Cause-specific decomposition of short-term mortality disturbances:

Application to the analysis of mortality disturbances by income level in 10 countries in 2020, during the first wave of the COVID-19 pandemic

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Long Abstract

Introduction

The assessment of the full impact of a period crisis on mortality is highly complex, and COVID-19 is not the exception. One part of the problem is that a substantial proportion of deaths caused by COVID-19 went underreported (Msemburi et al. 2023). The other main reason is that the pandemic also impacted mortality indirectly. The socioeconomic disruptions and behavioral changes induced by the pandemic produced substantial mortality changes in other causes than COVID-19. For instance, lockdowns modified the exposure to work-, recreational-, and environmental-related risk factors, and primary care and medical treatments were delayed or avoided. Mortality changes might have different magnitudes and directions depending on the cause of death under analysis; whereas mortality might have increased in several causes, it decreased in others. The extent of these changes and how such mechanisms affected mortality remains unknown.

Identifying the cause-specific variations and their contribution to total mortality disturbances is fundamental to understanding the multiple mechanisms modulating total mortality changes during the pandemic. This disaggregation of total disturbances into cause-specific contributions would allow us to understand better the differences in mortality between populations, evaluate the pros and cons of the different governmental strategies, and unveil how preexisting inequalities translate into mortality differentials during period crises.

To our knowledge, among the very few attempts to evaluate changes in mortality by cause during the COVID-19 pandemic, analyses are mainly based on cause-specific decompositions of life expectancy changes (Aburto et al. 2022; Spijker and Sergi Trias-Llimós 2023). Life expectancy is a key measure for analyzing changes in mortality over time and might be the most popular demographic measure to analyze changes in population survival over time. However, it is inadequate to rely exclusively on this measure to evaluate the impact of period shocks on mortality for at least three reasons. **First, life expectancy is based on a counterfactual scenario, which meaning can be easily misinterpreted.** This indicator assumes that a synthetic cohort is subject during its whole lifespan to the mortality risks observed during the crisis, a virtually impossible situation (Goldstein and Lee 2020); as seen several times during the pandemic, the interpretation of life expectancy changes was frequently misinterpreted for this reason. **Second, life expectancy gives more weight to younger than to older deaths** (Murphy and Grundy 2022)**.** When looking at all-cause mortality during the COVID-19 pandemic, this unequal treatment of age is critical because age is one of the main factors increasing mortality risk from COVID-19. As COVID-19 kills disproportionally old adults, the life expectancy measure underplays the mortality impact on the population. Likewise, when looking at cause-specific contributions to mortality changes, these contributions are distorted by the ages at which these causes tend to occur. **Third, most analyses of life expectancy change struggle to account for mortality trends properly.** Suppose a given cause contributes negatively to life expectancy changes during a crisis. Looking merely at this contribution, it is difficult to know whether mortality from that cause was as expected — considering the pre-shock trend — or, contrarily, is exceptional to the pandemic. This issue becomes more problematic as the contribution of one cause to life expectancy changes depends on the mortality experienced at younger ages, which is not always obvious to disentangle (e.g., see direct and indirect contributions in Arriaga's approach).

This study proposes an approach to analyzing cause-specific changes and their contribution to total mortality disturbances during period mortality shocks that overcomes the abovementioned limitations. The approach consists of decomposing mortality disturbances — known in the literature as excess mortality — into cause-specific contributions. The basic principle of this decomposition is that all-cause mortality disturbances are composed of the sum of cause-specific disturbances. In other words, by adding together cause-specific deficits and excess, we obtain all-cause mortality disturbances.

In the following sections, we present methodological aspects of the approach and then apply it to analyze differences in cause-specific disturbances between samples of high- and middle-income countries during the COVID-19 pandemic.

Method

Cause-specific decomposition of mortality disturbances

Mortality disturbances are obtained by comparing the observed mortality and a "free-pandemic" counterfactual scenario, also denoted as the baseline mortality. For estimating the baseline mortality, we fitted a Generalized linear model to annual deaths between 2015 and 2019 and predicted death counts for 2020. The model accounts for secular trends and changes in population-at-risk exposure and uses a quasi-poisson distribution to account for overdispersion.

