, A. M. The Economics of the COVID-19 Pandemic in Poor Countries. *Annu. Rev. Econ.* 2021 doi:https:// doi.org/10.1146/annurev-economics-051520-025412.

38. Azevedo, J. P., Hasan, A., Goldemberg, D., Geven, K. & Iqbal, S. A. Simulating the potential impacts of COVID-19 school closures on schooling and learning outcomes: A set of global estimates. *World Bank Res. Obs.* 2021: **36**, 1–40.

39. Departamento Administrativo Nacional de Estadística. Cuadros unificados: Defunciones no fetales cifras definitivas 2019. 2020.

40. Departamento Administrativo Nacional de Estadística. Cuadros unificados: Defunciones no fetales acumulado año 2020pr. 2021.

41. National Center for Statistics and Analysis. Early Estimate of Motor Vehicle Traffic Fatalities in 2020. 2021.

42. Krishnakumar, P. Murders rose sharply in 2020 but data is lacking across much of the country. 2021.

43. National Center for Health Statistics. Provisional Drug Overdose Death Counts. 2021.

44. Garrote Sanchez, D. *et al.* Who on earth can work from home? 2020.

45. Public Health England. *Disparities in the risk and outcomes of COVID-19*. 2020.

46. The New York Times, Nearly One-Third of U.S. Coronavirus Deaths Are Linked to Nursing Homes. *The New York Times*. 2020.

47. Winskill, P. *et al. Report 22: Equity in response to the COVID-19 pandemic: an assessment of the direct and indirect impacts on disadvantaged and vulnerable populations in low-and lower middle-income countries WHO Collaborating Centre for Infectious Disease Modelling MRC Centre for Global Infectious Disease Analysis*. 2020.

48. Levin AT, Owusu-Boaitey N, Pugh S*, et al*. Assessing the burden of COVID-19 in developing countries: systematic review, meta-analysis and public policy implications *BMJ Global Health* 2022;**7:**e008477.

49. Nepomuceno, M. R. *et al.* Besides population age structure, health and other demographic factors can contribute to understanding the COVID-19 burden. 2020. *Proc. Natl. Acad. Sci.* **117**, 13881–13883.

Figures Legend/Caption

Figure 1: Actual and predicted total deaths (all causes) by year, select countries in LAC

Figure 2: Age distribution of official COVID-19 deaths and excess deaths in 2020

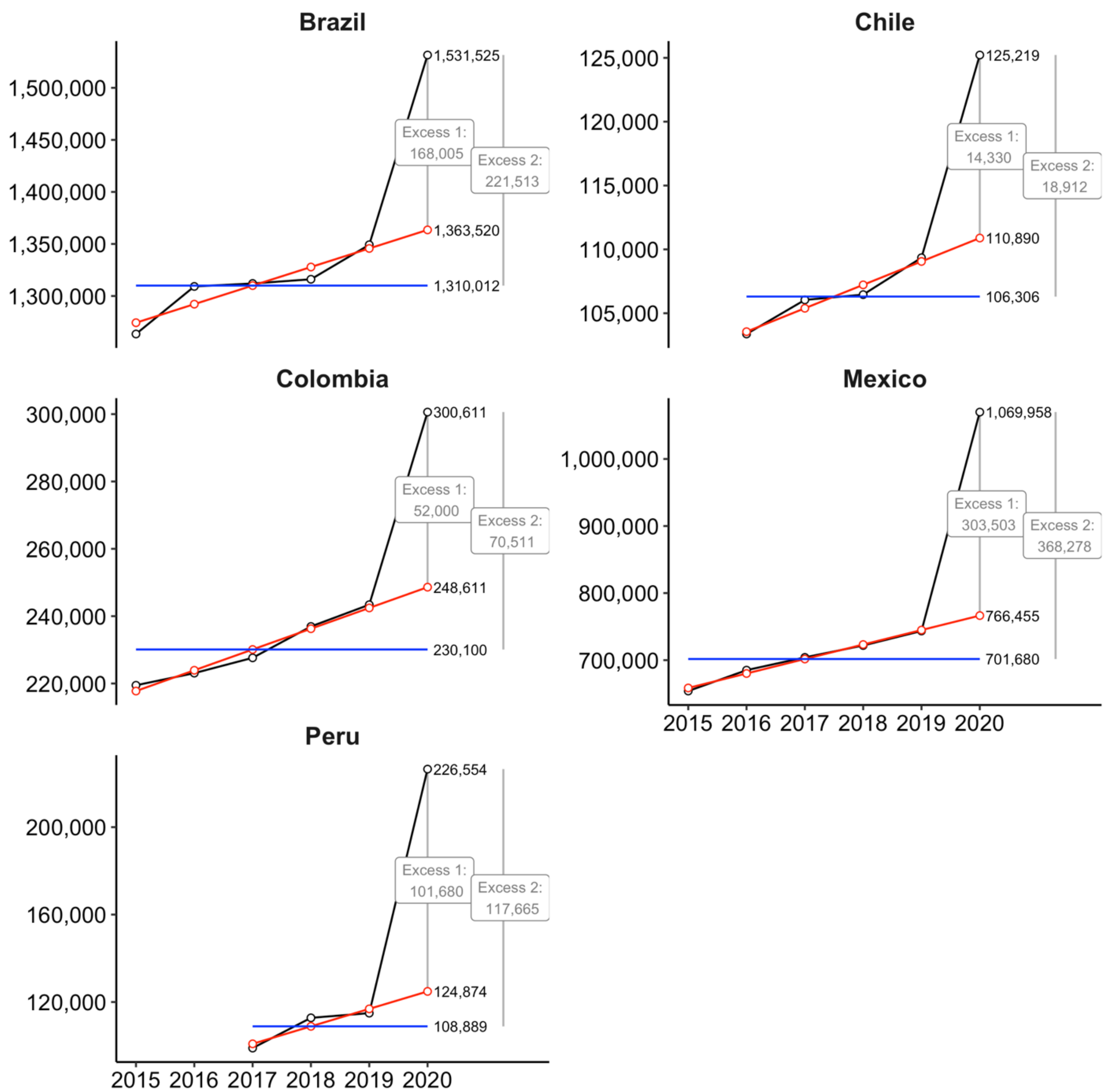
Figure 3: Hypothetical age distribution of official COVID-19 and excess deaths in 2020, using country age-specific mortality rates and the US population age distribution

Figure 4: Official COVID-19 vs excess deaths by age group (per 100,000 population) [log scale]

Figure 5: Official COVID-19 vs excess deaths by age group, select Latin American countries and the United States (per 100,000 population)

