# Beyond Deaths per Capita: Three CoViD-19 Mortality Indicators for Temporal and International Comparisons

Patrick Heuveline and Michael Tzen
California Center for Population Research (CCPR)
University of California, Los Angeles (UCLA)

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*Abstract*

With CoViD-19 reported in 216 countries and territories, we present 3 indicators to facilitate comparative assessments of its mortality impact: (1) *CCDR*, a period rate for periods of any duration that remains readily comparable to the annual Crude Death Rate (*CDR*); (2) *CCMR*, an indirectly age-and-sex standardized ratio that does not require the composition of CoViD-19 deaths; (3) expected impact on 2020 life expectancy at birth ($e_0$(2020)).

We calculate period *CCDR* and *CCMR* from estimates of CoViD-19 deaths to date for all countries/territories meeting data requirements, all provinces in China and states in the USA. Across countries, the USA ranks 14th in standardized *CCMR*, but values in 8 states are higher than in any country. Now declining, New York *CCDR* remains close to its annual *CDR* (5.99 v. 7.83 per thousand).

We derive *CCMR* and *CCDR* values from projections for 103 countries and states, and for countries estimate the impact on $e_0$(2020). The US reduction (.53) would bring $e_0$(2020) to its lowest since 2008, with a single-year drop larger than for HIV in 1993 and than for opioid overdoses over 3 years. Larger reductions, between .85 and 1.19, are projected in Spain, Belgium, Chile, Brazil and Peru.

These projections, (1) based on current estimates of CoViD-19 mortality that seem to underestimate the total increase in mortality to date and (2) do not factor possible new infection waves later this year, seem more likely to under- than to overestimate the eventual impact on $e_0$(2020).

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# Beyond Deaths per Capita

*Background*

As of June 1st, cases of the novel coronavirus disease 2019 (CoViD-19) have been reported in 216 of 235 countries and territories of the United Nations (UN). Worldwide, more than 6 million cases have been reported and more than 375,000 deaths attributed to the disease according to Johns Hopkins University's Center for Systems Science and Engineering (CSSE).[1] The most frequently cited of several online tools that have been developed to track the fast expanding pandemic, the CSSE interactive dashboard maps the location and number of confirmed CoViD-19 cases, deaths, and recoveries for all affected territories, countries, tand some sub-divisions thereof.

The CCSE data illustrate a public health emergency that developed at a very fast pace. In response, national and local institutions have issued public-health orders to slow the spread of the disease and "flatten the curve" so that the number of infected individuals in need of intensive care peaks at a level lower than local hospital capacity. Comparing CoViD-19 trends over time and place may thus provide important public health insights about the strategies that have succeeded in reducing the need for emergency hospitalizations and, eventually, the CoViD-19 death toll. The number of reported cases seems to represent only a small, varying fraction of the actual number of cases,[2] depending in particular on variable testing capacities. Deaths attributed to CoViD-19 provide a more reliable basis for comparative assessments. As the HIV pandemic made clear,[3] a pandemic is more reliably tracked with mortality data. While the current CoViD-19 death toll is also undercounted due to cause-of-death mis-diagnostics and delays in reporting deaths at home and nursing homes, this death undercount is of a much smaller magnitude than the case undercount and can be expected to decline further over time (also see discussion section).

The U.S.A. currently has the highest estimate of cumulative CoViD-19 deaths to date, having surpassed Italy, which earlier surpassed China. Obviously, comparing the number of deaths in countries home to 60 million (Italy), 330 million (U.S.A.) or 1.4 billion (China) people makes little sense. Dividing the number of CoVid-19 deaths by the population size, a comparative table on the CSSE website displays vastly different ratios: from .33 deaths per 100,000 people in China, to 32.45 in the United States and to 55.48 in Italy (as of June 1, 2020.)[1] Considering the countries with at least 100 deaths, the largest ratio at the time appeared to be in Belgium, with 6,917 deaths but a ratio of 83.22 deaths per 100,000 people.

While comparing the number of deaths to the population size is a necessary first step in comparing CoVid-19 mortality across countries, this ratio does not possess several desirable properties. First, the ratio does not control for age and sex population compositions, whereas strong variations in CoViD-19 mortality by age and sex have been clearly established in several countries.[4,5,6] Moreover, the ratio is not directly comparable to the most widely available measure of overall mortality, the Crude Death Rate (*CDR*): as it does not control for the time dimension, the ratio does not differentiate between numbers of deaths recorded in periods of different durations. The ratio may thus appear quite small in comparison to values of the CDR (say, 850 deaths per 100,000 person-year in the U.S.A.), but most CoViD-19 deaths to date occurred in the last 2 months whereas the *CDR* typically includes deaths for entire calendar years. Finally, the value of ratio does not provide any intuition regarding the level of CoViD-19 mortality relative to overall mortality, for which the most easily interpretable indicator remains life expectancy at birth.

