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Working paper

Assessing the potential impact of COVID-19 on life expectancy

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Abstract

Background

The COVID-19 pandemic has caused a significant number of deaths worldwide. If the prevalence of the virus infection continues to rise, it can potentially have an impact on life expectancy. This paper provides first estimates of the potential impact of the COVID-19 pandemic on period life expectancy.

Methods

From the estimates of bias-adjusted age-specific case fatality rates in Hubei (China) and a range of six assumptions of prevalence rates ranging from 1% to 70%, we built a discrete-time microsimulation model that simulates the number of infected by COVID-19, the number of dying from it and the number of dying from all causes week by week for a period of one year. We applied our simulation to four broad regions: North America and Europe, Latin America and the Caribbean, South Eastern Asia, and Sub-Saharan African. For each region, 100,000 individuals per each 5-year age group are simulated.

Results

At 10% prevalence rate, the loss in life expectancy at birth is likely above 1 year in North America and Europe and in Latin America and the Caribbean. In South Eastern Asia and in Sub-Saharan Africa, one year lost in life expectancy corresponds to a prevalence of infection of about 15% and 25%, respectively. Given the uncertainty in fatality rates, with a prevalence of COVID-19 infections of 50% under 95% prediction intervals, life expectancy would drop by 3 to 9 years in North America and Europe, by 3 to 8 years in Latin America and the Caribbean, by 2 to 7 years in South Eastern Asia and by 1 to 4 in Sub-Saharan Africa. In all prevalence scenarios, as long as the prevalence rate of COVID-19 infection remains below 1 or 2%, COVID-19 would not affect life expectancy in a substantial manner.

Interpretation

In the regions with relatively high life expectancy, for a prevalence of infection threshold above 1 or 2%, the COVID-19 pandemic will break the secular trend of increasing life expectancy resulting in a decline in period life expectancy. With life expectancy being a key indicator of human development, mortality increase, especially among the vulnerable subgroups of populations would set the country back on their path of human development.

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Acknowledgments

Introduction

The impact of the ongoing coronavirus disease 2019 (COVID-19) global pandemic which started at the end of 2019 will last for many years to come. Since the World Health Organization (WHO) confirmed that there was evidence of human-to-human transmission of a novel coronavirus, named 2019-nCOV or COVID-19, on 22 January 2020, the outbreaks of COVID-19 have caused a significant number of deaths worldwide. At the time of writing (5 May 2020), according to the Center for Systems Science and Engineering (CSSE) at Johns Hopkins University, the global death toll stands at 257,301, with about a half of coronavirus deaths occurred in Europe and almost one-third in the US alone (Dong et al. 2020). With many countries starting to ease their social distancing policies and movement restriction measures, the latest projections from the Institute for Health Modeling and Evaluation, University of Washington projected as many as 134,475 cumulative COVID-19 deaths for the US, 40,555 deaths for the UK, 31,458 deaths for Italy and 28,859 deaths for France by August (IHME 2020). Currently the US, UK, Italy Spain and France have recorded the highest number of deaths worldwide, but the situation is evolving quickly and countries in other parts of the world are experiencing a sharp and rapid rise in infections and mortality.

SARS-CoV2 virus – severe acute respiratory syndrome coronavirus 2 – is a serious threat to public health and is characterised by some features that differentiate it from most of the epidemics of the last decades. First of all, the transmission rate of COVID-19 is particularly high. With the basic reproduction number (R_0) ranging from 1.9 to 6.5 (Alimohamadi et al. 2020; Liu et al. 2020; Park et al. 2020), the virus is highly contagious and can spread very quickly. Part of this high infectivity is due to both asymptomatic and pre-symptomatic cases being able to transmit the virus (Bai et al. 2020), which represents a particularly insidious characteristic for setting up appropriate preventive measures. The high transmissibility coupled with increased globalisation and extensive global mobility resulted in the outbreak of COVID-19 in all world regions in a short period of time (Peeri et al. 2020).