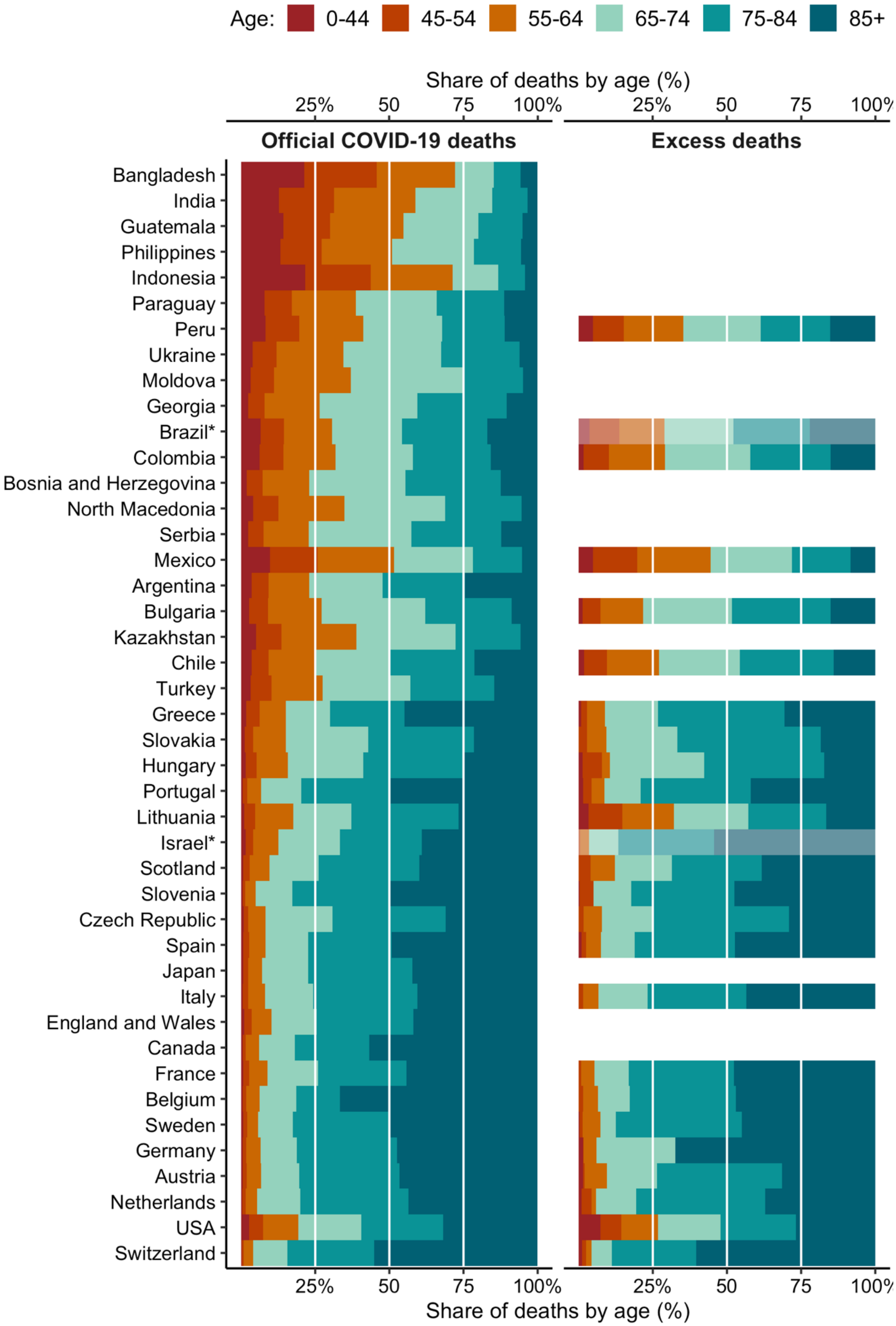
Figure 6: Slope of the age-mortality curve vs GNI per capita, official COVID-19 deaths vs excess deaths, all data Poisson model (estimates use all age group and deaths recoded to 0 where they are negative)

Figure 7: Slope of the age-mortality curve vs GNI per capita, official COVID-19 deaths vs excess deaths common set of countries/economies. Poisson model (estimates use all age group and deaths recoded to 0 where they are negative)



Notes: Actual deaths are shown in black. Predicted deaths based on a linear projection using annual mortality totals 2015-19 are shown in red. Mean deaths 2015-19 are shown in blue.

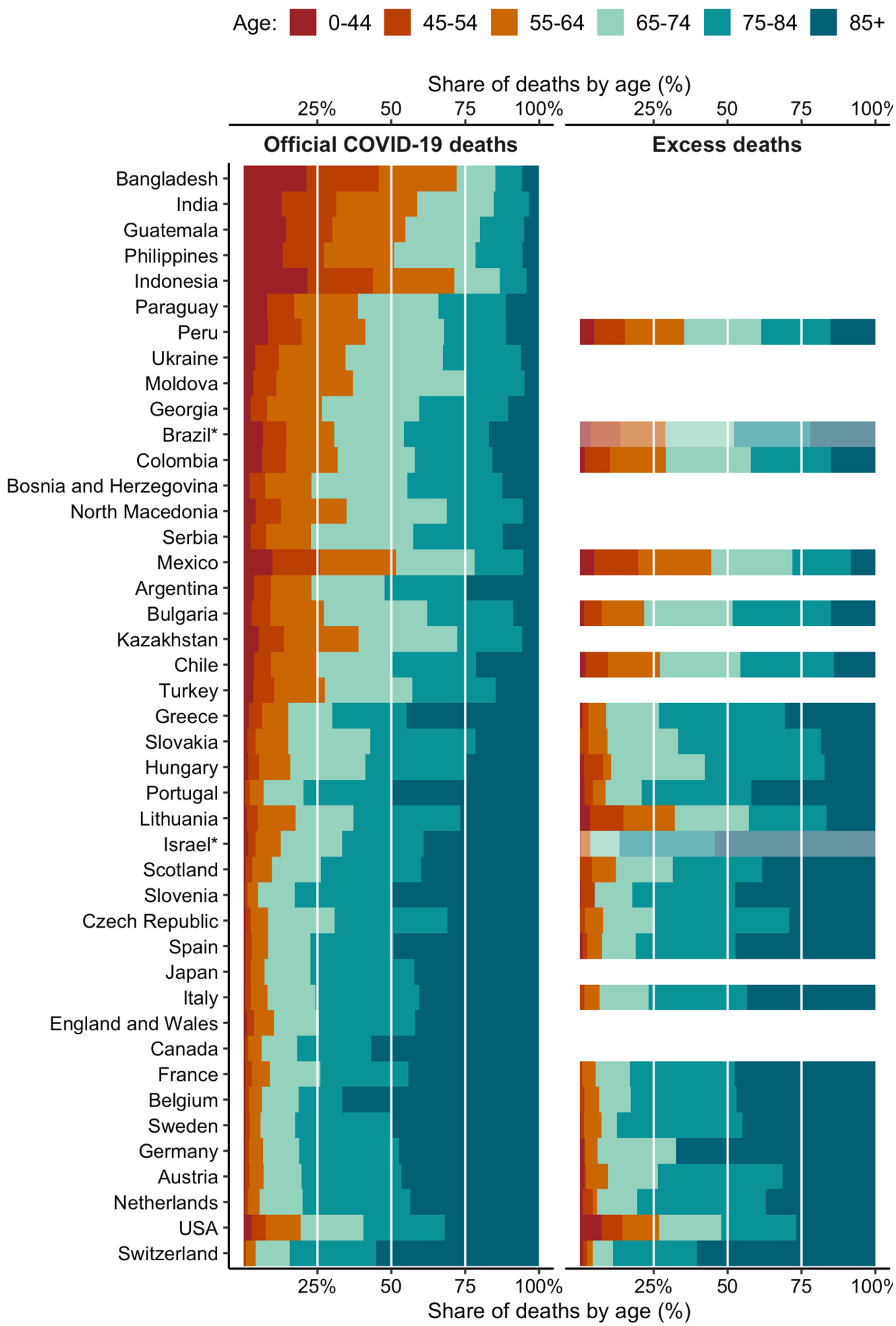
Figure 1: Actual and predicted total deaths (all causes) by year, select countries in LAC