We estimated independent mortality baselines for each country, cause of death, sex, and age. Then, the sum of cause-specific baselines is compared to the all-cause baseline and adjusted proportionally to guarantee the identity and consistency between both estimates.

Note that the quality of the match between the sum of cause-specific baselines and all-cause baseline depends on the definition and amount of causes of death under analysis, as well as the variability of cause-specific deaths during the training period. The more disaggregated the causes of death and the higher variability over time, the higher the risk and magnitude of mismatch between these two quantities.

Using wider definitions of causes of death considerably reduces data artifacts, such as the shift in classification over time between causes. For instance, changes in classification occurring within the cardiovascular diseases chapter do not affect our estimates if the chapter is analyzed together. A finner disaggregation increases the risk of data artifacts, such as shifts in classification between causes. This is under the assumption that most classification shifts occur within the same chapter.

For the applied analysis presented here, we initially used the 20 main chapters defined in the 10th version of the International Classification of Diseases (ICD-10), plus COVID-19. We then focus our analysis on those chapters representing an annual average of at least 10% of all-cause deaths by age group during the observation period (2015-2020). The only causes maintained regardless of their contribution to all-cause mortality are the external ones, as we are particularly interested in disentangling behavioral and contextual mechanisms affecting mortality. Note that, unlike the rest of the causes of death, all deaths classified as COVID-19 are considered automatically excess deaths, as these are not expected in the “pandemic-free” scenario.

Applied Analysis

Data

We apply the abovementioned approach to analyze mortality disturbances among several countries during the COVID-19 pandemic. We obtained cause-specific death counts by five-year age groups and sex from the WHO mortality database. Among the countries with available information in 2020, we selected two groups: 1) a set of five high-income countries with well-recognized high-quality cause-of-death data that suffered mortality increases during the pandemic, including Netherlands, Spain, Switzerland, the United Kingdom, and the US; and 2) a set of five middle-income countries with large populations and a good-enough quality of classification of causes of death, including Argentina, Brazil, Colombia, Mexico, and Peru. We assume that data from middle-income countries with large populations may reduce the risk of bias resulting from changes in causes of death classification over time. We obtained annual population-at-risk by age and sex between 2015 and 2020 from the WPP 2022 estimates.

All-cause mortality disturbances by age and income level

Figure 1 presents age-specific p-score estimates by income level and country. Despite large variation within income level groups, especially among middle-income countries, it is possible to recognize a distinctive pattern: high-income countries experienced considerably lower disturbances compared to middle-income countries, and this difference is much more pronounced in midlife age groups (i.e., 40-69yo). Whereas in these age groups, high-income countries experienced a 10% increase on average, middle-income reached an average increase of 46%.

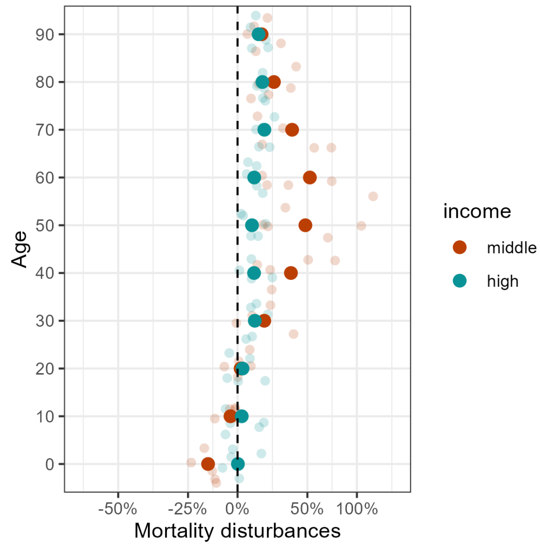

Figure 1. Age-specific all-cause mortality disturbances in relative terms (p-scores) in 2020, by income level. Small dots indicate country- and age-specific relative disturbances, whereas large opaque dots indicate average age-specific relative disturbances by income level.