The spectrum of illness severity of the virus is also quite unique. Most people manifest no or mild symptoms (Lake 2020). This group is estimated to represent 80% of the actual infected (Day 2020) although this figure is likely to be underestimated. For the remaining cases, the illness develops in mild to critical bilateral pneumonia, with patients showing symptoms varying from dyspnea to respiratory failure and death. At the moment of writing, case fatality rates are unknown since the dimension of the contagion and the number of the asymptomatics has yet to be investigated systematically (Odone et al. 2020). Likewise, there is no uniform system to count deaths across countries (Lazzerini and Putoto 2020). Data coming from highly affected countries like Italy, Spain, the US, the UK and China show very different figures from data related to countries that were able to effectively control the contagion such as South Korea. Uncertainty around the case-fatality rates is mainly due to the difficulty in identifying the real incidence and prevalence of COVID infection in a point in time.

From a demographic perspective, the main characteristic of COVID-19 is that, the large majority of severe cases involves older populations, especially those aged 70 years and over (Onder et al. 2020). According to Italian data, for example, a 40-49 years old infected by the virus is around 27 times less likely to die than 70-79 years old (Istituto Superiore di Sanità 2020). In addition, underlying medical conditions, including hypertension, respiratory system disease, cardiovascular disease, diabetes and chronic kidney disease are also found to be a risk factor for severe COVID-19 disease (Shahid et al. 2020; Yang et al. 2020; Zhou et al. 2020). Italian data show that only 2% of the deceased COVID patients had no comorbidities when they got infected (Istituto Superiore di Sanità 2020).

If mortality from COVID-19 continues to rise, it can potentially have an impact on period life expectancy. Previous epidemics such as the 1918 influenza and the 2014 Ebola virus outbreak resulted in as many as 11.8 years and 1.6 to 5.6 years drop in life expectancy at birth in the US and Liberia, respectively (Helleringer and Noymer 2015; Noymer and Garenne 2000). In severely affected countries, unprecedented surge of mortality from COVID-19 can result in significant years of life lost.

The impact of the COVID-19 epidemic on life expectancy of a population however is not so clear cut. On the one hand, since the virus kills a disproportionate number of older populations, the number of years lost with respect to the existing average life expectancy might be smaller than expected. On the other hand, its rapid spread might cause a high level of excess mortality as observed in many European countries (EuroMOMO 2020) that is consistently large enough to affect the life table of a country or a region.

This paper aims to provide first estimates of the potential impact of the COVID-19 pandemic on period life expectancy. We built a discrete-time microsimulation model that simulate life histories of 100,000 individuals by five-year age groups week by week for a period of one year. In order to account for a large range of possible outcomes of the pandemic, we built a range of scenarios combining bias-adjusted age-specific case fatality rates and their 95% credible interval (CrI) estimated for the province of Hubei (China) by Verity et al. (2020) and six assumptions of prevalence rates of COVID-19 infection. The estimates are carried out for four broad regions, namely: 1) North America and Europe; 2) Latin America and the Caribbean; 3) South Eastern Asia; and 4) Sub-Saharan Africa. Given different life tables and age structure in the four regions, our study also shows the impact of demographic structure on the outcome of the COVID-19 pandemic, all other things being equal (Dowd et al. 2020). Whilst this exercise does not serve as a prediction of what will happen to life expectancy in different contexts, it shows what would be a potential impact on life expectancy if the same age-specific infection rates and fatality rates of Hubei province were replicated elsewhere to regions with different population structures.