Age: 0-44 45-54 55-64 65-74 75-84 85+
Share of deaths by age (%)
25% 50 75 100%
Official COVID-19 deaths
Excess deaths
Bangladesh
India
Guatemala
Philippines
Indonesia
Paraguay
Peru
Ukraine
Moldova
Georgia
Brazil*
Colombia
Bosnia and Herzegovina
North Macedonia
Serbia
Mexico
Argentina
Bulgaria
Kazakhstan
Chile
Turkey
Greece
Slovakia
Hungary
Portugal
Lithuania
Israel*
Scotland
Slovenia
Czech Republic
Spain
Japan
Italy
England and Wales
Canada
France
Belgium
Sweden
Germany
Austria
Netherlands
USA
Switzerland

Notes: Countries with fewer than 2000 official COVID-19 deaths are excluded. The age-groups available to compute excess deaths for Brazil and Israel differ from those available in other countries. For Brazil and Israel, the age groups are: 0-39, 40-49, 50-59, 60-69, 70-79, 80+. Negative excess deaths estimated in the Philippines (age-groups 0-44 75-84 and 85+), Slovenia (55-64) and Scotland (0-44) are re-coded to zero. Countries are sorted by 2019 GNI per capita (PPP).

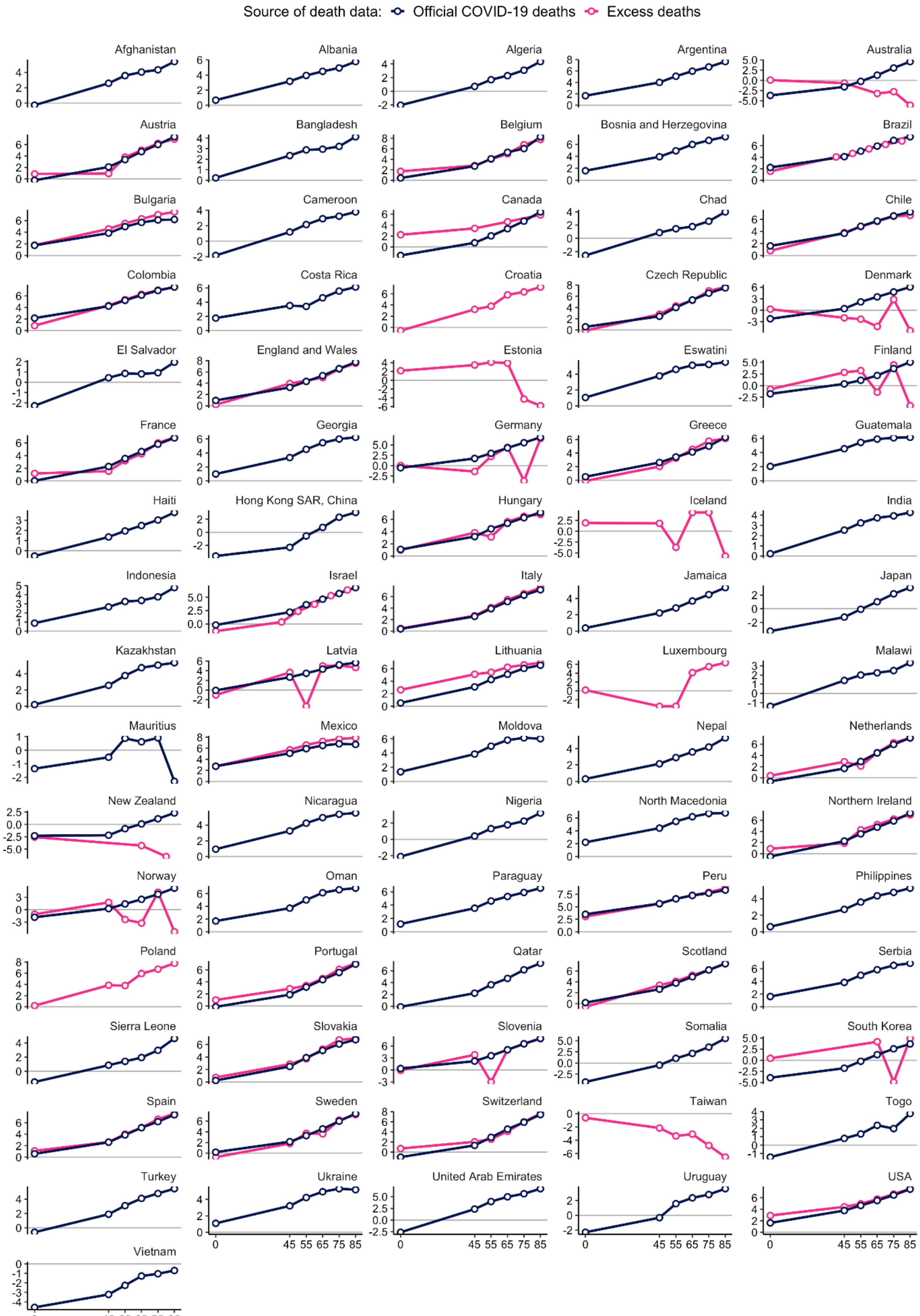
Figure 2: Age distribution of official COVID-19 deaths and excess deaths in 2020



Age: 0-44 45-54 55-64 65-74 75-84 85+
Share of deaths by age (%)
25% 50 75 100%
Official COVID-19 deaths
Excess deaths
Bangladesh
India
Guatemala
Philippines
Indonesia
Paraguay
Peru
Ukraine
Moldova
Georgia
Brazil*
Colombia
Bosnia and Herzegovina
North Macedonia
Serbia
Mexico
Argentina
Bulgaria
Kazakhstan
Chile
Turkey
Greece
Slovakia
Hungary
Portugal
Lithuania
Israel*
Scotland
Slovenia
Czech Republic
Spain
Japan
Italy
England and Wales
Canada
France
Belgium
Sweden
Germany
Austria
Netherlands
USA
Switzerland

Notes: Countries with fewer than 2000 official COVID-19 deaths are excluded. The age-groups available to compute excess deaths for Brazil and Israel differ from those available in other countries. For Brazil and Israel, the age groups are: 0-39, 40-49, 50-59, 60-69, 70-79, 80+; Negative excess deaths estimated in the Philippines (age-groups 0-44 75-84 and 85+), Slovenia (55-64) and Scotland (0-44) are re-coded to zero. Countries are sorted by 2019 GNI per capita (PPP).

