Vienna Yearbook of Population Research 2022 (Vol. 20), pp. 285–316

Human costs of the first wave of the COVID-19 pandemic in the major epicentres in Italy

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Abstract

Deaths from COVID-19 can be miscounted due to under-reporting and inaccurate death registration. Mortality is often reported at the national level, which can result in the underestimation of the true scale of the impact of the pandemic since outbreaks tend to be localised. This study exploits all-cause daily death registration data provided by the Italian Statistical Office (ISTAT) from 1 January to 31 October to estimate the excess mortality and the corresponding changes in life expectancy during the first wave of the COVID-19 pandemic. Focusing on the five most severely hit provinces in Italy (Bergamo, Brescia, Cremona, Lodi and Piacenza), we calculate the excess mortality in 2020 compared to the average mortality of the years 2015 to 2019. Moreover, we estimate the excess mortality in the first quadrimester of 2020, and the annual life expectancy at birth. The estimated excess deaths show that during this period, mortality was significantly higher than the official mortality statistics for COVID-19. According to our estimates for the first quadrimester, life expectancy in the five provinces declined by 5.4 to 8.1 for men and by 4.1 to 5.8 years for women. In addition, we find that annual life expectancy decreased by 2.4 to 4.1 years for men and by 1.9 to 2.8 years for women compared to the 2015–2019 average. Thus, we conclude that the first wave of the COVID-19 pandemic had a substantial impact on population health in the hardest hit areas in Italy.

Keywords: COVID-19; death registration; excess mortality; first wave; Italy; life expectancy; pandemic

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https://doi.org/10.1553/populationyearbook2022.res2.1

1 Introduction

As European countries are struggling to contain the third wave of the coronavirus disease 2019 (COVID-19) pandemic and limit the spread of the more infectious and deadlier new variants of the virus, governments face a difficult trade-off between supporting the economy and protecting public health. Therefore, it is crucial that officials understand the direct and indirect health effects of the pandemic when making policy decisions.

COVID-19-related mortality is one key indicator that is widely used to track the severity and the public health effects of the pandemic. When the pandemic began in early 2020, most of the existing literature on the impact of the pandemic relied on case-fatality rates (CFR) as a measure of mortality (CDC COVID-19 Response Team, 2020; Giangreco, 2020; Khafaie and Rahim, 2020; Onder et al., 2020). However, CFR are not informative for international and historical comparisons. Since they are calculated as the number of deaths divided by the number of confirmed cases, the absence of an accurate estimation of the infection rates in a reference population makes the denominator in the CFR reliant on testing strategies and capacities.

There is no uniform way of classifying, recording and reporting COVID-19 deaths (Garcia-Basteiro et al., 2020). Moreover, when the epidemic worsens, the counting of fatalities becomes more difficult. People who die at home or in long-term care facilities might not be tested at all simply because resource allocation prioritises emergency operations (Iacobucci, 2020; O'Dowd, 2020). Likewise, there may be indirect mortality effects due to congestion in healthcare services (The Lancet Oncology, 2020), or to patients with chronic conditions avoiding visiting health facilities because they are concerned about the risk of COVID-19 infection (Weinberger et al., 2020). Therefore, COVID-19 mortality reports that rely on data on COVID-19-attributed deaths are likely to undercount the pandemic's death toll.

With the release of mortality surveillance data, such as all-cause mortality data from vital statistics systems for various countries, recent studies have used the "excess deaths" approach to estimate the mortality burden of the COVID-19 pandemic (Rivera et al., 2020; Rossen, 2020; Stang et al., 2020; Vandoros, 2020). Excess mortality counts the total number of persons who have died, regardless of the cause of death, relative to the number of deaths that would have normally been expected for a given place and time. For instance, Modi et al. (2020) compared excess mortality data for Lombardy with the official fatality statistics for Italy, and found that the estimated excess mortality in Lombardy between January and April 2020 was about three times higher than the COVID-19 death rate reported in the official data. Thus, this measure allowed the authors to capture both under-reported COVID-19-related deaths and fatalities that could be indirectly attributed to a lack of health care access, economic deprivation or other causes.

While excess mortality is a useful measure of the health impact of the COVID-19 pandemic, using overall crude death rates or the proportion of deaths for cross-national or historical comparisons is not very informative, because these indicators are affected by the age distribution of the populations studied. By contrast, life expectancy, which is calculated based on human mortality data aggregated in life tables, is insensitive to the age structure of the population, and can therefore reflect differences in mortality reasonably well. Against this background, this study aims to measure the impact of the first wave of COVID-19 on life expectancy at birth by focusing on the hardest hit areas in Italy. As Italy was the first western country severely affected by a large COVID-19 outbreak, this approach allows us to reasonably capture the human cost of the first wave of the COVID-19 pandemic, especially in a context in which non-pharmaceutical interventions were delayed.

In particular, this study focuses on specific geographical areas in Italy that were the most severely affected by the early stages of the COVID-19 pandemic: four provinces in Lombardy (Bergamo, Lodi, Cremona, Brescia) and one province in Emilia Romagna (Piacenza). In modelling the spread of COVID-19 in Italy, Gatto et al. (2020) highlighted the importance of considering the spatial nature of the progress of the wave of infections. The selected provinces experienced the highest numbers of excess deaths in Italy in the observation period compared to the average mortality levels in the years 2015–2019. The highly clustered nature of local transmission resulted in a high concentration of severe illnesses and deaths in one area (Jia et al., 2020). Therefore, the direct impact of COVID-19 on mortality and average life expectancy was likely felt at the sub-national level, rather than at the national level. Indeed, our results suggest that even in Lombardy – which was the hardest hit region in Italy during the first wave of the pandemic (Sebastiani et al., 2020) – the reduction in life expectancy due to COVID-19 was significantly lower than in Bergamo, the province that contributed one-third of the total excess mortality in the Lombardy region. Thus, spatial granularity is needed to assess the full scale of the impact of the pandemic on human life.

Drawing on daily death registration data published by the Italian Statistical Office (ISTAT) for the period of 1 January to 31 October 2020, the present study compares the mortality rates in 2015–2019 and in 2020 across age and gender categories, and provides estimates of the changes in life expectancy following the first wave of the COVID-19 pandemic. While measures such as mortality rates are no doubt useful, they need to be collapsed in an index that is universal enough to provide a reliable measure of all of the human lives lost. By contrast, life expectancy is significantly related to the overall wellbeing of the population, and can therefore provide a simple, objective and immediate measure of the human casualties associated with unprecedented shocks, such as the COVID-19 pandemic (Aburto et al., 2020; Ghislandi et al., 2019; Sen, 1998). Furthermore, as reliable measures of life expectancy are available for some countries from the 19th century onwards, we can use life expectancy for historical comparisons of the human costs associated with major events.

2 Institutional and geographical contexts of the hardest hit areas

In the early hours of 21 February 2020, the first severe case of local transmission of COVID-19 was diagnosed in Europe at a small hospital in Codogno, a municipality in the province of Lodi, south-east of Milan (Paterlini, 2020). Initially, authorities reacted by tracing the connections of *patient one,* but ultimately failed to identify a *patient zero*. As early as 24 February 2020, 11 municipalities in the province of Lodi were placed under strict measures to contain the spread of the disease, and were declared a quarantine "red zone". Meanwhile, another cluster of COVID-19 cases emerged in Alzano Lombardo and Nembro, two municipalities in the province of Bergamo, north-east of Milan. In response to the rapid rise in the number of detected cases, especially in the municipalities surrounding these two epicentres, the Italian government announced on 8 March 2020 that it was imposing a (partial) nationwide lockdown starting on 9 March, followed by a total lockdown of all non-essential activities starting on 23 March (Galizzi and Ghislandi, 2020). While the Italian government was praised by the World Health Organization (WHO) for implementing such drastic measures (i.e., restrictions that had not been employed in modern democratic nations since World War II), the virus had already been spreading undetected in the northern part of the country since December 2019 (La Rosa et al., 2021). Thus, it appears that these containment measures were imposed a little too late (Signorelli et al., 2020). During this first wave of the pandemic, the outbreak put an unprecedented burden on the Italian healthcare system, resulting in an exceptionally high number of coronavirus deaths.

