The interplay between excess mortality and laboratory-confirmed COVID-19-related deaths in Switzerland, a nationwide study

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# Introduction

There are two main approaches to quantify the impact of COVID-19 mortality at the population level. The first approach relies upon the reporting of laboratory-confirmed deaths, i.e. deaths of people with a recent confirmed positive SARS-CoV-2 RT-PCR or rapid antigen test. This has the advantage of being available in real-time, but depends on the quality and comprehensiveness of the country’s registration system and on the testing availability. It is therefore almost never exhaustive, as some deaths will remain unidentified because of a lack of test (e.g. due to testing practices, test shortages or overwhelmed health systems) [1]. Laboratory-confirmed deaths also do not include deaths that have been indirectly caused (or averted) by the SARS-CoV-2 pandemic (e.g. in consequence of control measures). The second approach is based on excess mortality, and relies upon all-cause mortality data and counter-factual reasoning [2]. The idea is to compare the observed number of deaths to what would have been expected had the SARS-CoV-2 pandemic not occurred, based on mortality data from the previous years, demographic changes and a set of covariates associated with mortality patterns. Excess mortality has the advantage of summing all the negative and positive effects of the occurrence of the COVID-19 pandemic on mortality, at the cost of not being able to disentangle them [3]. It is also highly dependent on model assumptions and methodological choices, such as for instance age-specific population trends [4].

There have been many attempts at estimating excess mortality associated with COVID-19 in various settings [[5]][6][3], but new approaches are needed to distinguish the proportion of excess mortality that can be directly attributed to SARS-CoV-2 infections [3]. While data on laboratory-confirmed COVID-19-related deaths are incomplete, more information can be gained by linking their variations across time, space and population groups with variations in excess mortality. Excesses of deaths observed during peaks of epidemic activity, when laboratory-confirmed deaths are high, may serve to estimate the total number of deaths that can be directly attributed to SARS-CoV-2 infections, together with the proportion that was confirmed in laboratories (the ascertainment proportion). On the other hand, deficits or excesses in mortality observed between epidemic waves, when there is no or a weak epidemic activity, may provide estimates of the indirect effect of the COVID-19 pandemic on mortality. Deficits in deaths observed in the weeks following large epidemic waves may be attributed to mortality displacement (sometimes called the “harvesting” effect). Variations in mortality distributed more uniformly across the pandemic period may be attributed to mandated or spontaneous changes in behaviors that led to a reduction or an increase of the baseline risk of death. Examples include a diminution of social contacts preventing the spread of other pathogens such as influenza, work from home limiting traffic and thus road accidents, or in the other direction an increase in anxiety levels or substance abuse or a reduction in primary care contacts for acute physical and mental conditions [7].

In this nationwide study in Switzerland between February 2020 and April 2022, we aimed to characterize the similarities and discrepancies between laboratory-confirmed COVID-19-related deaths and excess mortality by time period, location and age group. We used a validated statistical approach to compute the expected number of all-cause deaths in 2020 and 2021 by week, age group and location using historical data from 2014-2019, accounting for the effect of temperature and population changes. We then developed a statistical method to decompose all-cause deaths into death excesses directly attributable to SARS-CoV-2 infections and deaths excesses or deficits indirectly attributable to the pandemic, and use this decomposition to study specific phenomenon such as death ascertainment, mortality displacement and other indirect effects of COVID-19 on all-cause mortality during different time periods of the pandemic.

# Methods

## Data sources

We retrieved population data for the prepandemic years 2010 to 2019 from the *Federal Statistical Office* (FSO) in Switzerland [8]. Estimates are available for 31 December of each year by age (5 groups: 0-39, 40-59, 60-69, 70-79 and 80 and older), sex (2 groups) and administrative region (26 cantons). These were used to predict population sizes in each stratum for each week of the entire study period. Data on all-cause deaths was also obtained from the FSO [9]. These consisted of counts of deaths from any cause by age, sex and canton for each week of 2014 to 2019, and afterwards up to 03 April 2022. Details about the cause of death as listed in the death certificate are encoded with a delay of several months and were not available for this analysis. Data from the prepandemic years were used to compute expected weekly death counts per stratum during the pandemic period. These predictions were supported by covariates known to be associated with mortality patterns: ambient temperature (obtained from *MeteoSwiss* [10]) and national holidays (obtained from *nager.date* [11]). Daily mean ambient temperature between 2014 and 2022 at 1km grid was aggregated by taking means per week and canton. National holidays were considered as dummy variables, and defined on a weekly basis for each canton, being 1 if there was at least 1 cantonal holiday in that week. The declaration of laboratory-confirmed SARS-CoV-2-related deaths has been mandatory in Switzerland since February 2020. All collected data at the individual are centralized at the *Federal Office of Public Health* (FOPH), and are available on motivated request [12]. Available information include age, sex, canton of residence, and the date and type of the positive SARS-CoV-2 test. Dates were grouped into 7 epidemic phases by the FOPH.