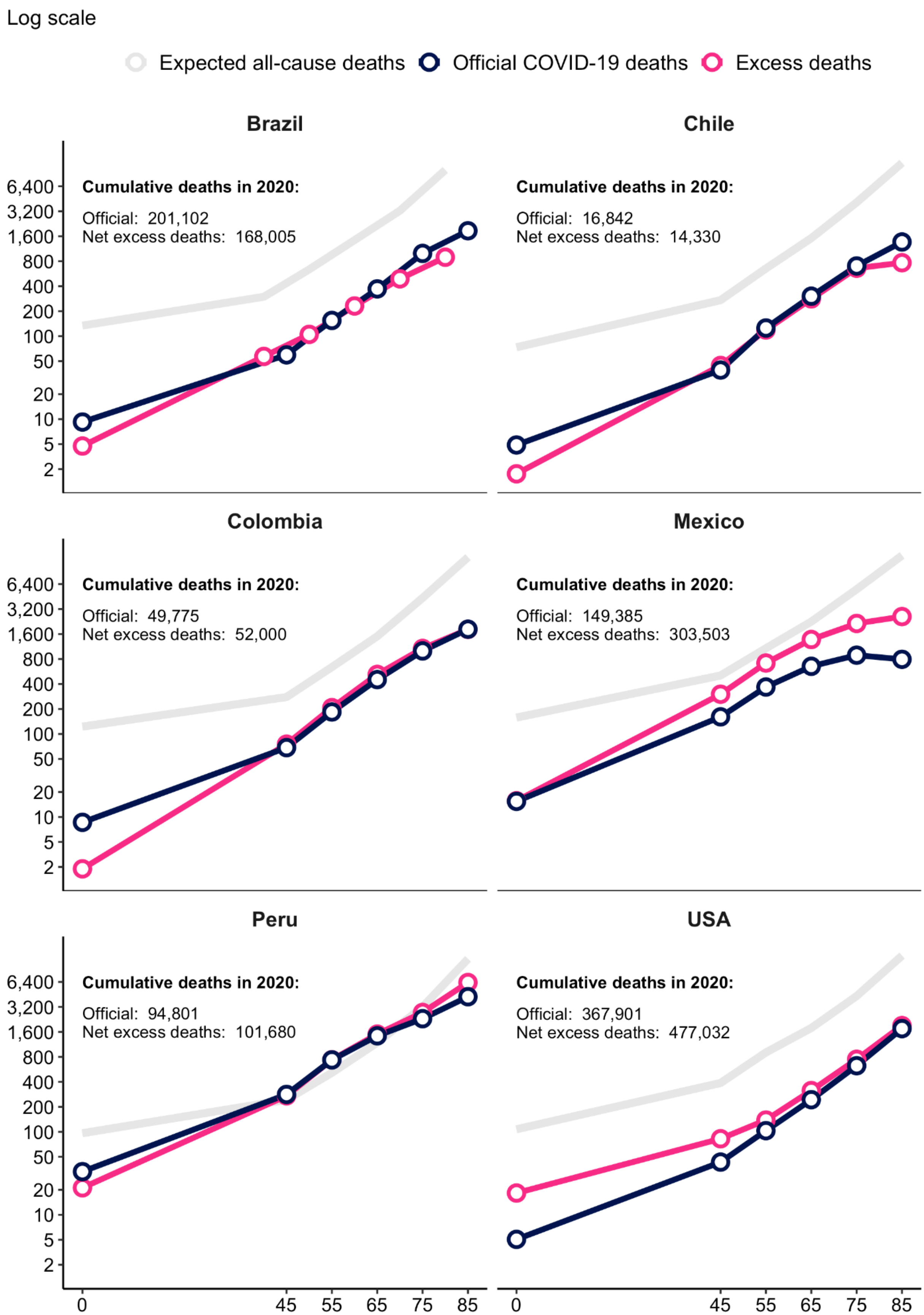
Figure 3: Hypothetical age distribution of official COVID-19 and excess deaths in 2020, using country age-specific mortality rates and the US population age distribution



Source of death data: Official COVID-19 deaths Excess deaths
Afghanistan
Albania
Algeria
Argentina
Australia
Austria
Bangladesh
Belgium
Bosnia and Herzegovina
Brazil
Bulgaria
Cameroon
Canada
Chad
Chile
Colombia
Costa Rica
Croatia
Czech Republic
Denmark
El Salvador
England and Wales
Estonia
Eswatini
Finland
France
Georgia
Germany
Greece
Guatemala
Haiti
Hong Kong SAR, China
Hungary
Iceland
India
Indonesia
Israel
Italy
Jamaica
Japan
Kazakhstan
Latvia
Lithuania
Luxembourg
Malawi
Mauritius
Mexico
Moldova
Nepal
Netherlands
New Zealand
Nicaragua
Nigeria
North Macedonia
Northern Ireland
Norway
Oman
Paraguay
Peru
Philippines
Poland
Portugal
Qatar
Scotland
Serbia
Sierra Leone
Slovakia
Slovenia
Somalia
South Korea
Spain
Sweden
Switzerland
Taiwan
Togo
Turkey
Ukraine
United Arab Emirates
Uruguay
USA
Vietnam
0 45 55 65 75 85

Note: Points are plotted at the start of each age group: 0-44,45-54,55-64,65-74,75-84, 85+
Vertical axis labels are expressed as log (deaths/100,000 population).

Figure 4: Official COVID-19 vs excess deaths by age group (per 100,000 population) [log scale]


Log scale
Expected all-cause deaths
Official COVID-19 deaths
Excess deaths
Brazil
Cumulative deaths in 2020:
Official: 201,102
Net excess deaths: 168,005
Chile
Cumulative deaths in 2020:
Official: 16,842
Net excess deaths: 14,330
Colombia
Cumulative deaths in 2020:
Official: 49,775
Net excess deaths: 52,000
Mexico
Cumulative deaths in 2020:
Official: 149,385
Net excess deaths: 303,503
Peru
Cumulative deaths in 2020:
Official: 94,801
Net excess deaths: 101,680
USA
Cumulative deaths in 2020:
Official: 367,901
Net excess deaths: 477,032
6,400
3,200
1,600
800
400
200
100
50
20
10
5
2
0
45
55
65
75
85

Note: Points are plotted at the start of each age group: 0-44,45-54,55-64,65-74,75-84, 85+. Brazil has different age group categories. The excess mortality calculation for Chile is based on the first 52 weeks of the ISO calendar year and thus excludes the last 4 days of the calendar year.