Geographically, Lodi and Codogno – two of the 12 provinces in Lombardy – are close to the other two provinces included in our sample: Cremona and Piacenza (see Figures A.1 and A.2 in the Appendix for the geographical location of the provinces being studied). The epidemic wave involving these provinces is thus considered as part of the Lodi-Codogno cluster. Bergamo and Brescia are located north-east of Milan, and, even though the first severe cases of COVID-19 were detected in these provinces just one day after *patient one* was identified in Lodi, they experienced a week-long delay in the arrival of the first epidemic wave (Galizzi and Ghislandi, 2020).

Of the regions in Italy, Lombardy is the most populated, and it has the highest Gross Domestic Product (GDP). Overall, one-sixth of the Italian population live in Lombardy, and the region produces one-fifth of the country's GDP. Lombardy is relevant for our analysis, because it was the region in Italy that was hardest hit by the COVID-19 pandemic during the first wave, accounting for almost 50% of the human casualties in the entire country (Odone et al., 2020). Indeed, with the exception of Piacenza (located in the Emilia Romagna region), a province that borders the Lombardy region, all of the other four hardest hit provinces included in the analysis are located in Lombardy. Thus, in the following, we will also present statistics for the region of Lombardy.

3 Materials and methods

3.1 Data

We rely on a compendium of administrative data provided by the Italian National Institute of Statistics (ISTAT) that covers all municipalities in Italy (7,903 as of 2020). Specifically, we combine three main datasets. First, we compile daily death counts for all causes at the municipality level, disaggregated by sex and five-year age classes, between 2015 and 2020. For the calendar year 2020, they cover the period between 1 January and 31 October; while for the calendar years 2015–2019, they cover the period between 1 January and 31 December. Second, we obtain data on the resident population at the municipality level, disaggregated by sex and single-year age classes, on 1 January of the years 2015–2020. We reclassify the age classes to five-year age groups to match those used by ISTAT for daily death counts, and aggregate the data accordingly. Third, we use data on monthly (live) births and deaths, disaggregated by sex, at the municipality level from January 2015 to December 2019.

3.2 Estimation procedure for excess mortality

Excess mortality is measured in any day t of 2020 as the difference between the observed and the expected number of deaths in 2020 in t. The expected number of deaths in t is defined as the average number of deaths observed in t over the period 2015–2019:

$$ {}_nD_x^{excess}(t_{2020}) = {}_nD_x^{observed}(t_{2020}) - {}_nD_x^{expected}(t_{2020}) \tag{1} $$

with

$$ {}_nD_x^{expected}(t_{2020}) = \frac{1}{5} \sum {}_nD_x(t_{2015\text{–}2019}) \tag{2} $$

where the number of deaths in the age interval x to $x+n$ at time t is defined as ${}_nD_x(t)$.

3.3 Estimate procedures for life expectancy

Life expectancy is calculated for two different reference periods: the life expectancy for the first quadrimester (i.e., life expectancy for the first four months of the year), and the period (annual) life expectancy (i.e., life expectancy for the entire calendar year).

Since the excess mortality wave was over by the end of April in all of the provinces (Blangiardo et al., 2020), we calculate the first quadrimester life expectancy for the period of 1 January to 30 April for the years 2015–2020 (for men and women separately). To do so, we calculate the first quadrimester age- and sex-specific mortality rates for each year. We aggregate the daily death counts (the numerators) over the period of 1 January to 30 April at the provincial level (and at the regional level for Lombardy). The corresponding exposures (i.e., the denominators) are estimated as follows. Starting from the estimated resident population on 1 January, we count the age-specific person-days up to 30 April of each year. Theoretically, these counts are a function of four demographic events: namely, births, ageing, migration and deaths. The daily inflow of births is estimated by using monthly birth data, and assuming that these births are uniformly distributed throughout the month. Since the monthly births for 2020 are not available, we estimate monthly births over 2020 in each province by sex by means of linear extrapolation using province-specific data on monthly live births by sex between January 2015 and December 2019. The effect of ageing – i.e., individuals might be in transition into and out of a given age interval – is modelled by giving each individual the probability of 1/365 of turning one year older during the observation period. The outflows due to deaths are straightforward, as the age-specific death counts are known on a daily basis. We assume no migration.[1] Formally, the exposed population at day t in age group x in province p is given by the population alive at day $t - 1$ in age group x in province p plus those who age into age group x at day t minus those who either die in age group x or age out of the age group x in day t in province p:

$$ {}_nE_x^p(t) = P_x^p(t-1) + {}_nAge^p_{in_x}(t) - D_x^p(t) - {}_nAge^p_{out_x}(t) \tag{3} $$

We express the obtained daily exposure values in terms of person-years by multiplying them by 1/365 (1/366 for leap years). Then, we derive age-specific mortality rates for the period of 1 January to 30 April by dividing $D_x^p(t)$ by $E_x^p(t)$. Finally, life tables are built following the standard procedures outlined by the Human Mortality Database protocol (Wilmoth et al., 2019).

While first quadrimester life expectancy does not require any assumptions and relies entirely on observed data, annual life expectancy needs assumptions on mortality trends for the rest of the year 2020 after 31 October when the available ISTAT data on all-cause mortality at the municipality level end. Given the timing of the second wave, which hit Italy in mid-October 2020, harvesting (i.e., the reduction in mortality rates following peak mortality associated with shock events) can be excluded. Thus, we assume that in November and December 2020, mortality returned to the average levels recorded in 2015–2019. It should be noted that this is a conservative approach, since the mortality levels in November and December are expected to be higher than in 2015–2019 due to the unfolding of the second epidemic wave. As we do not know the daily distribution of deaths after 31

[1] The no-migration assumption is fairly realistic. Due to the travel restrictions to and from Italy, and also within the country, it may be expected that migration flows declined. Indeed, the existing data suggest that labour migration as well as refugee admissions were far lower in 2020 than in 2019 (EASO, 2020; EMN/OECD, 2020; OECD, 2020).

October, we assume that the deaths were distributed uniformly across November and December 2020.

We then proceed with the estimation of population exposure for each day between 1 January and 31 December 2020 following the same procedure detailed above (sex- and age-specific population estimates by province are reported in Table A.1). Finally, we aggregate the death counts and population exposure values over the entire year to derive the age-specific mortality rates and life expectancies under both scenarios. For the calendar years 2015–2019, we compute the age-specific mortality rates by dividing the total annual death counts over the mid-year population, and derive the life expectancies accordingly.

We estimate confidence intervals for both the first quadrimester and the annual life expectancies by bootstrapping using Monte Carlo simulation methods, assuming the death counts follow a binomial distribution (Andreev and Shkolnikov, 2010; Chiang, 1984).

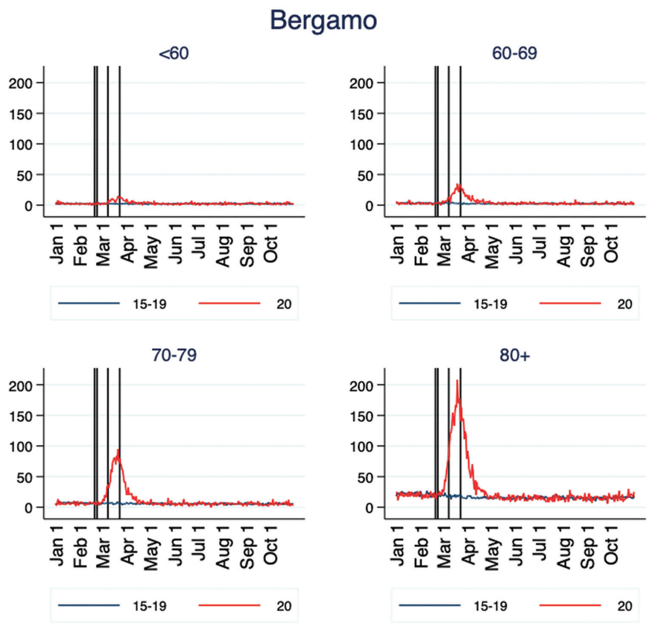
4 Results

Figures 1(a)–1(f) show the trends in daily mortality for the five provinces with the highest numbers of declared cases in Italy and in the whole Lombardy region.[2] Plotting the mortality distribution by age groups allows us to fully capture the progression of the first epidemic wave. It is evident that the epidemic curve inflated with age across all provinces. It is also clear that by 30 April, the daily mortality in all selected provinces approached the pre-pandemic values (i.e., no excess mortality). Hence, the wavelength of the epidemic in these provinces was between six and eight weeks, with the peak happening around two weeks after the onset of the outbreak.