*Methods and Data*

To address these shortcomings, this article illustrates the properties of 3 comparative indicators of CoViD-19 mortality. First, the Crude CoViD-19 Death Rate (*CCDR*) is simply a period death *rate*, structured like the *CDR*, that is, expressed in deaths per person-*year*:

$$CCDR[t_1, t] = \frac{D^C[t_1, t]}{N(t_m).(t - t_1)}$$

This indicator only requires an estimate or a projection of the cumulative number of CoViD-19 deaths in a given population by time $t$, $D^C[t_1,t]$, the time of the first CoViD-19 case in the area, $t_1$, and the size of the population at some point $t_m$ within that timeframe, $N(t_m)$.

Second, the Comparative CoViD-19 Mortality Ratio (*CCMR*) is an indirectly sex-and-age-standardized measure, structured like the Comparative Mortality Ratio (*CMR*):[7]

$$CCMR[t_1, t] = \frac{D^C[t_1, t]}{\sum_i {}^{US}M_i^C . N_i(t_m)}$$

where ${}^{US}M_i^C$ is the CoViD-19 death rate specific to age group $i$ in the U.S.A. and $N_i(t_m)$ is the size of the age group $i$ in the population of interest. This indicator was selected because a direct adjustment for age and sex would require numbers of CoViD-19 deaths by age and sex. Such breakdowns remain unavailable for many populations. Including the largest number of registered deaths to date, the weekly-updated Center for Disease Control (CDC) breakdown of CoViD-19 deaths by age for the U.S.A. was selected as the standard.

The third indicator translates the cumulative number of deaths due to CoViD-19 in the population during a reference period into an estimated reduction in life expectancy at birth for the population in that reference period. Reversing steps used to estimate the impact of *eliminating* a cause of death, this calculation requires previously projected life table functions for the period (i.e., not including CoViD-19 mortality). With life tables typically available for single or multiple calendar-year periods only, the difference can be calculated for a single calendar year, preferably for each sex separately, as:

$$\Delta e_0^o[Y] = e_0^o[Y] - {}^{-C}e_0^o[Y]$$

where ${}^{-C}e_0{}^0[Y]$ represents life expectancy at birth previously projected for the calendar year $Y$ (i.e., not including CoViD-19 mortality) and $e_0{}^0[Y]$ represents its new projected value accounting for projected CoViD-19 mortality.

Details on the calculation of these three indicators are described in the online supplementary materials of this article. To illustrate the properties of these indicators, we calculate their values for a weekly updated set of cumulative CoViD-19 death counts, from Johns Hopkins University's CSSE,[1] and projections, from the Institute for Health Metrics and Evaluation (IHME).[8] Specifically, we calculate the *CCDR* for the period starting on the date of the first CoViD-19 case reported in the population[9] and ending on the reference date of the estimates for the 216 UN countries and territories, all provinces in China, and all states in the U.S.A. We calculate the corresponding *CCDR* in these provinces and states and in countries/territories with a population size over 90,000, for which population composition is available from the UN.[10] We also calculate *CCDR* and *CCMR* values corresponding to the IHME projections (currently available for 52 countries and all states up to August 4$^{th}$). For these 42 countries, we use UN life tables to calculate the reductions in life expectancy at birth for calendar year 2020 corresponding to the IHME projections. Our results are updated weekly from updates of the CCSE, IHME and CDC data and shared on a Github repository.[11]

*Results*

We briefly describe the properties of the 3 indicators using calculations from the June-1 update (full results for that week, ranked on *CCMR* values, are also available in the online supplementary materials of this article). First comparing CoViD-19 mortality across the 247 populations for which *CCMR* values were calculated, 8 states (New York, New Jersey, Connecticut, Massachusetts, the District of Columbia, Louisiana, Rhode Island and Michigan) have higher values than any country. Across countries, 14 countries have *CCMR* values above 1—the US value by construction.