Figure 5: Official COVID-19 vs excess deaths by age group, select Latin American countries and the United States (per 100,000 population)

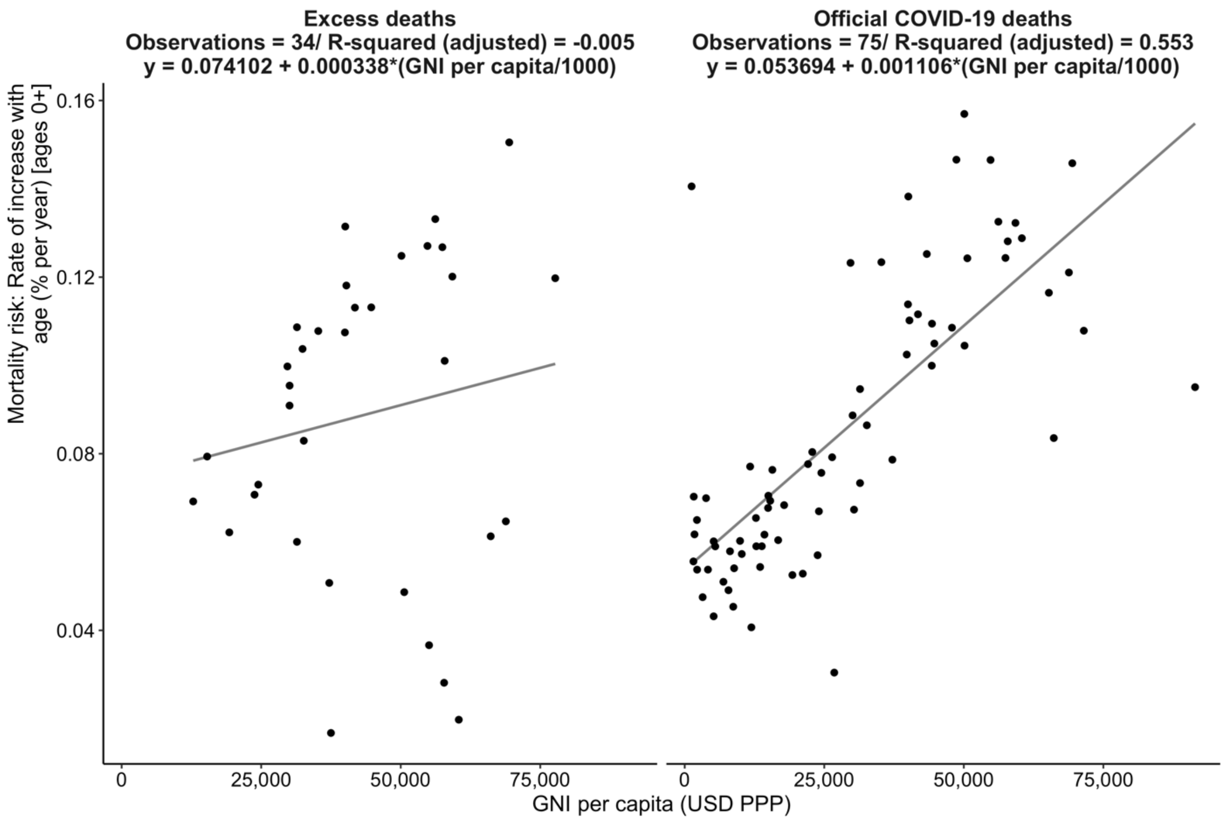


Figure 6: Slope of the age-mortality curve vs GNI per capita, official COVID-19 deaths vs excess deaths, all data Poisson model (estimates use all age group and deaths recoded to 0 where they are negative)

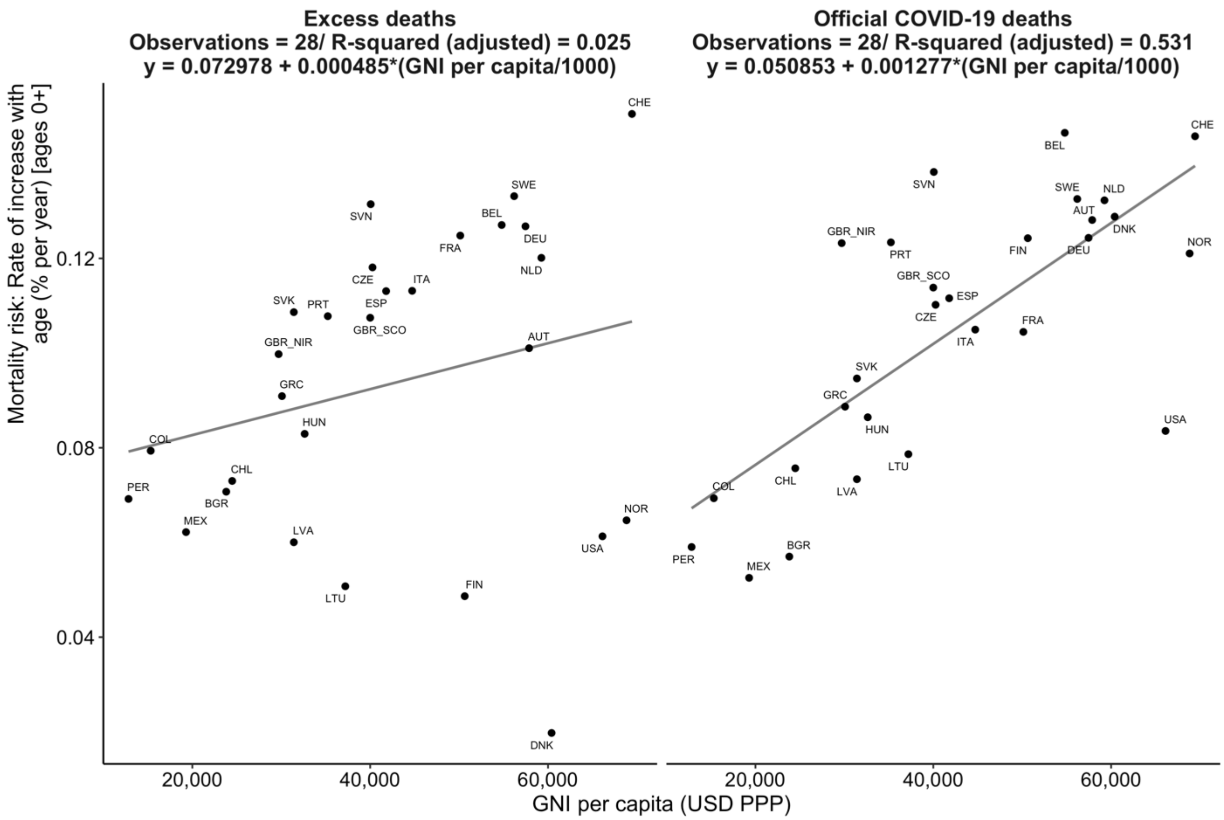


Figure 7: Slope of the age-mortality curve vs GNI per capita, official COVID-19 deaths vs excess deaths common set of countries/economies. Poisson model (estimates use all age group and deaths recoded to 0 where they are negative)

Online Appendix

Data Availability

Data sources

Official reported COVID-19 deaths aggregated in the COVerAGE database (Output_5.zip Version 395 downloaded May 16, 2022 from https://osf.io/7tnfh/. For this analysis the output file with death counts aggregated to 5-year age-groups is used [20].