## Statistical methods

### Population model

Data on population size on 31 December 2010-2019 by age group, sex and canton was used to predict population sizes in each stratum for each week of the entire study period (01 January 2010 to 03 April 2022) with a two-step procedure. First, we fitted a Poisson regression model to population data from 2010 to 2019. This model included a linear yearly trend, a fixed effect by sex, and independent random effects by week (seasonality), age group, sex and canton. We compared different models using higher interactions and yearly linear trends that vary by space, age and sex. We compared the different models using a cross-validation scheme that excludes the last three years of the data available (2017-2019) and determined that the best model included all possible two-way interactions between sex, age, canton, and week and an overdispersion parameter. This model was used to obtain posterior distributions of the population in each stratum for 31 December 2020, 2021 and 2022, under the counter-factual scenario that the pandemic did not occur. In a second step, we used linear interpolation to obtain weekly estimates of population size (with uncertainty).

### Expected deaths model

We estimated the expected number of all-cause deaths for each week between 24 February 2020, the day of the first confirmed SARS-CoV-2 case in Switzerland, and 03 April 2022 by age, sex and canton of residence using historical data (2014-2019) and expanding a previously proposed model [13]. Briefly, we used Bayesian spatio-temporal models accounting for population trends and including covariates related with temperature and national holidays. To account for uncertainty in population estimates, we applied the model multiple times over the samples of the posterior distributions of the population predictions. Since the effect of temperature on all-cause mortality is expected to be U-shaped, we used a random walk of order 2 to allow for a flexible fit. We accounted for seasonality using a random walk of order 1 at the weekly level, and for exceptional events using week-level independent random effects. We accounted for long-term trends with a linear slope at the yearly level, and for spatial autocorrelation using conditional autoregressive priors. In particular, we modeled spatial autocorrelation using an extension of the BYM model, allowing for a mixing parameter which measures the proportion of the marginal variance explained by the spatial autocorrelation term [15]. The model has been internally validated and found to have high predictive accuracy in the older groups, whereas the results were less reliable in for people years old [13]. The fitted model was used to obtain posterior distributions of the expected number of all-cause deaths by age group, sex and canton in each week between 24 February 2020 and 03 April 2022.

### Decomposition model

We developed a method to decompose the observed all-cause deaths into 1) the number that can be expected given historical trends and 2) the number of deaths attributed to the COVID-19 pandemic. We used a Poisson regression model with an identity link and no intercept term of the form:

where is the observed number of all-cause deaths on week , is the number of laboratory-confirmed SARS-CoV-2-related deaths, is the expected number of all-cause deaths given historical trends, and is a normally-distributed overdispersion term centered at zero.

Within this formulation, is the number of all-cause deaths for each unit increase in laboratory-confirmed deaths, after adjusting for the expected number of all-cause deaths given historical trends. That means that under perfect case ascertainment . If , then we observe a greater number of deaths attributed to SARS-CoV-2 infections compared with the number of laboratory-confirmed deaths. The ascertainment proportion of COVID-19-related deaths is obtained by . This relies on the assumption that when there is at least one laboratory-confirmed death in a given week, then the excess in observed all-cause deaths can be directly attributed to COVID-19. In a similar way, is the number of all-cause deaths for each unit increase in the expected number of all-cause deaths, after adjusting for the direct effect of COVID-19. We expect when the net effect of the pandemic-related behavioral, societal and health system changes on all-cause deaths is zero. The estimate of can thus be interpreted as a measure of the indirect effect of the pandemic on mortality. If , then there were fewer all-cause deaths than expected after removing the direct effect of COVID-19, which implies an indirect protective effect of all changes and control measures associated with the pandemic. Estimates of and thus provide a way to understand the interplay between laboratory-confirmed COVID-19-related deaths and excess all-cause deaths, and allow to differentiate between direct and indirect consequences of the COVID-19 pandemic on mortality.