Cause-specific mortality disturbances by age

Now, we decompose all-cause disturbances into cause-specific contributions. Figure S1 in the supplementary materials presents the relative difference between all-cause baseline mortality and the sum of cause-specific baselines by age and country. The difference between both measures is considerably small, reaching a maximum of 3% in the UK for the age group 0-9 and no higher than 1.4% for the rest of the ages and countries. Given this relative consistency between both measures, we adjust cause-specific baselines proportionally to be fully consistent with the all-cause baseline.

We focus now on specific causes that are predominant drivers of mortality disturbances in most ages and countries. Based on the results plotted in Figure S2, we identify neoplasms, circulatory diseases, respiratory diseases, external causes, and COVID-19 as the main modulators of disturbances.

Figure 2 shows the relative disturbances in cause-specific mortality (i.e., cause-specific p-scores) for these causes (except for COVID-19, whose relative change is infinite) by income level. Although there is wide heterogeneity within middle- and high-income levels — especially in the latter group —, several patterns are recognizable. First, cancer mortality shows opposite patterns in young ages by income level. Whereas young ages in middle-income countries experienced relatively small deficits, those in high-income countries experienced considerable excess cancer deaths. Second, disturbances of circulatory diseases present a cross-over between middle- and high-income countries. Whereas the young population in middle-income countries experienced deficits and those in high-income countries experienced excess, the opposite pattern is seen for those above 60. Third, whereas high-income countries experienced disturbances in external causes in both directions, with younger ages showing more excess and older ages very small changes, for middle-income countries, these disturbances indicate substantial deficits in external causes for all ages. Finally, although all countries experienced deficit deaths from respiratory diseases at young and old ages, the magnitude of the deficit was considerably higher for middle-income countries.

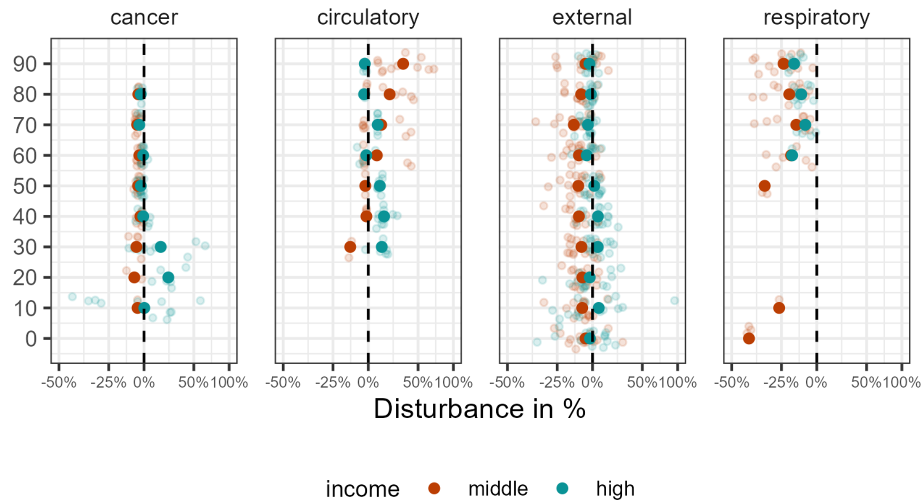

Figure 2. Cause-specific relative disturbances measured in p-scores by age and income level. Dots with transparency indicate country-specific p-scores, while opaque dots indicate the average p-scores in each income level.

Figure 3 presents average cause-specific contributions to all-cause mortality disturbances in death rates by income level. Visual comparisons of cause-specific mortality disturbances in death rates across all countries under analysis are very challenging, given the wide differences in mortality impacts and preexisting mortality levels. To overcome this limitation and have a better idea of cause-specific roles by country and age, Figure S2 in the supplementary materials compares standardized cause-specific contributions for all countries under analysis.