There are 125 countries in the COVerAGE database (excluding England and United Kingdom). For this analysis, the political units that make up the United Kingdom are treated separately as follows: England and Wales, Scotland, and Northern Ireland.

85 countries have at least one record of cumulative deaths during 2020.

76 countries have a record of cumulative deaths that covers at least 6 months since the first case was detected in the country (per case-data derived from Our World in Data). Countries with an "exposure" of less than 6 months as of the end of 2020 are excluded from the analysis.

The following is the set of 76 countries and economies with official reported deaths used in the analysis: Afghanistan; Albania; Algeria; Argentina; Australia; Austria; Bangladesh; Belgium; Bosnia and Herzegovina; Brazil; Bulgaria; Cameroon; Canada; Chad; Chile; Colombia; Costa Rica; Czech Republic; Denmark; El Salvador; England and Wales; Eswatini; Finland; France; Georgia; Germany; Greece; Guatemala; Haiti; Hong Kong SAR, China; Hungary; India; Indonesia; Israel; Italy; Jamaica; Japan; Jordan; Kazakhstan; Latvia; Lithuania; Malawi; Mauritius; Mexico; Moldova; Nepal; Netherlands; New Zealand; Nicaragua; Nigeria; North Macedonia; Northern Ireland; Norway; Oman; Paraguay; Peru; Philippines; Portugal;; Qatar; Scotland; Serbia; Sierra Leone; Slovak Republic; Slovenia; Somalia; Republic of Korea; Spain; Sweden; Switzerland; Togo; Turkey; Ukraine; United Arab Emirates; Uruguay; United States; Vietnam.

Excess all-cause deaths from vital statistics records, from the following sources:

Short term mortality fluctuations (STMF) harmonized data series from the Human Mortality Database [23], downloaded February 18, 2022 from https://www.mortality.org

For Colombia, Peru, Mexico, Brazil and the USA all cause death data are sources from national statistical authorities.

- For this analysis, the STMF input files are used. These input files cover 38 countries and economies: Australia; Austria; Belgium; Bulgaria; Canada; Switzerland; Chile; Czech Republic; Germany; Denmark; Spain; Estonia; Finland; France; Northern Ireland; Scotland; England and Wales; Greece; Croatia; Hungary; Iceland; Israel; Italy; Republic of Korea; Lithuania; Luxembourg; Latvia; Netherlands; Norway; New Zealand; Poland; Portugal; Russian Federation; Slovak Republic; Slovenia; Sweden; Taiwan, China; United States.
- Russia does not have data for 2020.
- Chile and Germany do not have data for 2015.

Colombia vital statistics tabulations (*Defunciones no fetales*) were compiled by DANE. 2019 and 2020 tabulations are preliminary [24].

Mexico vital statistics microdata are those compiled by INEGI (*Defunciones registradas, mortalidad general*) and cover 2015-2020 [25].

Peru death certificate microdata were compiled by SINADEF [26] obtained through the government's open data portal. These data cover 2017-2021.

Brazil vital statistics tabulations are obtained from the Ministry of Health's Sistema de Informação sobre Mortalidade (SIM) data portal [27]
http://tabnet.datasus.gov.br/cgi/deftohtm.exe?sim/cnv/obt10uf.def

Together there are 41 countries and economies with excess death estimates: Austria; Belgium; Brazil; Bulgaria; Switzerland; Chile; Czech Republic; Germany; Denmark; Spain; Estonia; Finland; France; Scotland; Greece; Croatia; Hungary; Iceland; Italy; Lithuania; Luxembourg; Latvia; Netherlands; Norway; Poland; Portugal; Slovak Republic; Slovenia; Sweden; Taiwan, Colombia; Peru; Mexico; England and Wales; United States; Australia; Canada; Israel; Republic of Korea; New Zealand.

Of these, four do not have corresponding official death records from the coverage database: Estonia, Croatia, Luxembourg, and Poland.

For all countries, the official COVID-19 death data is drawn from the COVerAGE database and the figures correspond to calendar year 2020. The excess mortality estimates are based principally on all-cause data compiled in the Short Term Mortality Fluctuations (SMTF) database and reported in terms of deaths by week, using weeks as defined by the International Organization for Standardization (ISO) weeks. All ISO weeks start on a Monday and end on a Sunday and thus do not conform precisely to the calendar year. There are 52 ISO weeks in most years but 53 ISO weeks in 2015 and 2020. Including all 53 ISO weeks for 2020 in the excess mortality calculations would result in an overestimate of excess mortality. In order to ensure that the excess mortality calculations are based on an identical number of days in each year, we use the first 52 weeks of each year, excluding week 53 from the calculations for 2015 and 2020 for all cases where the data comes from SMTF. The 52-week ISO year for 2020 thus starts December 30, 2019, and ends December 27, 2020. For the Brazil, Colombia, Mexico, Peru and United States excess mortality estimates, which are based on data sourced directly to national statistical agencies, we use the full calendar year.

The preferred age group categories for the analyses conducted in this paper were as follows: 0-14, 15-44, 45-54, 55-64, 65-74, 75-84, 85+. However, since the reporting of all-cause deaths by age used by the Human Mortality Database is not consistent from country to country (not all countries report death counts tabulated at 5-year intervals or less), successively broader age-groupings are used in cases where the preferred age groups could not be constructed directly from the STMF input data. These countries include the United States, England and Wales, Australia, Canada, New Zealand, Israel and the Republic of Korea. We compute excess mortality rates for all unique country-age group combinations (as shown in Figure 4) but to estimate the age gradient of mortality, we only include countries for which we could construct the preferred age-group categories as described above. Countries for which we could not construct the preferred age-group categories are Brazil, Israel, and New Zealand. To avoid excluding the United States from this analysis, we use mortality data from the CDC which reports deaths for consistent age groups for 2015 through 2020.