Note that this exercise does not aim to provide a precise estimation of the years of life lost due to COVID-19 given two important features of the actual pandemic. First of all, the available evidence regarding the prevalence of COVID-19 infection and, consequently, the case fatality rates of COVID-19 remains largely uncertain. Rather than providing an estimate, we offer a range of possibilities based on different scenarios of infection rates. The development of the situation will shed light on the real values of these parameters in different countries. A second reason for focussing on scenarios rather than point estimates is related to a further characteristic of the epidemic: most of the bleakest consequences of COVID-19 have been experienced in specific clusters limited to specific areas of a country. For the case of Italy, for instance, Bergamo and Lodi are geographically delimited areas in Lombardy in the north of Italy, and represent roughly 2% of the entire Italian population. The rest of the Italian provinces, despite being affected, have not witnessed such massive-scale diffusion of the virus. Similar patterns are the case of Wuhan in China, Madrid in Spain and New York in the US. The high concentration of infection in one small geographical area is partly due to the successful containment strategies put in place to limit the spread to other parts of the countries (Signorelli et al. 2020).

From a demographic perspective, the impact of the virus in terms of life expectancy therefore should be better considered as cluster-specific. Average life expectancy will probably not be affected so strongly at a country level but at sub-national clusters since severe illnesses and deaths tend to concentrate in one area (Jia et al. 2020). The evidence from our modelling could thus be applied to specific areas as well as to countries as a whole at given level of prevalence. By providing estimates of life expectancy based on different prevalence scenarios, the results are adaptable to Bergamo and Madrid as well as Italy and Spain.

Methods

To assess the impact of COVID-19 on life expectancy, we built a discrete-time microsimulation model that simulates the life of individuals week by week for a period of one year (52 weeks).

The model has two main parameters that change across scenarios:

- age-specific probabilities of dying from COVID-19 among the infected population (f_x);
- age-specific prevalence rate of COVID-19 infection (i_x), which are distributed over the year following a normal distribution centered on the middle of the year and with a standard deviation of 10 weeks. In the scenarios presented in this paper, the prevalence rates are assumed to be equal among all age groups;

In addition, the model includes additional parameters that are constant across scenarios:

- age-specific probabilities of dying (q_x): taken from aggregated lifetables (5-year age groups) (see data section);
- length of illness (z), which is set at 2 weeks[1].

From q_x, assuming constant intensity, age-specific probabilities of dying of COVID-19 at time t (q_x^t) are calculated as follows:

$$q_x^t = 1 - (1 - q_x)^{1/(5*52)} \qquad \text{eq. 1}$$

i_x are assumed to follow a normal trend over the year centered on the week 26 (S.D.=10). Therefore, age-specific probabilities of getting infected at time t (i_x^t) are calculated as follows:

$$i_x^t = i_x * \frac{1}{10\sqrt{\pi}} e^{-0.5(\frac{t-26}{10})^2} \qquad \text{eq. 2}$$

We assume that an individual can be infected only once. Therefore, the denominator in the probabilities of infection is adjusted accordingly:

t=1, $i_x'^t = i_x^t$

t>1, $i_x'^t = \frac{i_x^t}{1 - \sum_{a=1}^{t-1} i_x^a}$ \qquad eq. 3

The probability of dying from COVID-19 infection is only possible during the illness period, f_x is thus transformed accordingly:

$$f_x^t = 1 - (1 - f_x)^{1/z} \qquad \text{eq. 4}$$

For each age group, 100,000 individuals are simulated. Using the Monte Carlo method, the survival of an individual over a year is simulated given three events:

1. First, the death of an individual from all causes of death besides COVID-19 is simulated using q_x^t. An individual who dies is tagged as death from non COVID-19 cause and the simulation stops;
2. If the individual survives and has not been infected previously by COVID-19, the model simulates the infection using $i_x'^t$. If so, the individual is tagged as infected for week t and t +1. If not infected, the simulation is repeated from step 1 for week t+1;

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[1] **The length of illness is set at 2 weeks following the general findings that the risk for undetected symptomatic infection after 14 days is very low (1 in 10,000) (Lauer et al. 2020).**

3. If the individual is still alive and is tagged as being infected by COVID-19 (either from week t-1 or week t), the probability of dying from the disease is simulated using f_x^t. If the individual dies, he or she is then tagged as death from COVID-19 and the simulation stops. If the individual survives, the survival time goes on and the simulation is repeated from step 1 for the next week.

