**Reply to editors and reviewers**

We thank the editorial board for the opportunity to revise our manuscript. We also appreciate the reviewers' comments; their detailed reading of the manuscript and many suggestions have improved the article. Our responses to the editors and reviewers’ comments are outlined below in blue with editors and reviewers’ comments in black.

**From Editing team**

Statements on Licence for Publication and Competing Interest.

The revised version of the manuscript includes both statements as required by the Editing team.

**Reviewer: 1**

This is a well written paper on an important topic. The paper provides some new insights, also in addition to providing figures for the selected population.

Thank you, we are pleased that you appreciated the contributions of our manuscript.

The paper illustrates the demographic view and approach to the covid-19 mortality, as compared to an epidemiologic or public health view. Both methods and measures are somewhat different between these areas. It is customary in epidemiologic studies of excess mortality to compare the present figures to the average of five or so previous years, while in this paper several more detailed models are being used. The text says that four models are used but this reviewer can only see three?

Indeed, as you mention several accounts of excess mortality are based on crude methods that do not account for important biases such as age structure and seasonal trends in mortality, nor do they provide any estimate of uncertainty. These approaches also do not analyse variations by age and sex. We compare four models. Three of those are statistical approaches in the form of Generalized Additive Models and Generalized Linear Models, while the fourth is an extension of the average-based model where average death rates in the preceding five years is used as a baseline. To clarify that this last approach is the fourth model, we have now amended the text to indicate this (‘Finally, for our fourth model,...’).

The four approaches are explained in greater detail in the Supplementary Material as follows:

1. Generalized Additive Model assuming a Negative Binomial distribution to account for overdispersion of deaths during the period we study[1]. The model includes
   1. log-linear long-term mortality trends stratified by age group and sex,
   2. smoothed effects for mortality over age and seasonality stratified by sex,
   3. a smoothed interaction for mortality between age and seasonality stratified by sex, and
   4. age and sex specific effects for “special weeks”, i.e. the first and last week of a year and week 21 where holidays cause registration delays,
   5. logged exposure times as offset.

The structure of the model is as follows:

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Where are the expected deaths in a given week and population stratum, are the population exposures, and are smooth functions of continuous covariates. is a penalized spline for the age effect with a dimension 6 basis, is a penalized cyclic spline over week of year for the seasonality effect with a dimension 8 basis and is a smooth interaction of age and seasonality.

1. The second approach is a Generalized Additive Model assuming a Poisson distribution with the same structure as above.
2. The third approach is a Generalized Linear Model regression on weekly deaths assuming a Poisson distribution and featuring trigonometric terms for the seasonal effect. These so-called Serfling models [2,3] are used to estimate baseline mortality during influenza epidemics. The basic structure of the model is as follows:

where all the terms are fully interacted with age and sex and “special weeks” are included in the same way as in the Generalized Additive models.

1. We constructed an empirical baseline mortality based on the average mortality rate over the previous five years 2015-19 within each week and stratum. The associated deaths from this approach result from multiplying the average death rates by the population exposed to the risk.

By going beyond the straightforward annual average the paper addresses a critique that has been raised previously, and it is reassuring that there are no big differences between the results from the various models. Also, the division of excess deaths by age and sex is a clear bonus and informative.

We are pleased that the reviewer finds our approach useful. We note that the paper has been further updated with the latest information available through week 47 (ending November 20th, 2020) prior to resubmission.

The life expectancy calculations are of interest of course, as summary measures, but have been shown before for other countries. The discussion of how long it will take for the life expectancy to recover from the current down is not persuasive, though. After all, it is just a question about when death rates are back to “normal”.