Going beyond the general case at the country level for the whole period, we extended the model presented above to examine these associations by phase (from 1 to 6 as defined by the Federal Office of Public Health), by age group (0-39, 40-59, 60-69, 70-79 and 80+), and by area (26 cantons). To this end, we introduced multiple and for each phase, each age group or each area separately, with the additional constraint of a multilevel structure allowing a smoothing towards the global mean of the estimator [16]. We also fully propagated the uncertainty that comes with the expected number of deaths being a posterior distribution.

# Results

In Switzerland, there have been 156,193 observed all-cause deaths from 24 February 2020 to 03 April 2022, to be compared to an expected 142,408 (138,044 to 149,125) had the pandemic not occurred. This translates into 13,786 (7,068 to 18,149) excess all-case deaths over the whole pandemic period, a relative increase of 9.7% (95%CrI: 4.7 to 13.1). There were periods of massive excess mortality, with a relative excess of 7.3% (95%CrI: 3.8 to 10.8) during phase 1 (24 February 2020 to 07 June 2020), of 33.9% (95%CrI: 26.4 to 41.4) during phase 3 (28 September 2020 to 15 February 2021) and of 15.9% (95%CrI: 8.3 to 22.8) during phase 6 (11 October 2021 to 19 December 2021, Table 1). We also find some evidence suggesting a harvesting effect during phase 4 (15 February 2021 to 20 June 2021) with a relative excess mortality of -4.3% (95%CrI: -9.9 to 0.2). The age groups affected most by the pandemic were the ones over 70 (Figure 1A), whereas the cantons affected the most overall were Schwytz, Jura and St. Gallen. During the first phase of the pandemic the areas hit the most were the ones near the borders with France and Italy (cantons of Ticino, Geneva, Vaud and Valais), whereas excess mortality was more homogeneous during phase 3, and more focused on the northern and eastern regions during phase 6, in complete opposition with phase 1 (Figure 1B).

During the period, 13,130 laboratory-confirmed COVID-19-related deaths have been reported. Weekly counts of laboratory-confirmed deaths generally aligned with estimates of excess all-cause mortality in Switzerland. This corresponded to a correlation coefficient of 0.89 (95%CrI: 0.85 to 0.92) on aggregate at the country level (Figure 2), and of 0.72 (95%CrI: 0.65 to 0.76) when stratifying by canton and age group. Quantitatively, the number of excess all-cause deaths was greater than the counts of laboratory-confirmed deaths during epidemic waves (phases 1, 3 and 6). This translated into an overall estimate of of 1.38 (95%CrI: 1.22 to 1.54), suggesting that there were on average 38% (95%CrI: 22 to 54) more deaths directly attributable to COVID-19 than laboratory-confirmed deaths during the period, or that the ascertainment proportion was 72% (95%CrI: 65 to 82) (Table 1). Given the 13,130 laboratory-confirmed deaths over the period, this implies that the total number of deaths directly attributable to COVID-19 in Switzerland until 03 April 2022 can be estimated to 18,140 (15,962 to 20,174).

After accounting for COVID-19-related deaths, the observed number of all-cause deaths was slightly lower than expected based on historical trends. This is quantified by , estimated to 0.97 (95%CrI: 0.93 to 1.01), indicating that there have been 3% (95%CrI: -1 to 7) fewer all-cause deaths than expected during the COVID-19 pandemic (after adjusting for the direct effects of SARS-CoV-2 infection on mortality). Still, the data remains compatible with no indirect beneficial effect or a slightly harmful indirect effect.

Looking at the variation of these indicators across phases brings further insights. The relative number of deaths directly attributable to COVID-19 for each laboratory-confirmed death () was estimated around 1.5 during phases 1 and 3 and around 2 during phase 6, suggesting an ascertainment proportion of COVID-19 deaths during periods of high incidence ranging between 50 and 66% (Figure 3A). This estimate is less precise during periods where counts of laboratory-confirmed cases were low (phases 2, 4, 5 and 7), and remain compatible with 1 (perfect ascertainment). Variation of by age group suggests that more deaths were not ascertained in age groups 70-79 and 80+, while the data were compatible with 100% ascertainment () in age groups below 80. Estimates of by canton show generally homogeneous results for the whole of Switzerland, bringing more weight to our results. There were a few exceptions with higher estimates of , potentially signaling an issue in the local reporting system in cantons Jura and Zoug. The relative deficit in all-cause deaths that can be indirectly attributed to the COVID-19 pandemic () showed less variation by phase, age group or canton (Figure 3B), but the indirect beneficial effect was more pronounced during phases 1, 3 and 4 (corresponding to the periods with the most stringent control measures) and in age groups 40 to 69.