Once the simulation is done, we can estimate age-specific mortality rates with a presence of COVID-19 (m_x') by dividing the total number of deaths that occur in each age group by the total person-years exposure in this age group. Using standard lifetable calculations, m_x' are used to calculate life expectancies adjusted for the impact of COVID-19 (e_x'). The loss in life expectancy due to COVID-19 is calculated by subtracting e_x' from life expectancy not impacted by COVID-19 mortality (e_x).

In addition to loss in life expectancy, we also calculated the total fatality rate by COVID-19 by dividing the number of deaths from COVID-19 by the exposed population weighted by population size of the same age group in a respective world region (P_x) .

Data sources

Data for population by age (P_x) in 2020 are taken from the United Nations' World Population Prospects 2019 (United Nations 2019) (File POP/7-1: Total population (both sexes combined) by five-year age group, region, subregion and country, 1950-2100). Lifetables (q_x and e_x) projected in 2020-2025 under the medium variant are also taken from the same source (File MORT/17-1: Abridged life table, for both sexes combined, by region, subregion and country, 1950-2100).

Age-specific fatality rates (f_x) and their 95% credible intervals (CrI) are obtained from Verity et al. (2020). Using Bayesian methods on individual-case data for patients who died from COVID-19 in Hubei, mainland China, they provided first robust estimates of age-stratified case fatality ratio adjusted for the different denominator populations, including censoring, demography, and under-ascertainment of cases.

Scenarios

Scenarios are built combining age-specific fatality rates (f_x) with six prevalence rates (i_x) assumptions. The assumptions for f_x use the estimates from Verity et al. (2020) for Hubei province, China and their lower and upper limit of the 95% credible intervals (CrI). Up to now, bias-adjusted age-specific case fatality rates have not been estimated for other regions. Our calculations thus rely on the assumption that the age-specific case fatality rates would be the same in all world regions. In other words, our results show how the impact of COVID-19 on life expectancy might be affected by different demographic structures and lifetables, all other things being equal. Age-specific fatality rates are presented in Table 1.

Table 1 presents a strong age gradient in fatality from COVID-19, with much higher risk of death for older populations aged 70 and over than for younger adults. Fatality rates are close to 0 for the population aged below 30, and start to increase sharply for those aged 60 and over. It reaches 7.8% (95% CrI 3.80%-13.30%) for the population aged 80. Fatality rates in the lower limit of the 95% CrI are approximatively half lower, while those in the upper limit are twice higher.

We provide six alternative COVID-19 prevalence rates ranging from 1% to 70%. The 1% assumption would be a scenario in which the propagation of the virus is well-contained, while 70% prevalence would be a scenario in which the virus is spread widely due to limited public interventions to control the transmission. In all scenarios, prevalence rates are assumed to be reached within one year.

Table 1. Assumptions on age-specific case fatality rates (f_x) of COVID-19

Age	Central estimate	95% Credible interval (CrI)
0-9	0.00%	(0.00%-0.02%)
10-19	0.01%	(0.00%-0.05%)
20-29	0.03%	(0.01%-0.09%)
30-39	0.08%	(0.04%-0.19%)
40-49	0.16%	(0.08%-0.32%)
50-59	0.60%	(0.34%-1.28%)
60-69	1.93%	(1.11%-3.89%)
70-79	4.28%	(2.45%-8.44%)
80+	7.80%	(3.80%-13.30%)

Source: Verity et al. (2020)

Results

In Table 2, we first present total fatality rates by scenarios and regions. Note that these results are based on the assumption that all other things being equal (although we may expect poorer resilience of the health systems in lower income countries). The results thus show the effect of the age structure on fatality rates. The total fatality rate from COVID-19 is 1% in North America and Europe, and range from 0.6% under the lower 95% CrI of f_x to 2.0% under the upper one. Total fatality rates are about twice lower in Latin America and the Caribbean and in South Eastern Asia than in North America and Europe and 5 times lower in Sub-Saharan Africa, which highlights the role of age structure in vulnerability to mortality risk from COVID-19.