We thank the reviewer for this observation. Indeed the question is about when will death rates be back to ‘normal’. However as recent trends have shown, going back to normal will not be easy and requires careful thought in light of the second wave that has hit England and Wales and a consideration of both short- and medium-term factors. Previous evidence suggests that mortality shocks from mortality crises such as wars (Human Mortality Database, 2020) and historical epidemics and famines reduced life expectancy with a rapid recovery after these shocks (Zarulli et al, 2020). This evidence suggests a rapid recovery of life expectancy. However, previous mortality crises and wars generally happened in a context of lower levels of life expectancy and affected mortality also at infancy and at young ages, while the Covid-19 pandemic has primarily affected older ages.

It is therefore not clear *a priori* if life expectancy will return to the baseline level rapidly, and even if/when it recovers, how mortality patterns will be different in the aftermath. The prospect of vaccination being likely in the near future suggests a rapid recovery of life expectancy, although this will depend on the speed, coverage and efficacy of the vaccine (Mills *et al* 2020). In contrast, the combination of the after-effects of Covid-19, such as the long term consequences of the disease on individuals' health (Mahase, 2020), the implications of lockdown and non-pharmaceutical interventions on behaviours and mental health (Xiaowei and James 2020), cancer and other diseases treatment delay associated with increased mortality (Hanna *et al* 2020), and the unequal impact of Covid-19 across subgroups (by age, sex, ethnicity, SES) as suggested by Reviewer 2 (Bambra *et al* 2020) and regions (Trias-Llimós et al 2020), can create an unseen mortality profile that can maintain life expectancy at lower levels than the baseline beyond the short-term into the medium-term.

Life expectancy is a useful indicator for understanding the toll of the pandemic compared to previous years because the differences are intuitively expressed in years, and as an age-standardised indicator makes comparison over time (and space) possible. We have now included a discussion of the aforementioned issues in the revised Discussion section of the paper and have replaced the discussion about the expected second wave at time of the first submission with:

*Looking forward, it is unclear if life expectancy will return to the baseline level rapidly, and even if/when it recovers, how mortality will be different. The prospect of vaccination being likely in the near future suggests a potential for the rapid recovery of life expectancy, although this will depend on the rollout speed, coverage and efficacy of the vaccine[38]. In contrast, the combination of the after-effects of Covid-19, such as the long term consequences of the disease on individuals' health[39], the implications of lockdown and non-pharmaceutical interventions on behaviours and mental health [40], cancer treatment delay associated with increased mortality[41], and the unequal impact of Covid-19 across subgroups by age, sex, ethnicity, SES and regions[42,43], can create an unseen mortality profile that can maintain life expectancy at lower levels than beyond the short-term into the medium-term.*

However, this reviewer misses the significance of the life span inequality part of the paper. The way it is defined does not make immediate sense, and the discussion of whether it should decrease or increase with increasing mortality is also not quite clear. This section may fit better in some other context where it can be discussed broader.

Life expectancy is a key indicator used widely to capture mortality and health conditions of a population as it describes the average length of life individuals in a population would live if they experienced a given schedule of mortality rates. Lifespan inequality on the other hand focuses on a second dimension of mortality, the *variation* in lifespans between individuals and groups of individuals in a population (Tuljapurkar, 2010). As we mention in the manuscript, lifespan inequality is one of the most fundamental measures of inequality because it reflects how unevenly population health improvements (or deterioration) are shared within a population, moving beyond the perspective offered by an average-based measure. The significance of lifespan inequality lies in that it monitors the inequality as captured by the variation in the distribution in survival improvement (or worsening) and it uncovers underlying heterogeneity in health that can be overlooked by only focusing on standardised mortality rates or life expectancies alone. Two populations that share the same level of life expectancy could experience substantial differences in the timing of death, e.g., deaths could be more evenly spread over age in one population than another (Aburto et al, 2020). In our view, including lifespan inequality alongside excess mortality and life expectancy is the path toward a comprehensive measurement of mortality, and this has been acknowledged in recent work on population health (e.g. van Raalte et al (2018), Aburto et al (2020), Vaupel et al (2011), Seligman et al. (2016)).