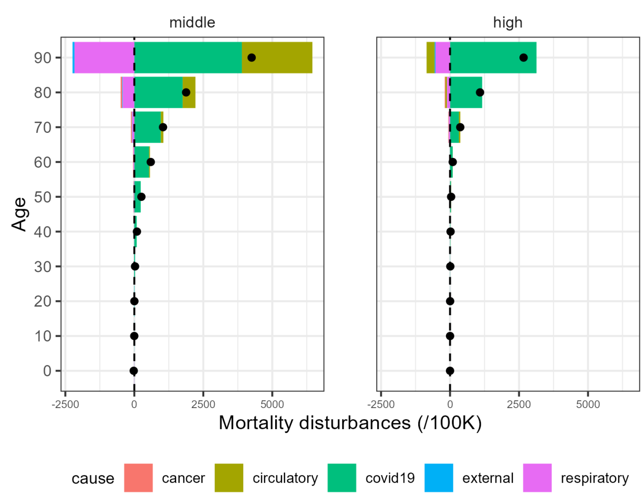

Figure 3. Cause-specific relative disturbances measured in p-scores by age and income level. Dots with transparency indicate country-specific p-scores, while opaque dots indicate the average p-scores in each income level.

We now look at the cause-specific contributions to mortality deficits and excess mortality separately. Figure 3 presents the contribution of each leading cause to mortality deficits (panel A) and excess mortality (panel B). According to these findings, there are notable differences between middle- and high-income countries. First, whereas COVID-19 deaths were responsible for almost all excess deaths in middle-income countries in most age groups, this is true only for old ages in high-income countries. Second, disturbances in external mortality were beneficial for middle-income countries but resulted in mixed outcomes for high-income countries. Third, the contribution of cardiovascular diseases to excess mortality might indicate either a misclassification of COVID-19 deaths that were wrongly attributed to those causes or an indirect result of the pandemic that led to mortality deterioration. Fourth, the contribution of respiratory diseases to mortality deficits suggests a mortality displacement resulting from lower exposure to airborne diseases during lockdowns.