In the absence of COVID-19, life expectancies for men and women combined in 2020 were expected to be 79.2 years in North America and Europe, 76.1 years in Latin America and the Caribbean, 73.3 years in South Eastern Asia and 62.1 years in Sub-Saharan Africa. Figure 1 shows the loss in life expectancy following different combinations of age-specific fatality rates and prevalence rates assumptions. Detailed results are in Supplementary S1.
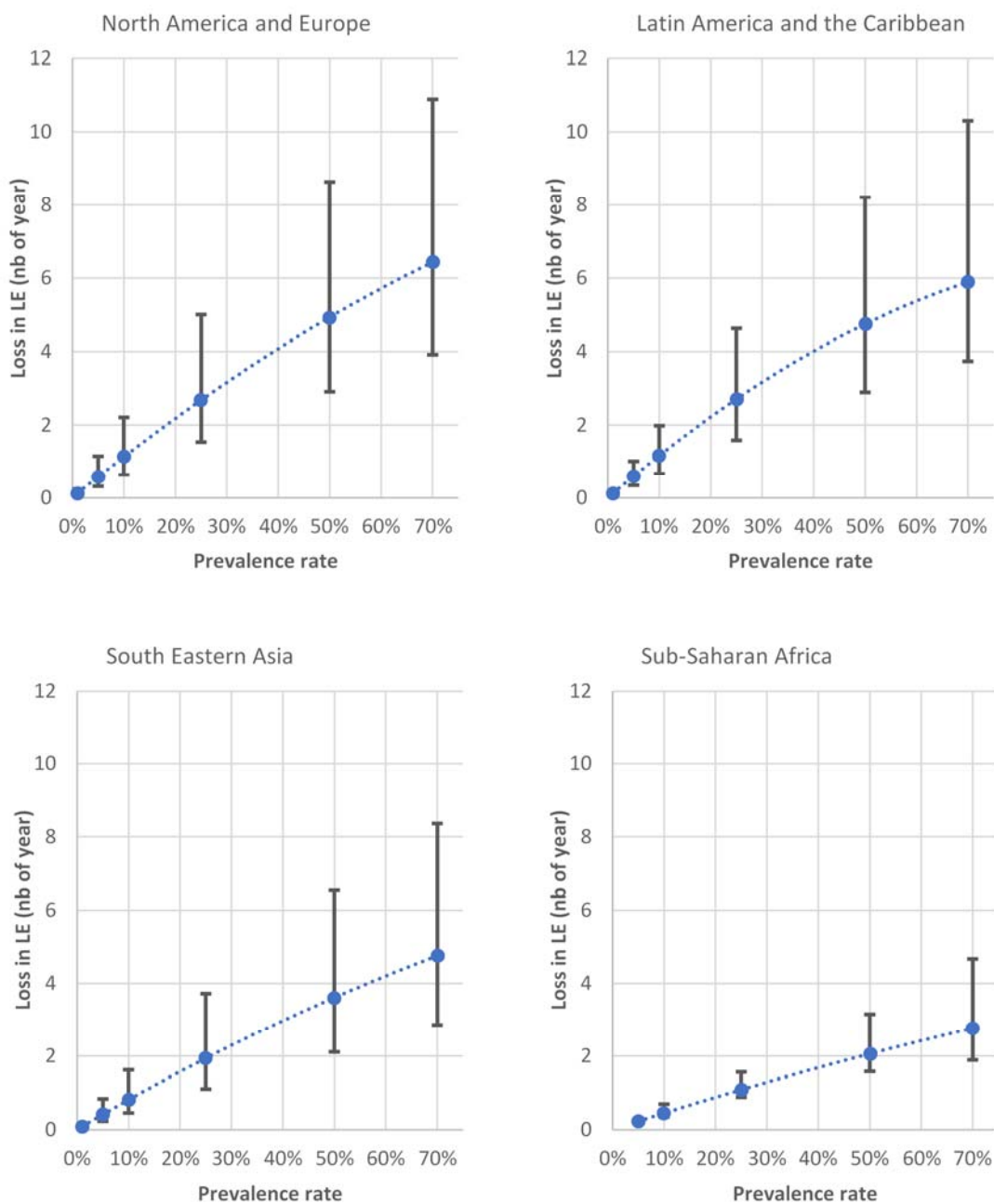
In North America and Europe and in Latin America and the Caribbean, each percentage increase in the prevalence of COVID-19 infection would reduce life expectancy by about 0.1 year. The reduction in life expectancy is slightly steeper when the prevalence is low and becomes flatten when the prevalence gets higher. At the prevalence of infection of 10%, a little over than one year of life expectancy is lost, and at 50% of prevalence, about 5 years are lost. In the latter case, the life expectancy in North America and Europe would become comparable to what is observed in Brazil in recent years, while for Latin America and the Caribbean, losing 5 years of the current average life expectancy would set them backward to their life expectancy of 20 years ago.