# Discussion

In this study, we propose a deeper dive into the patterns of all-cause mortality in Switzerland between 24 February 2020 and 03 April 2022. By integrating detailed data about population, mortality and weather over multiple years prior to the COVID-19 pandemic, we obtain a reliable assessment of what mortality would have been in 2020-2022 had the pandemic not occurred. This allows a detailed estimation of excess all-cause mortality during the pandemic period by time, space and age group, propagating uncertainty from all sources. Our results confirm the massive impact of the epidemic wave of autumn/winter 2020-2021 (phase 3, 28 September 2020 to 15 February 2021) on the Swiss population with a relative excess mortality of 33.9% (95%CrI: 26.4 to 41.4), a situation never observed since the 1918 influenza pandemic [6]. We also report evidence that the epidemic wave of autumn 2021 (phase 6, 11 October 2021 to 19 December 2021) also led to a large number of avoidable deaths (relative excess mortality of 15.9% (95%CrI: 8.3 to 22.8)).

We then aimed to gain more insight by comparing excess all-cause mortality over time with the number of laboratory-confirmed COVID-19-related deaths. As expected, we found that these two time-series were generally aligned, although imperfectly. Using a custom statistical model, we were able to characterize the similarities and discrepancies between laboratory-confirmed COVID-19-related deaths and excess mortality by time period, location and age group. We decomposed of all-cause deaths into mortality excesses directly attributable to COVID-19 and mortality excesses or deficits indirectly attributable to the pandemic. We found that during periods of high incidence, the estimated number of deaths directly caused by COVID-19 was higher than the number of laboratory-confirmed deaths by on average 38% (95%CrI: 22 to 54), or interchangeably that only 72% (95%CrI: 65 to 82) of deaths were ascertained. This result implies that COVID-19 directly caused 18,140 (15,962 to 20,174) deaths in Switzerland until 03 April 2022, while only 13,130 laboratory-confirmed COVID-19-related deaths were reported. Ascertainment was markedly lower during periods of high incidence (phases 1, 3 and 6), suggesting shortcomings with regards to testing and/or reporting in overwhelmed healthcare institutions. Even lower ascertainment in phase 6 could be partially explained by reduced testing due to the availability of vaccines. Under-ascertainment was also concentrated in older age groups, pointing towards retirement and nursing homes as the places where incomplete ascertainment occurs, confirming other reports [1].

Besides directly causing a large number of deaths, we also found some evidence that the COVID-19 pandemic had an indirect beneficial effect on all-cause mortality. This reduction of all-cause mortality was substantial, estimated to 3% (95%CrI: -1 to 7), although the data were still compatible with no indirect effect or a very small harmful indirect effect. This can be explained by a combination of different phenomena. A first explanation could be mortality displacement or a “harvesting effect”, whereby COVID-19 precipitated deaths that would have occurred shortly anyway. Mortality displacement appears to be visible in phase 4, following the largest wave of mortality, but does not explain the lower values of found during phases 1 and 3. This explanation is also in contradiction with the fact that the deficit of deaths not directly related to COVID-19 is mostly focused in age groups 40 to 69 with long life expectancy. Second, the deficit could be attributed to the indirect effect of the pandemic, including non-pharmaceutical interventions and a large array of changes such as reductions in mobility and traffic, social contacts and activities, or air pollution levels. This explanation is supported by the observation that the indirect beneficial effect was more pronounced during phases 1, 3 and 4, corresponding to the periods with the most stringent control measures [17]. The fact that it mostly occurred in age groups 40 to 69 favors explanations relating to reductions in mobility, traffic and outdoor activities, as opposed to a reduced circulation of other pathogens such as influenza, which would have led to mortality deficits in the elderly. In any case, we find no argument in favor of a detrimental effect of non-pharmaceutical interventions on mortality, which does not presume of any other harmful effects on mental and social health.