The vertical lines show four relevant dates for the evolution of the first epidemic wave. After the case of *patient one* was first identified in Codogno, located in the province of Lodi, the authorities quickly locked down 11 municipalities in the area on 24 February 2020. The containment measures associated with the lockdown were not implemented in other provinces until after 8 March. Although the earlier lockdown enabled Lodi to flatten the curve more effectively than other severely affected provinces (Figure 1), the province still experienced a notable increase in excess mortality. Considering that the incubation period – i.e., the time between the exposure and the onset of symptoms – can be up to 24 days, it is evident that the lockdown was imposed too late in these provinces. While political reasons prevented the authorities from implementing the lockdown earlier in the provinces where the number of cases had been rising rapidly, like in Bergamo, there is recent evidence showing that COVID-19 had already been circulating undetected in northern Italy

[2] All figures for the Lombardy region cover all 12 provinces in the region.

Figure 1(a):
Trends in total daily death counts in the province of Bergamo January 1 and October 31 2020 vs. 2015–2019 average



Note: The vertical lines show relevant dates for the evolution of the epidemic. The vertical lines indicate the following relevant days: 20 February = patient one found in Codogno; 23 February = red zones in Codogno. Schools and Universities in affected regions are closed; 8 March = orange zones were established in Lombardy and Piacenza; 23 March = all non-essential economic activities were closed.

since December 2019 (La Rosa et al., 2021). Thus, our study proxies the impact of the COVID-19 outbreak in the absence of containment interventions.

The geographical distribution of excess deaths in the first quadrimester across Italy (Figure 2) matches the distribution of confirmed cases (which comprise the deceased, the recovered individuals and the active cases) provided by the Italian Civil Protection Department, which publishes the official surveillance data on COVID-19.[3] This geographical pattern indicates that the excess mortality observed in our data represents mortality directly and indirectly related to COVID-19.

Note that in Figure 2, we focus on the 1 January-30 April period only in order to better capture the impact of the first wave of the COVID-19 pandemic. Compared to the average number of people who died in the same period in the previous five years (2015–2019), the excess number of deaths (for those aged 40 or older)

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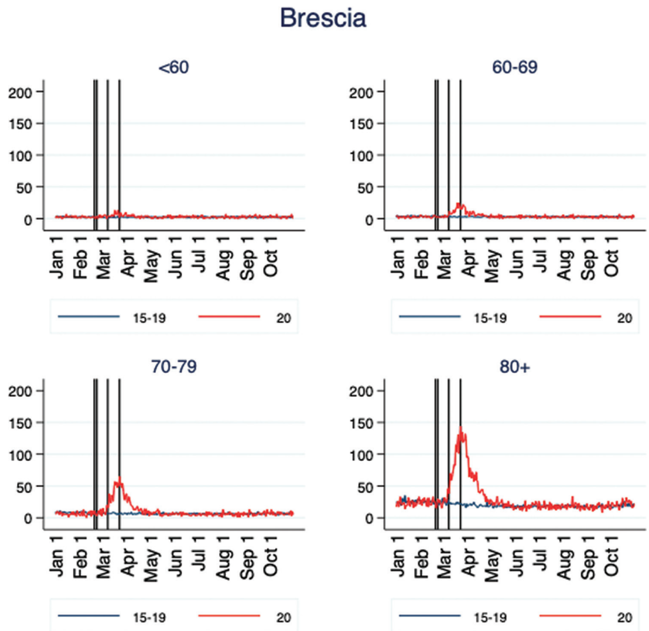
[3] Official statistics on COVID-19 cases and deaths provided by the Italian Civil Protection Department are available at http://www.protezionecivile.gov.it/home (Situation Map).

Figure 1(b):
Trends in total daily death counts in the province of Brescia January 1 and October 31 2020 vs 2015–2019 average

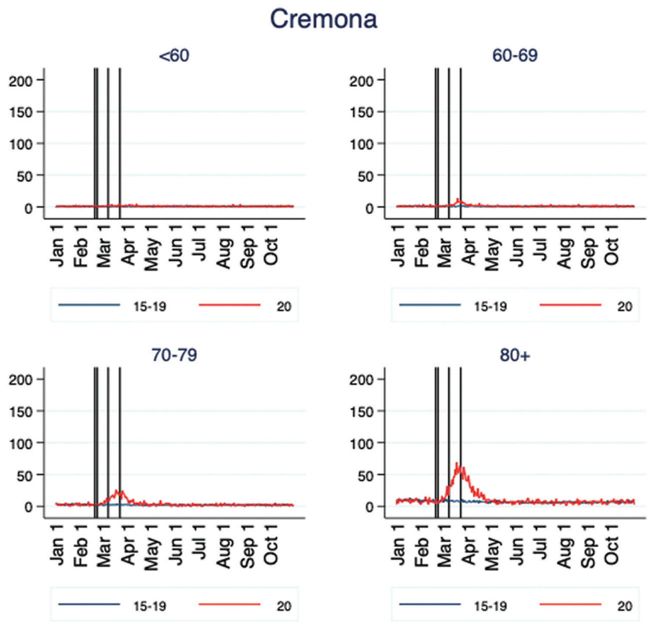


Notes: The vertical lines show relevant dates for the evolution of the epidemic. The vertical lines indicate the following relevant days: 20 February = patient one found in Codogno; 23 February = red zones in Codogno. Schools and Universities in affected regions are closed; 8 March = orange zones were established in Lombardy and Piacenza; 23 March = all non-essential economic activities were closed.

between 1 January and 30 April 2020 sums to 6,084 in Bergamo, 3,969 in Brescia, 2,030 in Cremona, 905 in Lodi and 1,170 in Piacenza. For the entire region of Lombardy, the excess number of deaths is approximately 23,649 (Table 1). The total number of COVID-19 deaths reported by the Italian Civil Protection Department for Lombardy as of 30 April 2020 is 13,772. This implies that the overall death toll of the first epidemic wave was about 70% higher than that suggested by official statistics on COVID-19 deaths. The mortality rate in the first quadrimester of 2020 increased substantially in all provinces and for all age groups, with the largest increase being observed for men aged 70–79 in Bergamo (a 347% increase). Age clearly represented a risk factor for excess mortality, in line with the age gradient in COVID-19 CFR observed in Italy and elsewhere. For instance, among the excess deaths observed in Bergamo, the mortality rate was much higher among older men aged ≥70 years. A similar ratio is found in the other provinces.

When we only consider the distribution of excess mortality without adjusting for population size in each age-sex category, we observe slightly more excess mortality

Figure 1(c):
Trends in total daily death counts in the province of Cremona January 1 and October 31 2020 vs. 2015–2019 average

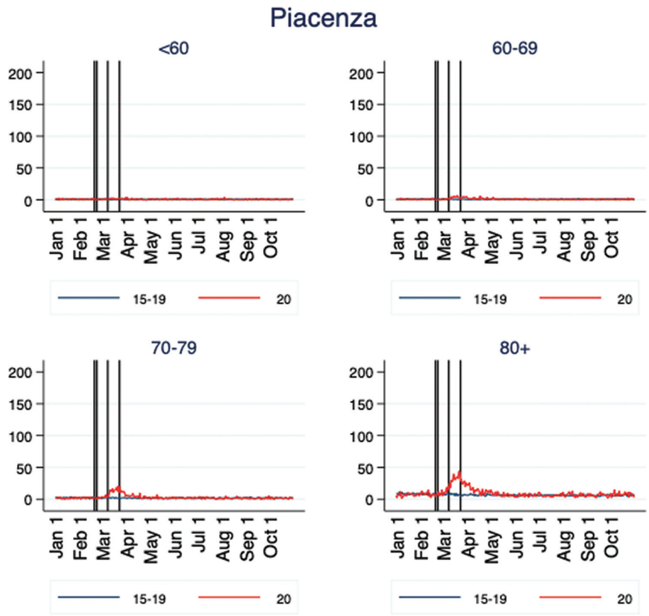


Notes: The vertical lines show relevant dates for the evolution of the epidemic. The vertical lines indicate the following relevant days: 20 February = patient one found in Codogno; 23 February = red zones in Codogno. Schools and Universities in affected regions are closed; 8 March = orange zones were established in Lombardy and Piacenza; 23 March = all non-essential economic activities were closed.

in men than in women (53% of excess deaths involved male subjects). However, when we consider the mortality risk ratio between the sexes, we find that the excess mortality for males was consistently higher than that for females across all age groups and provinces (relative risk ≥1).