To better motivate the consideration of lifespan inequality and its dynamics, and also following Reviewer 2’s advice, we have extended the motivation to monitor lifespan inequality by pointing out that it has been historically decreasing together with increasing life expectancy and the modal age at death, and that two populations with similar life expectancies could have substantially different levels of lifespan inequality. We additionally include a short explanation about how age-specific mortality changes affect life expectancy and lifespan inequality.

Specifically we have added the following:

In the introduction:

*Lifespan inequality is another complementary indicator of population health with implications for public health planning, which has increasingly been reported in population health research* [*[13–15]*](https://www.zotero.org/google-docs/?tFZNgc)*. While life expectancy is a measure of average mortality, lifespan inequality focuses on a second dimension of mortality, the variation in length of life between individuals in a population. It is possible for two populations to have the same life expectancy (i.e. average) with different levels of lifespan inequality because of the variation in the distribution of the ages of death. Thus, lifespan inequality provides a complementary perspective that reflects how unevenly population health improvements are shared within a population, which has important implications for health and social care planning*[*.*](https://www.zotero.org/google-docs/?E1NU7C) *Trends over the twentieth-century from high-income countries, including England and Wales, show that as life expectancy and the modal age at death have increased, lifespan inequality has tended to decrease*[*[16]*](https://www.zotero.org/google-docs/?eH0RgN)*. Nevertheless, the age dynamics driving improvement in each indicator are different. Reducing mortality at any age increases life expectancy. However for lifespan inequality to decrease when life expectancy is increasing, more lives need to be saved at younger than older ages, usually below life expectancy*[*[13]*](https://www.zotero.org/google-docs/?YWnA3g)*. This compresses the distribution of deaths, making ages at death more similar.*

In the discussion:

*Within a broader context of population health in which mortality is now largely concentrated at older ages, the elevated excess death rates at older age groups observed during the COVID-19 pandemic so far have reduced life expectancy. However, the disproportionate shift in the distribution of ages at death to older age groups made ages at death more similar thereby reducing variation but at the expense of increasing overall average mortality. As a result of these dynamics, life expectancy and lifespan inequality moved in the same, undesired direction.*

The section in the discussion on implications for health care planning does not contribute much.

We agree that it did not add much and hence we have shortened the section and instead elaborated on our findings more thoroughly as explained in the other points.

And finally, covid-19 deaths may be both over- and underreported in the cause of death statistics.

Thanks for this observation. We agree that COVID-19 may be both over- and under reported in the cause of death statistics. To avoid any misinterpretation we have rephrased the instances now referring to the potential of misclassification of causes of death, which includes both (over and under) possibilities, and also point out challenges linked to the measurement of COVID-19 mortality due to definitional inconsistencies across different sources. This further motivates the analysis of excess mortality through the focus on all-cause mortality, as our results are unaffected by issues of misclassification in causes of death.

**Reviewer: 2**

Comments to the Author

This is an important paper quantifying the excess deaths due to COVID-19 and the effect on life expectancy and lifespan inequality in England and Wales. It is a thorough piece of work, well written and generally easy to read. I have therefore only a couple of typographical errors to point out and then two areas that I think the authors could elucidate more clearly.

We thank the reviewer for the comments and we are pleased to hear that the reviewer found our manuscript well written and important.

Typographical errors:

1. Page 4 para 3. Sentence beginning 'Furthermore, life can shed ..' should read 'Furthermore, life expectancy can shed'.

It has been rephrased as:

*Furthermore, as life expectancy is sensitive to the ages at which deaths occur and because it is comparable across time, it can shed additional light on the cumulative burden of a crisis such as COVID-19 on population health and enable comparisons with previous population health conditions.*

2. Figure 2. In the legend for the lines in the 85+ age group Males are incorrectly denoted as Females.

Thanks for noting this mistake, we have corrected it.