Annex Table A1: Age Distribution of Official COVID-19 Deaths and Excess Deaths in 2020 (Data Shown in Figure 2)

			Share (%) of official COVID-19 deaths by age group						Share (%) of excess mortality deaths by age group					
Country	GNI per capita (PPP)	World Bank Income Group	0-44	45-54	55-64	65-74	75-84	85+	0-44	45-54	55-64	65-74	75-84	85+
Bangladesh	5,180	LMIC	21	25	27	13	9	6						
India	6,930	LMIC	13	19	27	26	12	3						
Guatemala	8,850	UMIC	14	16	25	25	15	5						
Philippines	10,220	LMIC	13	14	24	28	16	6						
Indonesia	11,940	LMIC	22	22	28	15	9	4						
Paraguay	12,760	UMIC	8	9	22	27	23	11						
Peru	12,820	UMIC	8	11	22	27	21	11	5	10	20	26	23	15
Ukraine	13,510	LMIC	4	8	23	33	26	6						
Moldova	14,280	LMIC	3	8	26	38	20	5						
Georgia	14,930	UMIC	2	6	19	33	30	10						
Brazil*	14,980	UMIC	7	8	16	24	29	17	4	10	15	23	26	22
Colombia	15,320	UMIC	6	8	18	26	26	16	2	9	19	29	27	15
Bosnia and Herzegovina	15,700	UMIC	2	5	16	32	32	13						
North Macedonia	16,740	UMIC	4	9	22	34	26	6						
Serbia	17,810	UMIC	2	5	15	35	30	12						
Mexico	19,290	UMIC	10	16	26	27	17	5	5	15	25	28	20	8
Argentina	22,090	UMIC	4	6	14	25	28	25						
Bulgaria	23,810	UMIC	3	6	18	35	29	9	1	6	14	30	33	15
Kazakhstan	24,040	UMIC	5	9	25	34	22	6						
Chile	24,480	HIC	4	6	16	25	29	21	2	8	18	27	32	14
Turkey	26,410	UMIC	3	7	17	30	28	15						
Greece	30,080	HIC	2	5	9	15	25	45	1	2	6	18	43	31
Slovakia	31,410	HIC	1	3	11	28	36	22	0	3	6	24	48	19
Hungary	32,630	HIC	2	4	11	25	34	25	1	7	3	32	40	17
Portugal	35,230	HIC	1	2	5	14	30	50	1	3	4	12	37	42

Lithuania	37,200	HIC	1	4	13	20	36	27	3	11	17	25	26	17
Israel*	39,780	HIC	2	3	8	21	28	39	0	1	3	10	32	54
Scotland	40,000	HIC	1	2	7	17	34	40	0	4	8	19	30	38
Slovenia	40,060	HIC	1	1	3	12	33	50	0	5	0	13	35	48
Czech Republic	40,260	HIC	1	2	6	23	38	31	0	2	6	17	46	29
Spain	41,790	HIC	1	2	6	14	28	49	1	2	5	11	34	47
Japan	44,260	HIC	1	2	5	16	35	42						
Italy	44,720	HIC	1	2	6	16	35	41	0	1	5	17	33	43
England and Wales	47,880	HIC	1	3	7	15	33	42						
Canada	48,670	HIC	1	1	4	12	25	57						
France	50,130	HIC	1	2	6	17	30	44	0	1	4	12	35	48
Belgium	54,790	HIC	1	1	5	12	15	67	0	2	5	11	36	47
Sweden	56,190	HIC	1	1	4	12	32	50	0	1	6	5	43	45
Germany	57,460	HIC	1	1	5	12	34	47	2	0	4	27	0	67
Austria	57,870	HIC	1	1	5	13	34	47	2	0	8	17	42	31
Netherlands	59,250	HIC	0	1	4	15	37	44	1	3	2	14	43	37
USA	66,120	HIC	3	5	12	21	28	32	7	7	12	21	25	27
Switzerland	69,440	HIC	0	1	3	12	29	55	1	1	2	7	29	60

* The age groups available to compute excess deaths for Brazil differ from those used in other countries and correspond to the following: 0-39, 40-49, 50-59, 60-69, 70-79, 80+. GNI is from 2019.

Annex Table A2: Hypothetical Age Distribution of Official COVID-19 and Excess Deaths in 2020, Using Country Age-Specific Mortality Rates and the US Population Age Distribution (Data Shown in Figure 3)

			Share (%) of official COVID-19 deaths by age group						Share (%) of excess mortality deaths by age group					
Country	GNI per capita (PPP)	World Bank Income Group	0-44	45-54	55-64	65-74	75-84	85+	0-44	45-54	55-64	65-74	75-84	85+
Bangladesh	5,180	LMIC	21	25	27	13	9	6						
India	6,930	LMIC	13	19	27	26	12	3						
Guatemala	8,850	UMIC	14	16	25	25	15	5						
Philippines	10,220	LMIC	13	14	24	28	16	6						
Indonesia	11,940	LMIC	22	22	28	15	9	4						
Paraguay	12,760	UMIC	8	9	22	27	23	11						
Peru	12,820	UMIC	8	11	22	27	21	11	5	10	20	26	23	15
Ukraine	13,510	LMIC	4	8	23	33	26	6						
Moldova	14,280	LMIC	3	8	26	38	20	5						
Georgia	14,930	UMIC	2	6	19	33	30	10						
Brazil*	14,980	UMIC	7	8	16	24	29	17	4	10	15	23	26	22
Colombia	15,320	UMIC	6	8	18	26	26	16	2	9	19	29	27	15
Bosnia and Herzegovina	15,700	UMIC	2	5	16	32	32	13						
North Macedonia	16,740	UMIC	4	9	22	34	26	6						
Serbia	17,810	UMIC	2	5	15	35	30	12						
Mexico	19,290	UMIC	10	16	26	27	17	5	5	15	25	28	20	8
Argentina	22,090	UMIC	4	6	14	25	28	25						
Bulgaria	23,810	UMIC	3	6	18	35	29	9	1	6	14	30	33	15
Kazakhstan	24,040	UMIC	5	9	25	34	22	6						
Chile	24,480	HIC	4	6	16	25	29	21	2	8	18	27	32	14
Turkey	26,410	UMIC	3	7	17	30	28	15						
Greece	30,080	HIC	2	5	9	15	25	45	1	2	6	18	43	31
Slovakia	31,410	HIC	1	3	11	28	36	22	0	3	6	24	48	19