The trends in the first quadrimester and the annual life expectancies are illustrated in Figures 3 and 4. When we look at the trends in the first quadrimester of 2020, it is evident that the drop in life expectancy was significant for both men and women in all provinces. Compared to the average life expectancy of the 2015–2019 period, the reduction for men ranged from 5.5 years in Brescia to 8.1 years in Bergamo, and the reduction for women ranged from 4.1 years in Piacenza to 5.8 years in Bergamo. The larger reduction in the first quadrimester life expectancy for men was due to sex differentials in the COVID-19 mortality risk, as both the official case fatality data and our death registration data consistently show. Indeed, when we decompose the loss in life expectancy to identify which age groups contributed the most to the reduction in life expectancy (Figure A.3 in Appendix), it becomes clear

Figure 1(d):
Trends in total daily death counts in the province of Piacenza January 1 and October 31 2020 vs 2015–2019 average



Notes: The vertical lines show relevant dates for the evolution of the epidemic. The vertical lines indicate the following relevant days: 20 February = patient one found in Codogno; 23 February = red zones in Codogno. Schools and Universities in affected regions are closed; 8 March = orange zones were established in Lombardy and Piacenza; 23 March = all non-essential economic activities were closed.

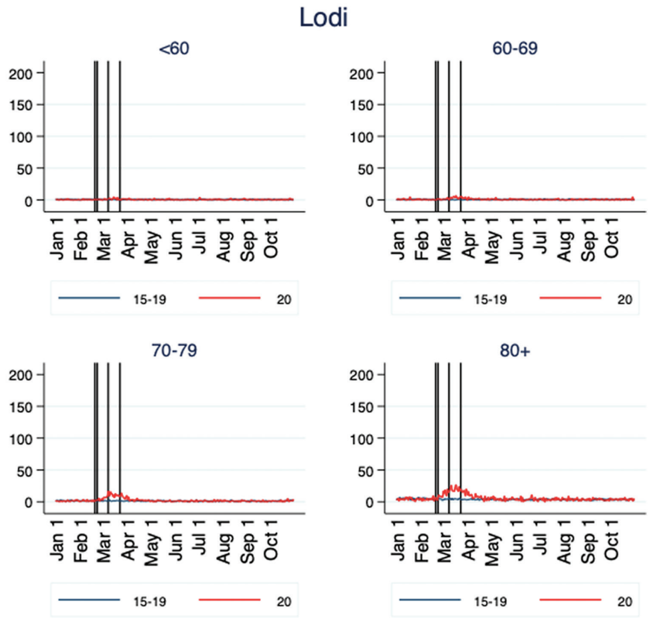
that the older populations, and especially men aged 60–79 years, played a major role.

When life expectancy is extrapolated for the whole year, the loss in life expectancy is diluted over a longer period. Thus, the drop in life expectancy due to COVID-19-related excess mortality was less steep than that observed in the first quadrimester life expectancy.

In the most severely hit province of Bergamo, life expectancy dropped by 4.1 years for men and 2.8 years for women when compared to life expectancy for the years 2015–2019. In the slightly less affected provinces of Brescia, Cremona, Lodi and Piacenza, the reduction in life expectancy ranged between 2.4 in Brescia and 3.8 in Cremona for men, and between 1.9 in Piacenza and 2.6 in Cremona for women. As expected, the reduction in life expectancy was smaller in Lombardy, at 1.9 years for males and 1.5 years for females.

When we turn to the national level, we see that the results are extremely heterogeneous (Figure 5). It is evident that the higher excess mortality experienced in the northern part of Italy, particularly in Lombardy, was not experienced in most

Figure 1(e):
Trends in total daily death counts in the province of Lodi January 1 and October 31 2020 vs. 2015–2019 average



Notes: The vertical lines show relevant dates for the evolution of the epidemic. The vertical lines indicate the following relevant days: 20 February = patient one found in Codogno; 23 February = red zones in Codogno. Schools and Universities in affected regions are closed; 8 March = orange zones were established in Lombardy and Piacenza; 23 March = all non-essential economic activities were closed.

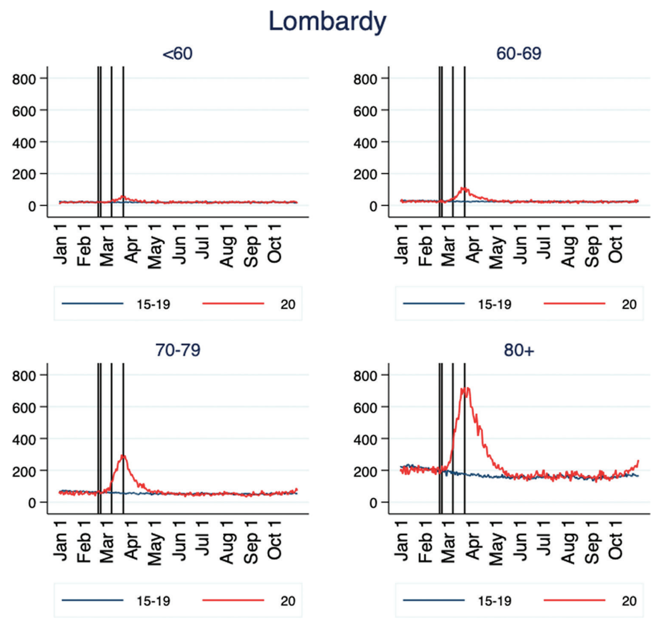
of the provinces of the central part and the south of the country. For example, in provinces like Sassari and Nuoro in Sardegna and Cosenza in Calabria, the lockdown *reduced* mortality in the first four months of the year, resulting in an estimated increase in life expectancy up to two years for both men and women.

5 Discussion

By avoiding the inconsistencies in the classification of causes of death and in testing practices, and by focusing on the five areas in Italy that were most severely affected by the first wave of the pandemic, this study provided an assessment of the full impact of the first wave of the COVID-19 pandemic on human life.

Two empirical regularities clearly emerged when we looked at demographic differentials. First, the age gradient in excess mortality was steep, and age was the most evident risk factor for COVID-19 mortality. In Lombardy, men and women

Figure 1(f):
Trends in total daily death counts in the region of Lombardy January 1 and October 31 2020 vs. 2015–2019 average



Notes: The vertical lines show relevant dates for the evolution of the epidemic. The vertical lines indicate the following relevant days: 20 February = patient one found in Codogno; 23 February = red zones in Codogno. Schools and Universities in affected regions are closed; 8 March = orange zones were established in Lombardy and Piacenza; 23 March = all non-essential economic activities were closed.

over age 70 were 23 times more likely to die than their counterparts under age 70. These patterns were replicated in all five provinces. Therefore, areas where older people made up a high proportion of the population (e.g., 17% of the population were over age 70 in the Lombardy region in 2019) had a higher burden of COVID-19 mortality (Dowd et al., 2020). Second, within each province, the risk of dying was consistently higher for men than for women for all age classes and provinces considered. Evidence that men are more likely than women to suffer from COVID-19, as measured by hospitalisations, admissions to intensive care units and fatality rates, has been consistently reported for other countries across different studies and subsamples (Gebhard et al., 2020; Peckham et al., 2020; Scully et al., 2020). Higher mortality rates for men than for women translate into a larger reduction in life expectancy for men than for women.

Although these data provided evidence of the severity of the first wave of the COVID-19 pandemic in Europe, a further measurement effort was needed, particularly for geographical and historical comparability purposes. In terms of life expectancy, we showed that for the period of 1 January to 30 April 2020, the reduction in the first quadrimester life expectancy, compared with the average of the years 2015–2019, was as high as 8.1 years for men and 5.8 years for women in Bergamo.