This study has several strengths and limitations. We used a statistically rigorous approach to estimate the expected number of deaths in 2020-2022 had the pandemic not occurred by age group and over space and time. Our approach has been thoroughly validated, and accounts for the most important determinants of deaths count data, including projected population sizes and observed temperature. We also properly handle the uncertainty coming from different sources of data, and propagate it into the final estimates. Our estimates of excess mortality are in accordance with other works [REFS]. We then developed a statistical method to differentiate all-cause deaths into death excesses directly attributable to SARS-CoV-2 infections and deaths excesses or deficits indirectly attributable to the pandemic. This approach was tailored to the research question, and allowed us to bring further insights about the mortality patterns during the COVID-19 pandemic. This work also has a number of limitations. Most importantly, we could not access information about the cause of death, that could help solving some remaining questions about the mechanisms of the indirect beneficial effect of the COVID-19 pandemic on mortality. Our study also remain subject to ecological bias.

Comparisons:

* Compare numbers to ref. 3 and <https://elifesciences.org/articles/69336> (see <https://github.com/dkobak/excess-mortality>). Karlinsky et al. report an excess mortality of 12,000 (18% of baseline annual deaths) and 90% ascertainment.

# Conclusions

# Table and figures

**Table 1.** Summary of mortality patterns in Switzerland between February 2020 and December 2021.

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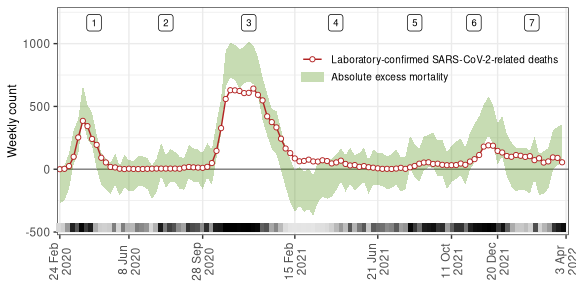
| Epidemic phase | Dates | Expected all-cause deaths | Observed all-cause deaths | Excess all-cause deaths | Relative excess all-cause deaths | Laboratory-confirmed COVID-19 deaths |
| --- | --- | --- | --- | --- | --- | --- |
| 1 | 24 February 2020 to 07 June 2020 | 19,376 (18,767 to 20,033) | 20,791 | 1,415 (758 to 2,024) | 7.3% (95%CrI: 3.8 to 10.8) | 1,725 |
| 2 | 08 June 2020 to 27 September 2020 | 19,180 (18,440 to 20,042) | 19,103 | -76 (-939 to 663) | -0.4% (95%CrI: -4.7 to 3.6) | 104 |
| 3 | 28 September 2020 to 14 February 2021 | 27,004 (25,569 to 28,604) | 36,157 | 9,154 (7,553 to 10,588) | 33.9% (95%CrI: 26.4 to 41.4) | 7,652 |
| 4 | 15 February 2021 to 20 June 2021 | 23,386 (22,320 to 24,834) | 22,369 | -1,017 (-2,465 to 49) | -4.3% (95%CrI: -9.9 to 0.2) | 895 |
| 5 | 21 June 2021 to 10 October 2021 | 19,174 (18,284 to 20,223) | 20,007 | 832 (-216 to 1,723) | 4.3% (95%CrI: -1.1 to 9.4) | 380 |
| 6 | 11 October 2021 to 19 December 2021 | 13,036 (12,298 to 13,944) | 15,105 | 2,070 (1,161 to 2,807) | 15.9% (95%CrI: 8.3 to 22.8) | 956 |
| 7 | 20 December 2021 to 03 April 2022 | 21,370 (20,067 to 22,894) | 22,661 | 1,291 (-233 to 2,594) | 6.0% (95%CrI: -1.0 to 12.9) | 1,418 |

da\_408\_figure1()



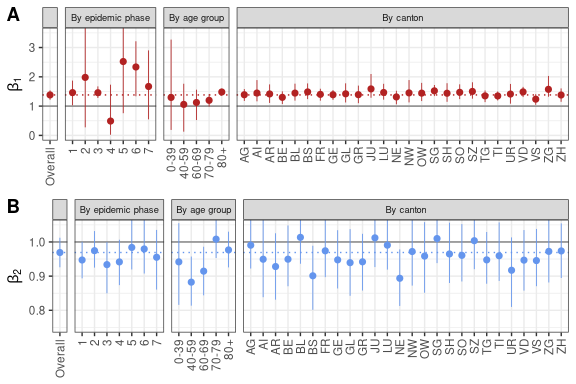
**Figure 1.** (A) Relative excess mortality in Switzerland between 24 February 2020 and 03 April 2022 by epidemic phase (1 to 7) and age group (median with 95% credible intervals). (B) Map of the relative excess mortality in Switzerland between 24 February 2020 and 03 April 2022 by epidemic phase and canton.