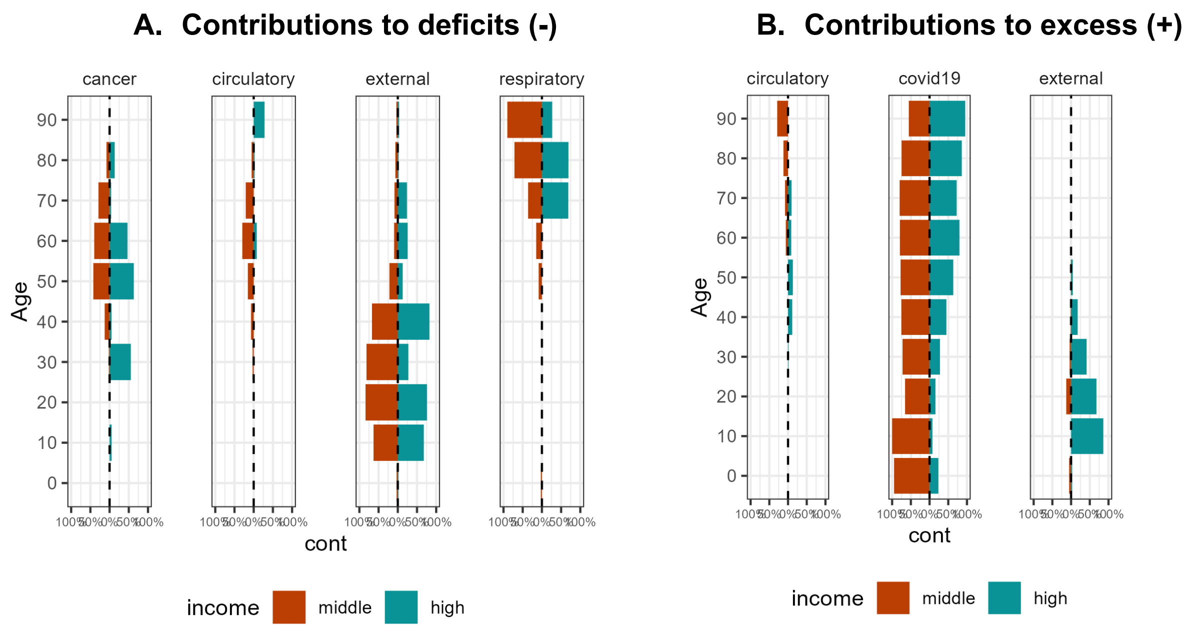

Figure 3. Average cause- and age-specific relative contributions to all-cause mortality disturbances. Panel A presents relative cause-specific contributions to excess mortality (i.e., positive mortality disturbances), and Panel B to mortality deficits (i.e., negative mortality disturbances) by income level in 2020.

Further steps

We plan to improve this manuscript in several ways. First, we will make methodological adjustments to guarantee consistency between cause-specific and all-cause disturbances. This improvement in the model robustness will be achieved by modeling cause-specific fractions that add to the unity without the need for further adjustments.

This methodological improvement will also allow us to increase the detail of the causes of death under analysis, gaining additional clues about the mechanisms driving mortality deficits and excess. For instance, much more can be learned about factors modulating behavioral causes of death by disaggregating external mortality into accidents, suicides, and homicides. As all-cause mortality, external mortality masks the different variations in these subchapters.

Another potential improvement of the current manuscript is the inclusion of mortality during 2021 and 2022 once this information becomes available. During the pandemic, there were substantial variations in the adoption of non-pharmaceutical measures by governments, in the burden of the healthcare system, in the intensity of outbreaks, and in the population's responses, among other factors. It is expected that these variations also changed the mechanisms driving mortality changes during the development of the pandemic. Some disturbances could have been attenuated while the pandemic developed, while others might have been exacerbated. Analyzing these variations over time is fundamental to assessing the direct and indirect impacts of the pandemic on population mortality.

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Supplementary materials

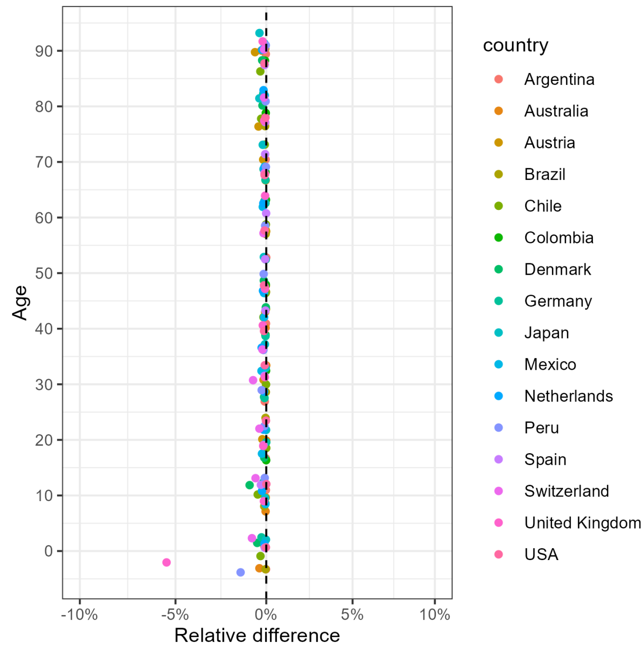

Figure S1. Relative differences between all-cause baselines mortality and the sum of country-age-specific baselines by age and country.

Standardization of country- and cause-specific contributions to all-cause mortality disturbances

We standardized country- and cause-specific contributions relative to the maximal contribution in each country-age combination. This standardization is useful to compare contributions across countries and ages, as there are massive differences in the impact of the pandemic and pre-pandemic mortality levels across countries. Figures S2 and S3 present the standardized country- and cause-specific contributions.