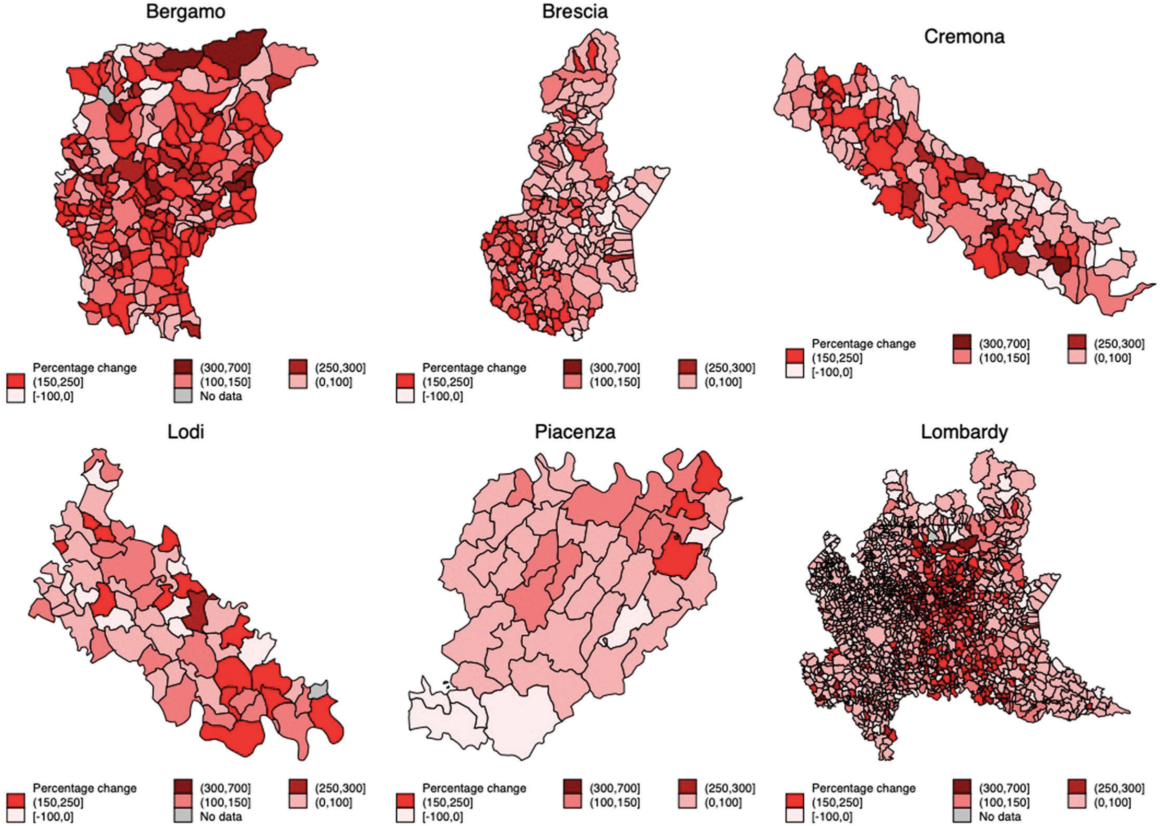
When the analysis was extended to the whole year, under the assumption that the mortality rates from November onwards were back to "normal", life expectancy was reduced by up to four years (for men in Bergamo). However, significant uncertainties remain about the longer-term effects of the pandemic on health conditions among, for instance, patients who recovered from COVID-19 with major co-morbidities and mental health issues, and pregnant women. It is also possible that indirect physical and mental health consequences of changing socio-economic conditions affected the mortality patterns in 2020.

What can we say regarding the validity of the no harvesting assumption? Figure 1 provides evidence that after the end of the first wave, the mortality patterns in all age-provinces groups were largely similar to those in the previous years. This result is not consistent with harvesting, which would require negative excess mortality to compensate for the high levels of mortality registered in the first quadrimester. It should also be noted that since November 2020, Italy has been experiencing a severe second wave of infections that has not fully finished. Moreover, since March 2021, the country has been bracing for a third wave. Therefore, mortality in Italy is likely to increase even further. Thus, the figures provided can be considered estimates of the human life lost only *for the first wave* of the COVID-19 epidemic in the affected provinces.

It should also be noted that in the first quadrimester, some provinces in Italy experienced an improvement in life expectancy thanks to a reduction in mortality compared to the average of the previous years. There may have been spill-over benefits of the lockdown measures that contributed to a decline in premature deaths, such as from road traffic fatalities, alcohol consumption, violence and injuries at work (Qi et al., 2020; Qureshi et al., 2020). Moreover, our observation that the epidemic had a differential impact across different regions within Italy shows the importance of considering specific geographic areas when estimating the effect of the COVID-19 pandemic on human life. Indeed, focusing on national-level statistics only would further bias downward the estimation of the impact of the virus. Thus, our explicit focus on a local context can be considered the main strength of this analysis. Because the COVID-19 outbreaks have been geographically concentrated, looking at country-level life expectancy is misleading, and underestimates the actual impact of the pandemic.

Along with Italy, other European countries have been experiencing sharp declines in life expectancy due to the COVID-19 pandemic. Estimating weekly life expectancy for Spain, Trias-Llimós et al. (2020) found a particularly large drop at the beginning of April 2020, with a decline of up to 7.6 years at the national level. At the regional level, the authors reported an even more pronounced drop in life expectancy, with Madrid in particular experiencing a large reduction, ranging from 11.2 years in week 13 to 14.8 years in week 14 for both men and women. Moreover, the findings of a study for Sweden based on mortality data for the first 33 weeks

Figure 2:
Excess mortality between January 1 and April 30 2020 by municipalities in selected provinces and in Lombardy



Notes: The maps plot the percentages change in total number of deaths recorded between 1 January and 30 April 2020 with respect to the 2015–2019 average.

Table 1:
Total population as of January 1 2020, excess mortality and male to female relative risk (RR) for selected provinces and Lombardy region, by age and sex (1 January–30 April 2020)

Age	Population males	Population females	Excess deaths males	Excess deaths females	Increase MR Males	Increase MR Females	RR
				BERGAMO			
40–49	87798	83447	18	11	1.419	1.418	1.555
50–59	90465	87550	130	41	2.230	1.586	3.069
60–69	65932	67646	456	123	2.910	1.967	3.804
70–79	48938	55601	1109	473	3.399	2.465	2.664
80–89	23213	35807	1398	1088	2.936	2.329	1.982
90+	2878	8995	391	846	2.623	2.233	1.444
				BRESCIA			
40–49	100560	96071	6	2	1.148	1.104	2.866
50–59	100949	98976	81	31	1.748	1.427	2.562
60–69	72690	76000	241	76	1.909	1.558	3.315
70–79	56544	64688	728	304	2.364	1.858	2.740
80–89	27054	42900	934	757	2.085	1.800	1.956
90+	3575	11875	277	809	1.804	1.926	1.137
				CREMONA			
40–49	27269	26207	7	6	1.539	1.906	1.121
50–59	28706	28163	42	5	2.241	1.192	8.241
60–69	22333	23107	109	27	2.349	1.569	4.177
70–79	17463	19921	336	136	2.804	2.092	2.818
80–89	8941	14449	388	411	2.346	2.162	1.526
90+	1278	4068	168	395	2.475	2.249	1.354