da\_301\_summary\_plot(summ\_week\_temp)



**Figure 2.** Weekly counts of excess all-cause deaths (95% uncertainty intervals) and of laboratory-confirmed SARS-CoV-2-related deaths between 24 February 2020 and 03 April 2022 in Switzerland. The bar at the bottom shows the probability that excess all-cause deaths is greater than laboratory-confirmed SARS-CoV-2-related deaths (light gray is 0, black is 1). Numbers at the top indicate epidemic phases 1 to 7.

da\_404\_plot\_regbma(summ\_regbma,panel\_labels = c("A","B"))



**Figure 3.** (A) Posterior estimates of , the additional number of deaths to be observed for each unit increase in laboratory-confirmed deaths, after adjusting for the expected number of all-causes deaths given historical trends. (B) Posterior estimates of , the additional number of deaths to be observed for each unit increase in the expected number of all-cause deaths, after adjusting for the direct effect of SARS-CoV-2 infections. Estimates of and are shown for the whole period, by phase, by age group and by canton.

**References**

[1] Y. Li, F. Fang, and M. He, “RESEARCHFactors associated with nursing Homesʼ late participation in COVID-19 reporting,” *Journal of the American Geriatrics Society*, vol. 68, no. 11, pp. 2468–2469, 2020.

[2] T. Beaney *et al.*, “Excess mortality: The gold standard in measuring the impact of COVID-19 worldwide?” *Journal of the Royal Society of Medicine*, vol. 113, no. 9, pp. 329–334, 2020.

[3] H. Wang *et al.*, “Estimating excess mortality due to the COVID-19 pandemic: A systematic analysis of COVID-19-related mortality, 2020–21,” *The Lancet*, 2022.

[4] G. De Nicola, G. Kauermann, and M. Höhle, “On assessing excess mortality in germany during the COVID-19 pandemic,” *AStA Wirtschafts-und Sozialstatistisches Archiv*, pp. 1–16, 2022.

[5] G. Konstantinoudis, V. Gómez-Rubio, M. Cameletti, M. Pirani, G. Baio, and M. Blangiardo, “A framework for estimating and visualising excess mortality during the COVID-19 pandemic,” *arXiv preprint arXiv:2201.06458*, 2022.

[6] K. Staub *et al.*, “Historically high excess mortality during the COVID-19 pandemic in switzerland, sweden, and spain,” *Annals of internal medicine*.

[7] K. E. Mansfield *et al.*, “Indirect acute effects of the COVID-19 pandemic on physical and mental health in the UK: A population-based study,” *The Lancet Digital Health*, vol. 3, no. 4, pp. e217–e230, 2021.

[8] “Federal Statistical Office. STAT-TAB interactive tables.” <https://www.pxweb.bfs.admin.ch/pxweb/en/>.

[9] “Federal Statistical Office. Births and deaths.” <https://www.bfs.admin.ch/bfs/en/home/statistics/population/births-deaths.html>.

[10] “Federal Office of Meteorology and Climatology MeteoSwiss.” [https://www.meteoswiss.admin.ch](https://www.meteoswiss.admin.ch/).

[11] “Nager.date: Worldwide public holiday.” <https://date.nager.at/>.

[12] “Federal Office of Public Health. COVID-⁠19 Switzerland.” <https://www.covid19.admin.ch/en/overview>.

[13] G. Konstantinoudis *et al.*, “Regional excess mortality during the 2020 COVID-19 pandemic in five european countries,” *Nature Communications*, vol. 13, no. 1, pp. 1–11, 2022.

[14] A. Riebler, S. H. Sørbye, D. Simpson, and H. Rue, “An intuitive bayesian spatial model for disease mapping that accounts for scaling,” *Statistical methods in medical research*, vol. 25, no. 4, pp. 1145–1165, 2016.

[15] J. Besag, J. York, and A. Mollié, “Bayesian image restoration, with two applications in spatial statistics,” *Annals of the institute of statistical mathematics*, vol. 43, no. 1, pp. 1–20, 1991.

[16] A. Gelman, J. B. Carlin, H. S. Stern, and D. B. Rubin, *Bayesian data analysis*. Chapman; Hall/CRC, 1995.

[17] “Federal Office of Public Health. Coronavirus: Measures and ordinances.” https://www.bag.admin.ch/bag/en/home/krankheiten/ausbrueche-epidemien-pandemien/aktuelle-ausbrueche-epidemien/novel-cov/massnahmen-des-bundes.html .

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