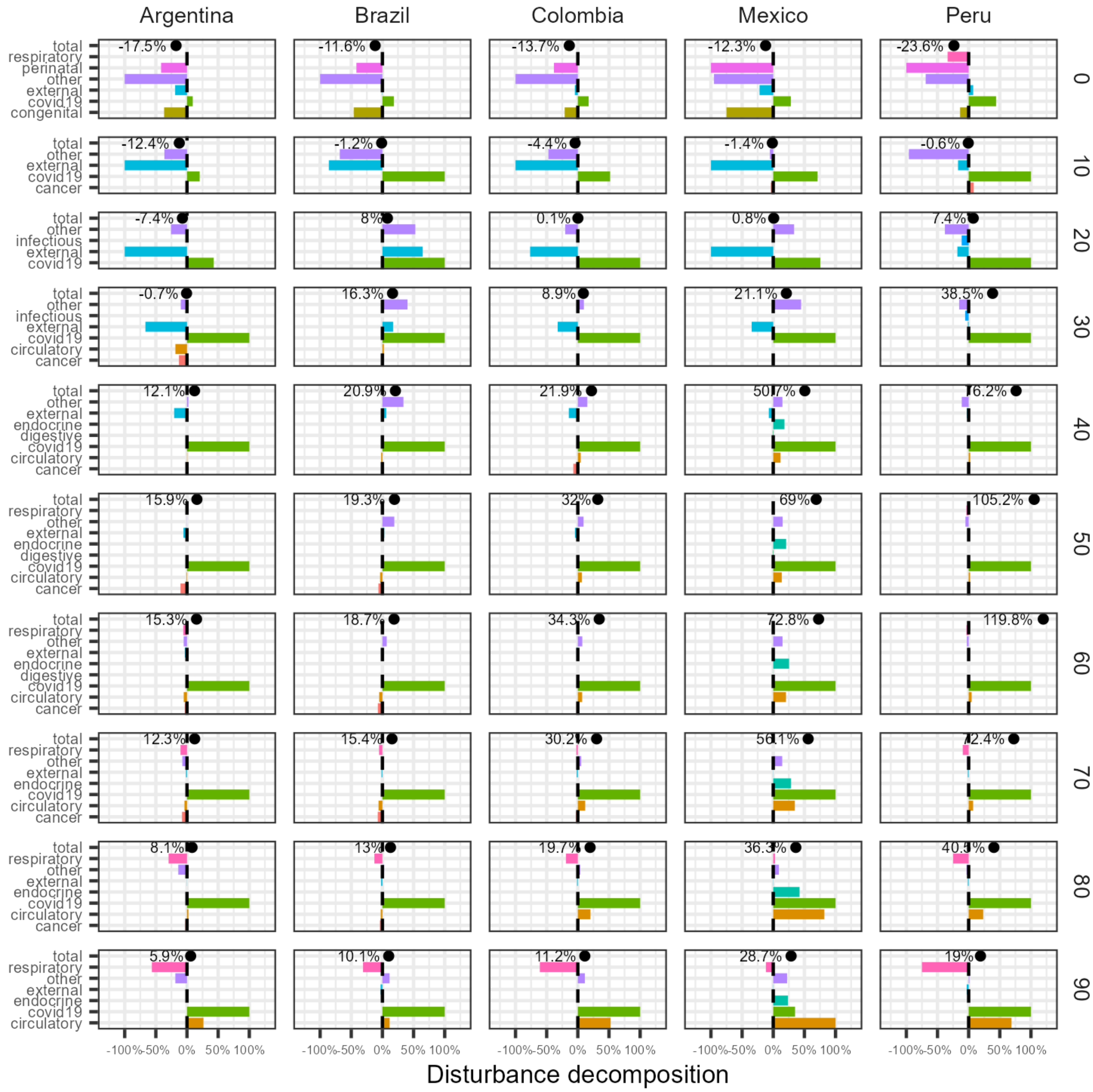

Figure S2. Standardized cause-specific contributions to total mortality disturbances in middle-income countries under analysis. Standardization is made relative to the largest cause-specific contribution — either to excess or deficit — within each country-age combination. Black dots indicate the age-specific all-cause mortality disturbance by country