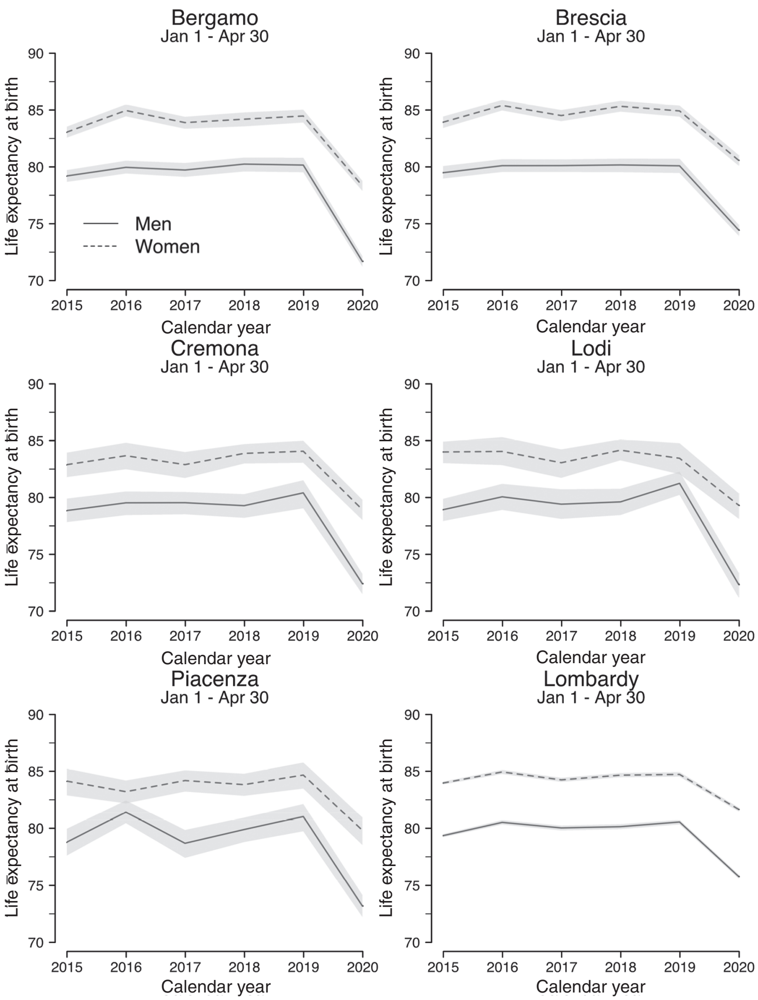
Continued

Table 1:
Continued

Age	Population males	Population females	Excess deaths males	Excess deaths females	Increase MR Males	Increase MR Females	RR
				LODI			
40–49	18554	17694	4	1	1.431	1.232	3.815
50–59	18757	18214	20	0	1.837	0.974	
60–69	13548	14073	73	23	2.485	1.859	3.297
70–79	10264	11802	215	76	2.967	1.983	3.253
80–89	4770	7890	184	131	2.128	1.667	2.323
90+	587	1940	34	148	1.549	1.988	0.759
				PIACENZA			
40–49	21381	21089	3	−5	1.363	0.293	−0.592
50–59	22926	22790	29	7	2.001	1.370	4.118
60–69	17373	18099	83	16	2.377	1.416	5.404
70-79	14041	16290	207	99	2.367	2.093	2.426
80–89	7945	12234	275	185	2.063	1.595	2.289
90+	1258	3598	78	193	1.656	1.695	1.156
				LOMBARDY			
40–49	734989	715954	69	34	1.200	1.167	1.977
50–59	711601	716834	440	94	1.535	1.176	4.715
60–69	518652	560324	1312	400	1.705	1.377	3.544
70-79	414020	494374	3609	1560	1.906	1.565	2.762
80–89	205659	331869	5338	4592	1.891	1.652	1.876
90+	27458	85968	1835	4366	1.814	1.718	1.316

Notes: Excess deaths: (Number of deaths 1 January-30 April 2020) – (Average number of deaths 1 January 1–30 April 2015–2019). RR(M/F): Risk Ratio (Male/Female) = (excess deaths males/pop males)/(excess deaths females/pop females).

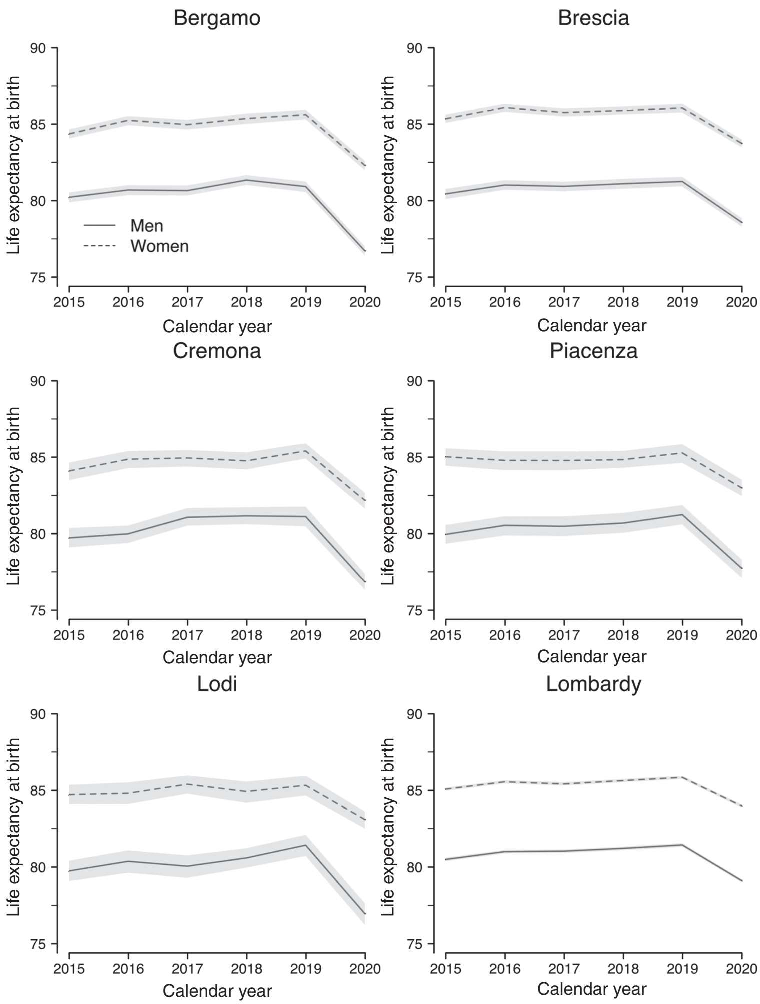
Figure 3:
Estimates of the first quadrimester (1 January–April 30) by sex in selected provinces and in Lombardy (95% confidence intervals in grey)



Notes: Confidence intervals (95%) for life expectancies are estimated by bootstrapping using Monte Carlo simulation methods, assuming death counts follow a binomial distribution.

of the pandemic suggest that life expectancy at age 50 in Stockholm decreased by about two years for men and about 1.5 years for women (Modig et al., 2021). At the national level, the reduction in annual life expectancy during the COVID-19 pandemic is expected to be smaller. Similarly, a study that calculated life expectancy at birth in England and Wales on the basis of data for the first 47 weeks of the

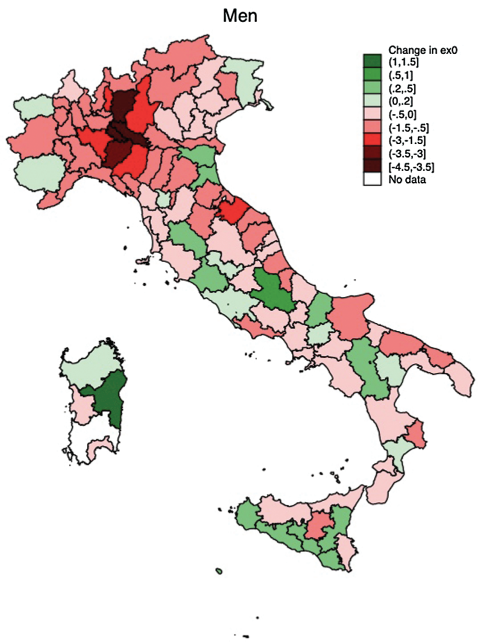
Figure 4:
Estimates of the annual life expectancies by sex in selected provinces of Lombardy and in the Lombardy region as a whole (95% confidence intervals in grey)



Notes: Confidence intervals (95%) for life expectancies are estimated by bootstrapping using Monte Carlo simulation methods, assuming death counts follow a binomial distribution.

pandemic found that it declined by 0.9 years for women and 1.2 years for men between 2019 and 2020 (Aburto et al., 2021). Our results are in line with those of these previous studies, as we also found the largest declines in life expectancy at a local level; in our case, in the north of Italy.

Figure 5:
Differences between life expectancy at birth (ex0) in 2020 in Italian provinces and 2015–2019 average, by sex



Under normal conditions, life expectancy at birth is calculated with mortality data for one calendar year, and provides an estimate of mean longevity for a hypothetical group of individuals who experience the mortality regime of a given period over their entire life course. Obviously, in reality, no group of people will be exposed over their life course to the mortality regime of the worst hit regions in Italy during the first wave of the COVID-19 pandemic. With the development, approval and rollout of several vaccines and the implementation of protective measures, it is highly likely that in the future, mortality in these regions will bounce back to lower levels. Still, life expectancy is a powerful tool for summarising and comparing mortality rates between regions and over time, especially because it accounts for differences in age-specific mortality (Marois et al., 2020; Trias-Llimós et al., 2020).

As the results of this study show, the cost in terms of human life of the delays in public interventions to reduce the transmission of the virus was disturbingly high. As European countries struggle to manage the successive waves of the coronavirus by striking a balance between protecting public health and reducing the economic effects of restriction measures, it is important to keep in mind the potential risk of viral reintroduction, and the direct and indirect dangers it poses to human life. Well-planned government measures aimed at flattening the epidemic curve while preventing a new wave of infections, along with public cooperation in maintaining physical distancing, wearing a face mask and practicing proper hygiene until there is widespread access to vaccination for the novel coronavirus, are key to achieving a balance between protecting public health and sustaining the economy.