To illustrate the effect of age-and-sex standardization, Figure 1 compares the *CCDR* and *CCMR* values in the 11 countries and 5 states with a *CCMR* of 1 or more and a population size over 10 million. Relative to the U.S.A., the standardized ratio is lower in European countries. While Belgium *CCDR* is 2.9 the US *CCDR*, for instance, its *CCMR* is 2.3. On the contrary, the standardized ratio is higher in the South American countries, again relative to the U.S.A. Ecuador, Peru and Brazil *CCDR* are lower than in the US *CCDR* but their *CCMR* are above 1.

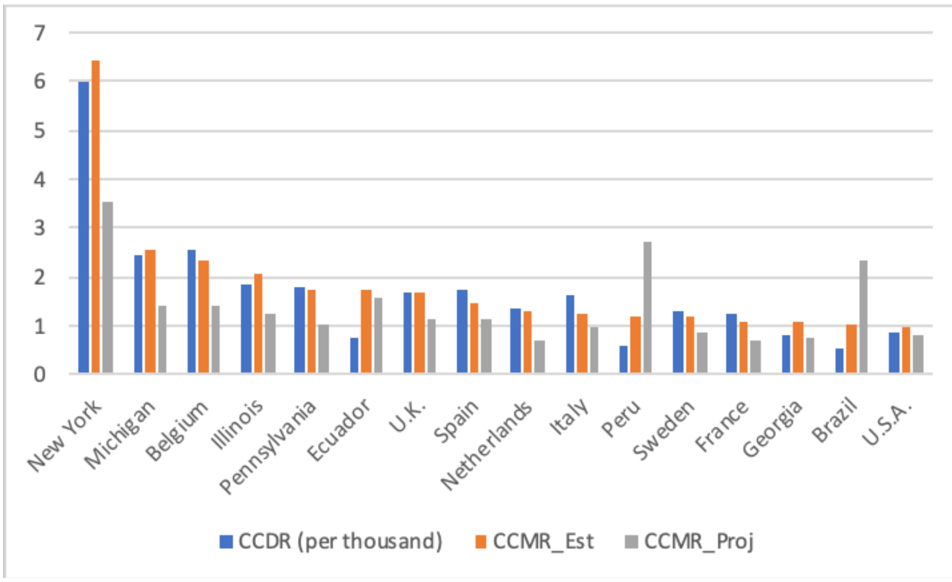


Figure 1: Estimated value of the *CCDR* and *CCMR*, and projected value of the *CCMR*, by country and state (countries and states with an estimated *CCMR* of 1 or more and population size over 10 million)

To assess CoViD-19 mortality over time, Figure 1 shows both currently estimated and projected values of the *CCMR*. Whereas the ratio of cumulative deaths per capita can only increase over time, both the unstandardized rate and standardized ratio are period indicators that may increase or decrease to reflect the changing intensity of mortality over their reference period. Specifically, these indicators begin to decline when the daily number of additional deaths drops below its average for the period. Figure 1 shows *CCMR* are projected to decline in most countries but to increase sharply in Peru and Brazil.

Comparing CoViD-19 mortality with overall mortality, even declining for the reasons just noted, the period *CCDR* for New York (5.99 deaths per thousand person-years) remains close to the state's most recent annual *CDR* (7.83 deaths per thousand person-years in 2017).[12] This indicates that in the three months since its first reported CoViD-19 *case*, the state has seen roughly 3 deaths from CoViD-19 for every 4 deaths from all other causes.

Finally, based on the IHME projections, 2020 life expectancies at birth are expected to be reduced by more than half of year in the U.S.A., 7 European countries (from -.55 year in Ireland to -.88 year in Belgium, with intermediate values in France, Sweden, Italy, the United Kingdom and Spain) and 4 South American Countries (from -.84 year in Ecuador to over 1 year in Chile and Brazil, and -1.19 year in Peru). To put these numbers in perspective, the US .53 reduction would induce a larger single-year decline in life expectancy at birth than during each of the last two public health crises in the U.S.A.: a decline from 75.8 in 1992 to 75.5 years in 1993 (HIV/AIDS-related mortality) and from 78.9 years in 2014 and 78.6 years in 2017 (opioid-overdose-related mortality).[13] As illustrated in Figure 2, it would more than eliminate any longevity gain the country could have made over a 12 years period (2009-2020).