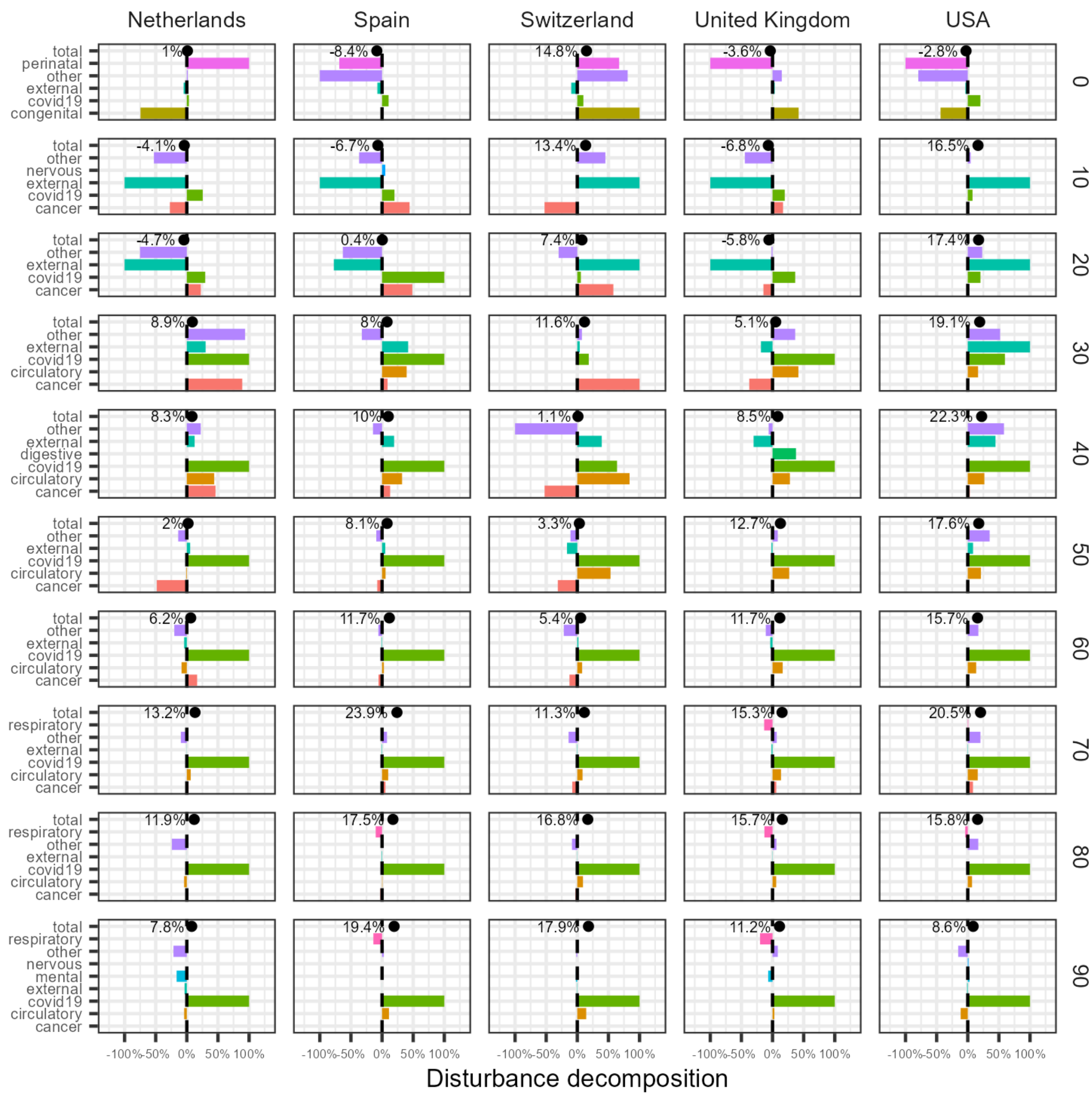

Figure S3. Standardized cause-specific contributions to total mortality disturbances in high-income countries under analysis. Standardization is made relative to the largest cause-specific contribution — either to excess or deficit — within each country-age combination. Black dots indicate the age-specific all-cause mortality disturbance by country