Author contributions

SG and BS designed the research; BS acquired data, performed the analysis and created the display items with the help of MS. SG, RM, MS and BS contributed to the writing of the manuscript.

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Appendix

Figure A.1:
Distribution of excess mortality in March–April 2020 across Italian provinces. The provinces in Lombardy are highlighted by the bold black line. The province of Piacenza is indicated by the blue arrow. Excess mortality is calculated as the percentage difference with respect to baseline mortality (2015–2019 average)

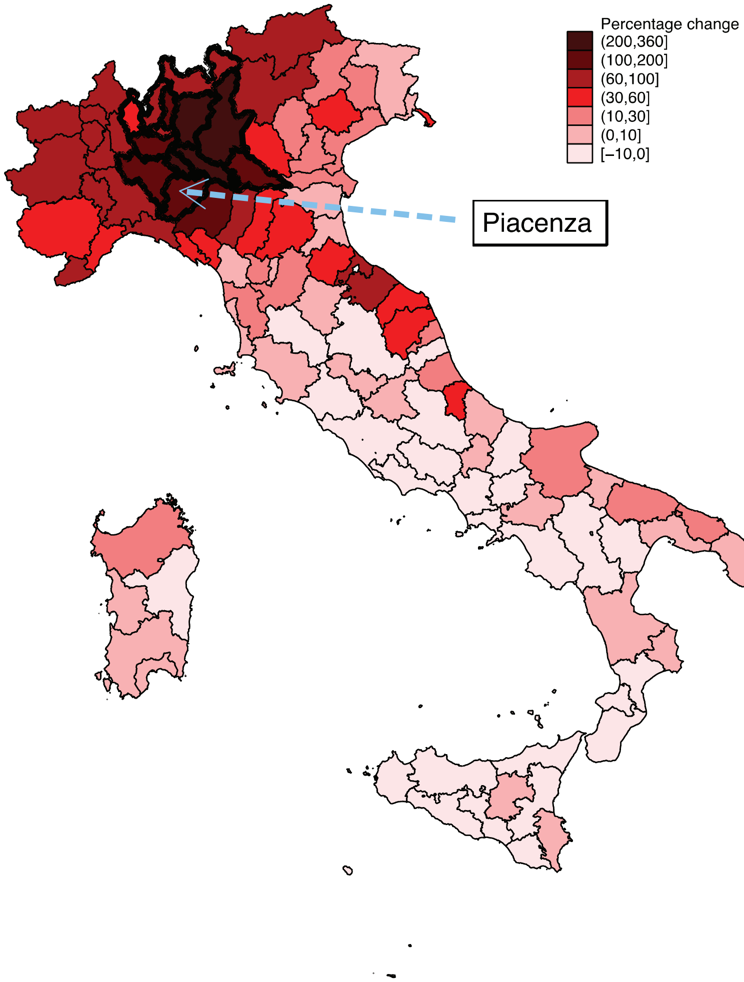


Figure A.2:
Distribution of excess mortality in March–April 2020 across municipalities in Lombardy and in the province of Piacenza

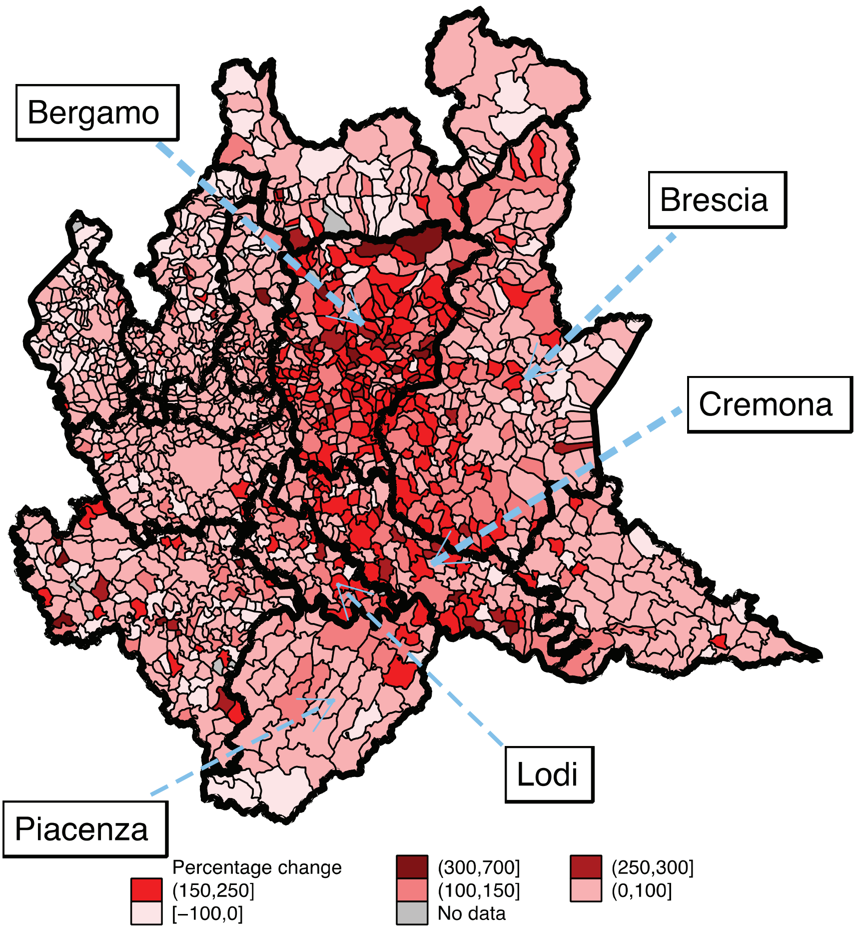
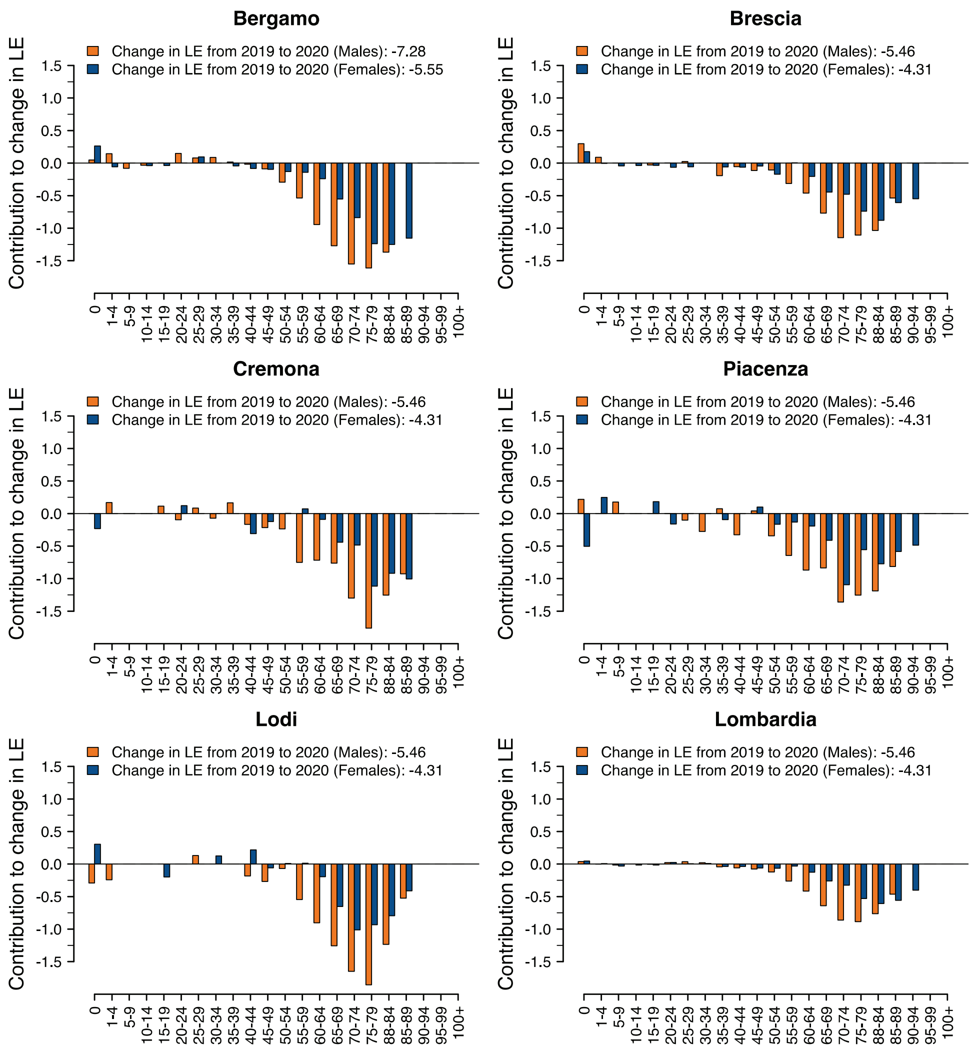


Figure A.3:
Decomposition of the loss of life expectancy in the first quadrimester, by age and sex and province



Note: For decomposing changes in life expectancy into age-specific contributions, the method proposed by Arriaga (1984)[3] is applied. This approach is used to assess which age-groups have primary contributed to the change in the first quadrimester life expectancy between 2019 and 2020

[3] Arriaga, E.E. (1984). Measuring and Explaining the Change in Life Expectancies. Demography 21(1):83–96. doi: 10.2307/2061029.