Minor comments:

1. Although most readers have a good understanding of life expectancy, I think fewer will be familiar with lifespan inequality. Though the authors explain it in the introduction in terms of its similarity to the Gini coefficient, again I think this is a more specialised statistic. It would help the more general reader to have a better explanation of lifespan inequality, perhaps pointing out that it has been decreasing (as the authors pointed out in the discussion) and making comparisons with the modal age at death.

Thank you for this comment. Reviewer 1 also emphasised the need to better motivate the significance of lifespan inequality. To explain the importance of lifespan inequality we have followed your suggestions along with Reviewer 1.

Specifically we have added the following:

In the introduction:

*Lifespan inequality is another complementary indicator of population health with implications for public health planning, which has increasingly been reported in population health research* [*[13–15]*](https://www.zotero.org/google-docs/?tFZNgc)*. While life expectancy is a measure of average mortality, lifespan inequality focuses on a second dimension of mortality, the variation in length of life between individuals in a population. It is possible for two populations to have the same life expectancy (i.e. average) with different levels of lifespan inequality because of the variation in the distribution of the ages of death. Thus, lifespan inequality provides a complementary perspective that reflects how unevenly population health improvements are shared within a population, which has important implications for health and social care planning*[*.*](https://www.zotero.org/google-docs/?E1NU7C) *Trends over the twentieth-century from high-income countries, including England and Wales, show that as life expectancy and the modal age at death have increased, lifespan inequality has tended to decrease*[*[16]*](https://www.zotero.org/google-docs/?eH0RgN)*. Nevertheless, the age dynamics driving improvement in each indicator are different. Reducing mortality at any age increases life expectancy. However, for lifespan inequality to decrease when life expectancy is increasing, more lives need to be saved at younger than older ages, usually below life expectancy*[*[13]*](https://www.zotero.org/google-docs/?YWnA3g)*. This compresses the distribution of deaths, making ages at death more similar.*

In the discussion:

*Within a broader context of population health in which mortality is now largely concentrated at older ages, the elevated excess death rates at older age groups observed during the COVID-19 pandemic so far have reduced life expectancy. However, the disproportionate shift in the distribution of ages at death to older age groups made ages at death more similar thereby reducing variation but at the expense of increasing overall average mortality. As a result of these dynamics, life expectancy and lifespan inequality moved in the same, undesired direction.*

2. In the discussion page 9 lines 18-19 the authors make a rather opaque reference to the inequalities in life and healthy life expectancy between social (particularly deprivation) groups in England and Wales. I would like to see a clearer exposition of the form of this inequality with perhaps reference to another JECH paper recently published (Bambra C, Riordan R, Ford J, Matthews F. The COVID-19 pandemic and health inequalities. J Epidemiol Community Health. 2020 Nov;74(11):964-968. doi: 10.1136/jech-2020-214401. Epub 2020 Jun 13. PMID: 32535550; PMCID: PMC7298201).

We thank the reviewer for pointing out Bambra et al (2020)’s article. We have included this reference and reinforced the point that based on previous research the impact of pandemics has affected more populations in lower socioeconomic groups and also that there are potential long-term impacts on life expectancy and lifespan inequality. More research at the subgroup level is needed to put in context our findings and we see this as a potential area of research work when data become available. We included the following:

*In contrast, the combination of the after-effects of Covid-19, such as the long term consequences of the disease on individuals' health*[*[39]*](https://www.zotero.org/google-docs/?Se01pw)*, the implications of lockdown and non-pharmaceutical interventions on behaviours and mental health* [*[40]*](https://www.zotero.org/google-docs/?XYCa6C)*, cancer treatment delay associated with increased mortality*[*[41]*](https://www.zotero.org/google-docs/?B0ETLV)*, and the unequal impact of Covid-19 across subgroups by age, sex, ethnicity, SES and regions*[*[42,43]*](https://www.zotero.org/google-docs/?YvJ85s)*, can create an unseen mortality profile that can maintain life expectancy at lower levels than beyond the short-term into the medium-term.*

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