Hungary	32,630	HIC	2	4	11	25	34	25	1	7	3	32	40	17
Portugal	35,230	HIC	1	2	5	14	30	50	1	3	4	12	37	42
Lithuania	37,200	HIC	1	4	13	20	36	27	3	11	17	25	26	17
Israel*	39,780	HIC	2	3	8	21	28	39	0	1	3	10	32	54
Scotland	40,000	HIC	1	2	7	17	34	40	0	4	8	19	30	38
Slovenia	40,060	HIC	1	1	3	12	33	50	0	5	0	13	35	48
Czech Republic	40,260	HIC	1	2	6	23	38	31	0	2	6	17	46	29
Spain	41,790	HIC	1	2	6	14	28	49	1	2	5	11	34	47
Japan	44,260	HIC	1	2	5	16	35	42						
Italy	44,720	HIC	1	2	6	16	35	41	0	1	5	17	33	43
England and Wales	47,880	HIC	1	3	7	15	33	42						
Canada	48,670	HIC	1	1	4	12	25	57						
France	50,130	HIC	1	2	6	17	30	44	0	1	4	12	35	48
Belgium	54,790	HIC	1	1	5	12	15	67	0	2	5	11	36	47
Sweden	56,190	HIC	1	1	4	12	32	50	0	1	6	5	43	45
Germany	57,460	HIC	1	1	5	12	34	47	2	0	4	27	0	67
Austria	57,870	HIC	1	1	5	13	34	47	2	0	8	17	42	31
Netherlands	59,250	HIC	0	1	4	15	37	44	1	3	2	14	43	37
USA	66,120	HIC	3	5	12	21	28	32	7	7	12	21	25	27
Switzerland	69,440	HIC	0	1	3	12	29	55	1	1	2	7	29	60

* The age groups available to compute excess deaths for Brazil differ from those used in other countries and correspond to the following: 0-39, 40-49, 50-59, 60-69, 70-79, 80+. GNI is from 2019.

Annex Table A3: Rate of Increase in Risk of Death by Age and Ratio of Mortality Risk Between Age Groups

	Official deaths		Excess deaths	
Country	Exponential rate of increase in risk of death for each year of age	Ratio (MR 75-84/ MR 45-54)	Exponential rate of increase in risk of death for each year of age	Ratio (MR 75-84/ MR 45-54)
Afghanistan	0.06	5.74		
Albania	0.06	5.88		
Algeria	0.08	10.72		
Argentina	0.08	14.89		
Australia	0.16	103.71		
Austria	0.13	50.11	0.10	195.28
Bangladesh	0.04	2.39		
Belgium	0.15	28.08	0.13	52.81
Bosnia and Herzegovina	0.08	15.22		
Brazil	0.07	16.70		
Bulgaria	0.06	9.59	0.07	11.48
Cameroon	0.07	7.73		
Cada	0.15	52.78		
Chad	0.07	5.58		
Chile	0.08	17.96	0.07	14.85
Colombia	0.07	14.63	0.08	14.24
Costa Rica	0.05	7.67		
Croatia			0.10	22.54
Czech Republic	0.11	61.17	0.12	64.18
Denmark	0.13	78.46	0.02	-2.31
El Salvador	0.05	1.62		
England and Wales	0.11	27.90		
Estonia			0.02	-2.26
Eswatini	0.06	4.26		
Finland	0.12	26.90	0.05	5.10
France	0.10	34.25	0.12	87.28
Georgia	0.07	14.21		
Germany	0.12	44.66	0.13	-164.35
Greece	0.09	11.09	0.09	41.67
Guatemala	0.05	4.66		
Haiti	0.05	5.29		
Hong Kong SAR, China	0.12			
Hungary	0.09	21.90	0.08	14.44
Iceland			0.03	12.27
India	0.05	4.03		

Indonesia	0.04	3.02		
Israel	0.10	32.91		
Italy	0.10	39.76	0.11	46.03
Jamaica	0.06	9.42		
Japan	0.10	29.85		
Kazakhstan	0.07	12.00		
Latvia	0.07	12.95	0.06	4.29
Lithuania	0.08	18.85	0.05	4.42
Luxembourg			0.12	-7.52
Malawi	0.06	2.93		
Mauritius	0.03	4.19		
Mexico	0.05	5.53	0.06	7.13
Moldova	0.06	9.75		
Nepal	0.05	7.62		
Netherlands	0.13	72.86	0.12	29.32
New Zealand	0.11	28.02		
Nicaragua	0.06	8.32		
Nigeria	0.06	6.32		
North Macedonia	0.06	9.73		
Northern Ireland	0.12	37.00	0.10	74.72
Norway	0.12	32.03	0.06	11.47
Oman	0.07	18.21		
Paraguay	0.07	10.69		
Peru	0.06	8.17	0.07	10.09
Philippines	0.06	7.94		
Poland			0.10	17.50
Portugal	0.12	39.63	0.11	24.73
Qatar	0.10	52.10		
Scotland	0.11	34.29	0.11	16.75
Serbia	0.07	14.42		
Sierra Leone	0.06	8.29		
Slovakia	0.09	36.46	0.11	48.40
Slovenia	0.14	78.16	0.13	16.23
Somalia	0.14	56.77		
South Korea	0.13	78.62		
Spain	0.11	36.59	0.11	54.12
Sweden	0.13	47.08	0.13	79.55
Switzerland	0.15	96.99	0.15	51.80
Taiwan			0.04	13.73
Togo	0.05	3.22		
Turkey	0.08	18.27		
Ukraine	0.05	8.09		
United Arab Emirates	0.11	26.72		
Uruguay	0.08	23.17		
USA	0.08	14.50	0.06	9.07
Vietnam	0.05	8.74		

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract **Yes, in title**
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found. **Yes, in abstract**
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported. **P. 3**
Objectives	3	State specific objectives, including any prespecified hypotheses. **P. 3**
Methods		
Study design	4	Present key elements of study design early in the paper. **P 3-4**
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection **P. 4**
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants **P. 4**
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable **P 4-5.**
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group **P. 4**
Bias	9	Describe any efforts to address potential sources of bias **P. 4-5**
Study size	10	Explain how the study size was arrived at **P 4.**
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why **P. 4-6**
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding P. 4-6
		(*b*) Describe any methods used to examine subgroups and interactions **P. 4-6**
		(*c*) Explain how missing data were addressed
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy **P. 6**
		(*e*) Describe any sensitivity analyses. **Figure 3, Figure 7, P. 7 and 9.**

Continued on next page

Results		
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed. **Not applicable as the unit of analysis is the country.**
		(b) Give reasons for non-participation at each stage
		(c) Consider use of a flow diagram
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders. **Countries are classified by income level.**
		(b) Indicate number of participants with missing data for each variable of interest
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount) N.A.
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time
		Case-control study—Report numbers in each exposure category, or summary measures of exposure
		Cross-sectional study—Report numbers of outcome events or summary measures **P. 6-9.**
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included. Figures 2 and 3.
		(*b*) Report category boundaries when continuous variables were categorized
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses **Figure 3, Figure 7, P. 7 and 9.**
Discussion		
Key results	18	Summarise key results with reference to study objectives **P. 9-10**
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias **P. 10**
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence **P. 10-12**
Generalisability	21	Discuss the generalisability (external validity) of the study results **P. 10**
Other information		
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based. **No funding to report.**

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.