Table A.1:
Population exposure by province, year 2020

Age class	Pop 2020 males (beginning)	Pop 2020 males (end)	Exposure males (person-years)	Pop 2020 females (beginning)	Pop 2020 females (end)	Exposure females (person-years)
			BERGAMO			
0	4140	4127	4133	4112	4100	4106
1–4	19110	19109	19110	17998	17995	17997
5–9	28054	28051	28052	26278	26277	26277
10–14	30073	30068	30070	28448	28445	28446
15–19	29875	29866	29871	27856	27854	27855
20–24	29701	29687	29694	27304	27300	27302
25–29	29134	29124	29129	27849	27845	27847
30–34	30332	30315	30323	30035	30029	30032
35–39	34293	34272	34283	33522	33512	33517
40–44	41078	41036	41057	39572	39537	39554
45–49	46720	46623	46671	43875	43822	43848
50–54	47710	47547	47628	45497	45399	45448
55–59	42755	42490	42622	42053	41917	41985
60–64	35011	34594	34802	35498	35304	35401
65–69	30921	30258	30589	32148	31859	32003
70–74	27929	26875	27402	30184	29695	29939
75–79	21009	19661	20335	25417	24570	24994
80–84	15480	13775	14627	21472	20105	20789
85–89	7733	6227	6980	14335	12483	13409
90–94	2463	1696	2080	6901	5272	6087
95–99	396	212	304	1918	1189	1554
100+	19	2	10	176	62	119

Continued

Table A.1: Continued

Age class	Pop 2020 males (beginning)	Pop 2020 males (end)	Exposure males (person-years)	Pop 2020 females (beginning)	Pop 2020 females (end)	Exposure females (person-years)
			BRESCIA			
0	4823	4810	4816	4504	4496	4500
1–4	21513	21509	21511	20613	20610	20611
5–9	30953	30952	30952	29459	29457	29458
10–14	33484	33483	33483	31670	31669	31669
15–19	32860	32853	32856	30250	30245	30248
20–24	33324	33312	33318	30213	30206	30210
25–29	33204	33192	33198	31884	31878	31881
30–34	34943	34927	34935	34248	34243	34246
35–39	39634	39598	39616	38994	38975	38984
40–44	47140	47093	47116	45568	45537	45552
45–49	53420	53340	53380	50503	50457	50480
50–54	53368	53208	53288	51550	51451	51501
55–59	47581	47314	47447	47426	47295	47360
60–64	38707	38337	38522	39872	39701	39787
65–69	33983	33421	33702	36128	35840	35984
70–74	31695	30752	31223	34845	34372	34608
75–79	24849	23609	24229	29843	29061	29452
80–84	18232	16602	17417	25725	24384	25054
85–89	8822	7382	8102	17175	15335	16255
90–94	3022	2192	2607	9114	7157	8135
95–99	516	292	404	2514	1621	2068
100+	37	10	24	247	107	177

Continued

Table A.1: Continued

Age class	Pop 2020 males (beginning)	Pop 2020 males (end)	Exposure males (person-years)	Pop 2020 females (beginning)	Pop 2020 females (end)	Exposure females (person-years)
			CREMONA			
0	1299	1294	1297	1186	1181	1183
1–4	5567	5567	5567	5185	5185	5185
5–9	8152	8152	8152	7417	7417	7417
10–14	8674	8673	8673	7897	7896	7897
15–19	8414	8411	8412	7685	7684	7684
20–24	9036	9032	9034	8038	8035	8037
25–29	9189	9188	9189	8693	8692	8693
30–34	9684	9674	9679	9321	9320	9320
35–39	10738	10735	10737	10267	10261	10264
40–44	12943	12922	12932	12463	12451	12457
45–49	14326	14298	14312	13744	13730	13737
50–54	15146	15091	15118	14494	14461	14477
55–59	13560	13458	13509	13669	13623	13646
60–64	11665	11537	11601	12120	12058	12089
65–69	10668	10444	10556	10987	10883	10935
70–74	9967	9623	9795	10787	10625	10706
75–79	7496	7015	7256	9134	8821	8977
80–84	5986	5399	5692	8541	8018	8279
85–89	2955	2411	2683	5908	5141	5524
90–94	1065	710	887	3095	2338	2716
95–99	204	104	154	895	536	716
100+	9	3	6	78	33	55

Continued

Table A.1: Continued

Age class	Pop 2020 males (beginning)	Pop 2020 males (end)	Exposure males (person-years)	Pop 2020 females (beginning)	Pop 2020 females (end)	Exposure females (person-years)
			LODI			
0	855	851	853	836	835	836
1–4	3987	3984	3986	3827	3827	3827
5–9	5576	5576	5576	5213	5213	5213
10–14	5973	5973	5973	5470	5470	5470
15–19	5503	5503	5503	5331	5330	5330
20–24	5728	5723	5726	5275	5275	5275
25–29	5908	5906	5907	5742	5742	5742
30–34	6544	6542	6543	6338	6335	6336
35–39	7323	7320	7322	7085	7083	7084
40–44	8678	8671	8675	8410	8405	8407
45–49	9876	9856	9866	9284	9270	9277
50–54	10106	10069	10087	9737	9716	9727
55–59	8651	8604	8627	8477	8459	8468
60–64	7209	7128	7169	7444	7410	7427
65–69	6339	6213	6276	6629	6565	6597
70–74	5958	5737	5847	6429	6324	6377
75–79	4306	4031	4168	5373	5206	5289
80–84	3216	2875	3046	4828	4555	4691
85–89	1554	1284	1419	3062	2710	2886
90–94	501	356	428	1491	1128	1309
95–99	78	42	60	422	254	338
100+	8	5	6	27	9	18

Continued

Table A.1: Continued

Age class	Pop 2020 males (beginning)	Pop 2020 males (end)	Exposure males (person-years)	Pop 2020 females (beginning)	Pop 2020 females (end)	Exposure females (person-years)
			PIACENZA			
0	997	995	996	1058	1055	1056
1–4	4661	4660	4660	4241	4241	4241
5–9	6339	6338	6339	5984	5984	5984
10–14	6579	6579	6579	6273	6273	6273
15–19	6516	6515	6516	6060	6060	6060
20–24	7113	7110	7111	6202	6201	6201
25–29	7584	7580	7582	7059	7057	7058
30–34	7692	7685	7689	7516	7516	7516
35–39	8388	8385	8386	7950	7945	7947
40–44	9921	9908	9914	9596	9590	9593
45–49	11460	11445	11452	11493	11484	11489
50–54	11967	11919	11943	11736	11717	11727
55–59	10959	10893	10926	11054	11012	11033
60–64	9444	9331	9388	9725	9677	9701
65–69	7929	7797	7863	8374	8298	8336
70–74	7605	7358	7481	8583	8427	8505
75–79	6436	6069	6252	7707	7494	7600
80–84	5079	4597	4838	7076	6689	6882
85–89	2866	2397	2631	5158	4562	4860
90–94	1043	753	898	2685	2055	2370
95–99	202	126	164	831	526	678
100+	13	5	9	82	37	59

Note: Population at the beginning of 2020 is provided by ISTAT. Population at the end of 2020 is estimated following the procedure outlined in the Methods section. Exposure (person-years) is given by the rounded average of population at the beginning and at the end of the year.