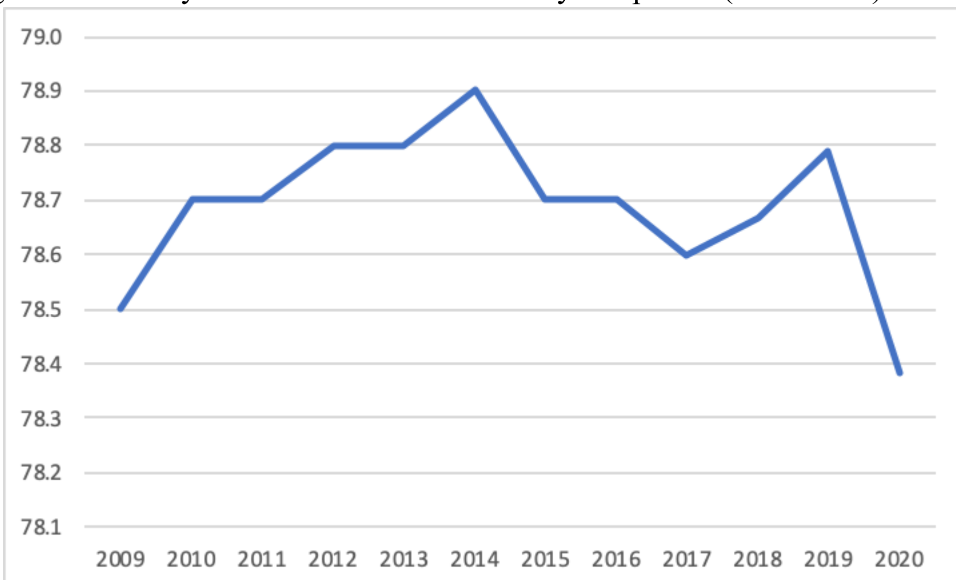


Figure 2: Estimated life expectancy at birth, U.S. population, both sexes, by year
Sources. 2009-1017: CDC[11], 2017-2020: UN and authors' calculations (see technical appendix)

*Discussion*

The results above are intended to illustrate the properties of the 3 proposed indicators for comparisons of CoViD-19 mortality across populations and with overall mortality. For comparisons across populations, the *CCMR* controls for 3 important determinants of the cumulative number of CoViD-19 deaths in a population: the length of the period during which these deaths occurred, the size of the population, and its age-and-sex composition. Caveats are in order with respect to each of these three components. First, comparing values for current estimates and future projections in the same population highlights that both the unstandardized rate (*CCDR*) and the standardized ratio (*CCMR*) are period measures that increase and decrease as waves of the pandemic develop. This accurately reflects for CoViD-19 mortality a temporal dimension that can often be neglected for overall mortality. This also implies, however, that comparing *CCMR* values across populations at too different durations of exposure to CoViD-19 would not be meaningful.

Second, with respect to population size, comparing *CCMR* values in the U.S.A. and across the different states illustrates how conclusions may differ depending on the scale at which comparisons are performed. Belgium *CCMR* may be the highest of any country, but it is lower than in 6 states more comparable in population size (ranging from 3.6 to 19.8 million v. 11.6 million for Belgium) than the whole U.S.A. With a similar population size as well, Lombardy (Italy) has a ratio of CoViD-19 deaths per capita 2.9 times the national average, suggesting a *CCMR* around 3.6 for the province (assuming the same population composition as Italy, result not shown). This would place the province above Belgium and immediately below the top five most-affected states. At this point, we only present results below the country level for UN territories, provinces in China, states in the U.S.A. The two countries were prioritized because of both their size and within-country differences in CoViD-19 prevalence. As shown, New York *CCMR* is 6.4 times the country average, whereas Hubei *CCMR* is 18 times the country average. Results would also be more meaningful at the province/state level in other large countries like India or Brazil, although their within-country differences do not appear as strong at the moment. Further disaggregation may even prove more informative depending on the type analysis.

Third, with respect to age-and-sex variations, the indirect standardization performed in the computation of the *CCMR* circumvents the need for data on CoViD-19 deaths by age and sex which may not be available for many populations. For comparisons across populations for which these data are available, however, direct standardization might be preferable. Indirect standardization relies on an assumption of similarity in age-patterns of CoViD-19 mortality which warrants further investigation as age patterns become available for additional populations. An age-patterns of CoViD-19 mortality that deviates from the US pattern may bias the *CCMR* value as well as the estimated impact on life expectancy at birth for a given population.

With respect to comparison between CoViD-19 and overall mortality, however, this source of bias probably remains secondary. The main factors of uncertainty are rather (1) the degree to which CoViD-19 is properly recognized and reported as the cause of death and (2) the "downstream" effects of the pandemic and mitigating policies on mortality from other causes. CDC data on excess deaths[14] shows that for the 8-week period ending on May 16, the number of deaths in the U.S.A. exceeded expectations based on past trends by over 107 thousand at a time when the cumulative CoViD-19 deaths still stood at 86 thousand. Whether CoViD-19 deaths are under-reported or mortality from other causes has also increased, life-expectancy reductions will likely be larger than estimated here, since based on the assumption that mortality from other causes remains unchanged.