The impact of COVID-19 on the period life-expectancy would be lower in South Eastern Asia, and to even much lower in Sub-Saharan Africa. For South Eastern Asia, one year lost in life expectancy corresponds to a prevalence of infection of about 15% as compared to a prevalence of 25% in Sub-Saharan Africa. At 50% prevalence of infection, the years of life lost is 3.5 years in South Eastern Asia and 2 years in Sub-Saharan Africa. In short, loss in life expectancy in Sub-Saharan Africa would be half of those in North America and Europe, while years of life lost due to COVID-19 in South Eastern Asia would lie between the other two regions.

Table 2. Total fatality rate by region, 2020

Region	f_x = central estimate	f_x = lower limit *95% CrI*	f_x = upper limit *95% CrI*
North America and Europe	1.0%	0.6%	2.0%
Latin America and the Caribbean	0.5%	0.3%	1.1%
South Eastern Asia	0.5%	0.2%	0.9%
Sub-Saharan Africa	0.2%	0.1%	0.4%

Figure 1. Loss in life expectancy according to different prevalence rates, error bar=95% credible interval

Given the uncertainty in the estimates age-specific case fatality rates, the number of years lost in life expectancy can fall within the upper and lower 95% CrI of fatality rates. When considering the upper limit, life expectancy is lost by 11 years at 70% of prevalence in North America and Europe, 10 years in Latin America and the Caribbean, 8 years in South Eastern Asia and 5 years in Sub-Saharan Africa. Even in the most advanced countries, this would likely bring down their life expectancy to below 70 years, which is equivalent of the life expectancy in Western Europe 60 years ago. If the true age-specific case fatality rates are close to the estimated upper limit of the CrI and the prevalence of infection reach 70%, the impact of COVID-19 on life expectancy would be similar to that of the of the 1918 flu pandemic.

Naturally, the years of life lost in the lower limit are lower, equivalent of 4 years under 70% prevalence of COVID-19 infection in North America and Europe and in Latin America and the Caribbean. In South-Eastern Asia and Sub-Saharan Africa, the loss would be even smaller, 3 years and 1 year, respectively.

In general, the loss in life expectancy remains low as long as the prevalence does not exceed a certain threshold. Indeed, under the prevalence of infection below 1%, years of life lost are likely to be smaller than the annual secular increase, which is about 0.2 in high income countries, and the trend would remain unaffected. However, above 20% of prevalence of COVID-19 infection, the effect on the secular trend can become sizable. At very high prevalence (70%), the loss in the period life expectancy in North America and Europe would range from 4 to 11 year. A clear break in the historical trend might be observed and would be visible when plotting the age pyramids in the coming few years.