With so much unknown about the direct and indirect mortality impact of the pandemic to date, forecasts must obviously be used with caution. The CDC currently tracks no less than 15 forecasting models.[15] Our choice of the IHME projections among those to illustrate the properties of the 3 indicators was not based on a quality assessment, which would be beyond our expertise. The IHME projections have a broader international coverage and longer time horizon than most other models. Comparisons with other models when populations and horizons overlap do not show the IHME projections as particularly alarmist. To take a single example, when we first estimated the 3 indicators (April 29), IHME projected 68,000 CoViD-19 deaths in the U.S.A. by August 4, compared to between 60,000 and 121,000 by May 12 predicted under the "mitigated" scenario with stay-at-home policy with the Global Epidemic and Mobility Model (GLEAM).[16] To illustrate the current uncertainty, within 2 weeks the US figure was nearly doubled to 134,000. Likewise, the figure for Sweden was nearly halved, from 10,600 to 5,800 within a single week. Finally, at this moment none of these models can realistically factor in possible new infection waves later this year.

Overall, the current numbers seem more likely to under- than to overestimate the eventual impact on life expectancy at birth in 2020. The rapidly evolving understanding of CoViD-19 mortality will likely continue to require frequent updates and flexibility. These calculations can also easily be customized for different periods, different geographical scales, or to accommodate uncertainty across different sources of estimates and forecasts.

## References

[1] Dong, E., H. Du & L. Gardner. Forthcoming. "An Interactive web-based dashboard to track COVID-19 in real time," *The Lancet Infectious Diseases*. Published online first, February 19, 2000, at: https://www.thelancet.com/journals/laninf/article/PIIS1473-3099(20)30120-1/fulltext

[2] Modi, C. et al. 2020. "How deadly is COVID-19? A rigorous analysis of excess mortality and age-dependent fatality rates in Italy," online preprinted posted on May 14, 2020. https://www.medrxiv.org/content/10.1101/2020.04.15.20067074v3

[3] Brookmeyer, R. & M. H. Gail. 1994. *AIDS Epidemiology: A Quantitative Approach*. Oxford: Oxford University Press.

[4] Breakdowns for 8 European countries and South Korea can be found for instance at https://dc-covid.site.ined.fr/en/

[5] https://data.cdc.gov/NCHS/Provisional-COVID-19-Death-Counts-by-Sex-Age-and-S/9bhg-hcku

[6] Dowd, J.B. et al. 2020. "Demographic science aids in understanding the spread and fatality rates of COVID-19," *Proceedings of the National Academy of Sciences of the United States of America* 117(8): 9696-8. https://doi.org/10.1073/pnas.2004911117

[7] Preston, S. H., P. Heuveline & M. Guillot. 2001. *Demography: Measuring and Modeling Population Processes*. Blackwell: Malden, MA, USA; Oxford, UK; Carlton, Victoria, Australia.

[8] Institute for Health Metrics and Evaluation. https://covid19.healthdata.org/

[9] Dates for most Countries and States were retrieved from the Institute for Health Metrics and Evaluation at https://covid19.healthdata.org. For other Countries, dates were obtained from the World Health Organization's daily situation reports at https://www.who.int/emergencies/diseases/novel-coronavirus-2019/situation-reports/

[10] https://population.un.org/wpp/Download/Standard/CSV/

[11] https://github.com/statsccpr/ind-cov-mort

[12] Kochanek, K. D., S. L. Murphy, J. Q. Xu & E. Arias. 2019. "Deaths: Final data for 2017," *National Vital Statistics Reports* 68(9). Hyattsville, MD: National Center for Health Statistics

[13] Arias, E. & J. Xu. 2019. "United States Life Tables, 2017," *National Vital Statistics Reports* 68(7). Hyattsville, MD: National Center for Vital Statistics.

[14] https://www.cdc.gov/nchs/nvss/vsrr/covid19/excess_deaths.htm

[15] For different forecasts of the cumulative number of deaths in the U.S.A., for instance, see the CDC page at: https://www.cdc.gov/coronavirus/2019-ncov/covid-data/forecasting-us.html

[16] "Modeling Covid-19 in the United States." http://covid19.gleamproject.org