The impact of COVID-19 on life expectancy primarily relies on age-specific mortality rates. Therefore, in all prevalence scenarios, losses are larger in North America and Europe and in Latin America and the Caribbean, where life expectancy is higher, than in South-Eastern Asia and Sub-Saharan Africa. Indeed, the smaller the number of survivals at older ages in the lifetable, the smaller the impact of COVID-19 on life expectancy. This is because COVID-19 is disproportionately fatal amongst the older age groups.

Discussion and conclusion

As long as the prevalence of COVID-19 infection remains low in a region, the pandemic would not affect life expectancy substantially. However, above a certain threshold of COVID-19 prevalence, the secular increasing trend in life expectancy would be broken by a period drop in life expectancy, in particular in regions where life expectancy is high.

Therefore, a failure to contain the spread of the virus would result in a higher number of deaths (Ferguson et al. 2020; IHME 2020) and as a consequence lower life expectancy in a sizable magnitude. At merely 2% of prevalence of COVID-19 infection, the secular increase in life expectancy is likely to be suspended. At 10% of prevalence, the loss in life expectancy is likely be above 1 year in high life expectancy countries. At 50%, it would translate into the years of life lost between 3 to 9 years in high life expectancy regions, between 2 to 7 years in medium life expectancy regions and between 1 to 4 in low life expectancy regions.

Although countries may have managed to contain the prevalence of COVID-19 infection at the national level, it is still possible that the impact of COVID-19 on life expectancy is felt at the sub-national level. Given that cases are not evenly spread within a country as evident in the cases of Hubei province in China, Lombardy in Italy, Madrid in Spain and New York in the US, life expectancy in these local areas is likely to be affected whilst it might not be the case for the whole nation.

This study provides first assessments of the potential impact of COVID-19 on period life expectancies according to a range of scenarios of prevalence rates over a one-year period. The results should be interpreted in the context that all other things are kept constant, albeit being rather unrealistic. The limitation

of the study lies in the fact that true case-specific fatality rates are unknown. We rely on the estimates of age-specific case-fatality rates adjusting for biases based on data from Hubei province, China. It is highly likely that the true case-fatality rates in other regions differ from that of Hubei province given country differentials in policy interventions, health infrastructure and population behaviors. The results from this study represent a preliminary exercise to investigate what could potentially be the impact of the COVID-19 pandemic on human life.

In fact, mortality rates are not independent of the prevalence of COVID-19 infection. As the prevalence get higher, health infrastructures are likely to be overloaded and to not be able to provide care for everyone who needs it, resulting in higher mortality rates both from the virus itself and from other causes. This problem is likely to exacerbate in low income countries where health care facilities have already been overwhelmed. On the other hand, the fatality of the virus might decrease as its spreads, giving that people who get severe symptoms are less likely than those with mild symptoms to contaminate others. It therefore remains to be seen how many years of life will actually be lost following the COVID-19 pandemic.

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Supplementary information

S1. Number of years lost in life expectancy

Age-specific fatality scenario (f_x)	Region	Prevalence assumption (i_x)					
		1%	*5%*	*10%*	*25%*	*50%*	*70%*
Central	North America and Europe	0.13	0.65	1.26	2.90	5.08	6.46
	South Eastern Asia	0.07	0.36	0.72	1.79	3.53	4.89
	Sub-Saharan Africa	0.04	0.20	0.41	1.01	2.03	2.84
Lower 95% CrI	North America and Europe	0.07	0.33	0.65	1.59	3.04	4.11
	South Eastern Asia	0.04	0.19	0.37	0.95	1.96	2.81
	Sub-Saharan Africa	0.02	0.09	0.18	0.46	0.94	1.32
Upper 95% CrI	North America and Europe	0.22	1.09	2.14	4.98	8.73	10.85
	South Eastern Asia	0.17	0.86	1.67	3.86	6.68	8.19
	Sub-Saharan Africa	0.08	0.41	0.81	2.00	3.91	5.36