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Excess Mortality in Austria during the COVID-19 Pandemic

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Abstract

The impact of the COVID-19 pandemic on the mortality in Austria is investigated. A recent pre-pandemic generation life table is developed. Using this pre-pandemic life table, the expected number of deaths for the years 2020 to 2023 is derived. Comparing the expected number of deaths to the observed number of deaths during the pandemic years yields the excess mortality for Austria in the years 2020 to 2023.

The Austrian life table can be adjusted to the Austrian federal states, yielding for each Austrian federal state the excess mortality for the pandemic years. The excess mortality varies substantially across federal states and during the pandemic years.

The results are discussed against some state-specific health-related and economic quantities, yielding correlations of excess mortality with age, medical care, economic quantities, and COVID-19 related quantities.

Keywords: expected number of deaths, excess mortality in Austrian federal states, COVID-19.

1. Introduction

There has been a large number of contributions which try to quantify the burden of the COVID-19 pandemic on the mortality: Australian Bureau of Statistics (2023); Baum (2022); COVID-19 Excess Mortality Collaborators (2022); De Nicola and Kauermann (2022, 2024); Mølbak and Mazick (2013); Kowall, Standl, Oesterling, Brune, Brinkmann, Dudda, Pflaumer, Jöckel, and Stang (2021); Kuhbandner and Reitzner (2023); Levitt, Zonta, and Ioannidis (2022); Pizzato, Gerli, La Vecchia, and et al. (2022); Staub, Panczak, Matthes, and et al. (2022); Thum (2022); World Health Organization (2022), and in particular Bauer, Speringer, Frühwirt, Seidl, and Trautinger (2022) for Austria. A first attempt would be to count the number of COVID-19 deaths. Yet it turns out that this quantity is not sufficiently precise since the definition of "COVID-19 death" is imprecise and is unclear how many COVID-19 deaths occurred 'because of' or only 'with' a COVID-19 infection. Further, since a large number of COVID-19 deaths occurred in the group of vulnerable people, even if someone died because of COVID-19 this might not rule out the possibility that this person would have died anyway within some months because of other diseases. On the other hand, it might also be that the number of COVID-19 deaths underestimates the true burden because of indirect effects of the pandemic like e.g. overcrowded hospitals, shifted medical treatments, etc.

Hence most contributions quantify the mortality burden of the COVID-19 pandemic using the total number of deaths within the pandemic years. The first step is to determine the *expected number of deaths* which might have occurred if there would have been no pandemic, and then compare this to the observed total number of deaths. We define the absolute *excess mortality* in a year as the difference between the observed number of deaths and the expected number of deaths.

Whereas the observed number of deaths is given and in most cases (as in this present contribution) provided by a statistical office of the corresponding country, the expected number of deaths has to be computed using a mathematical model. The state-of-the-art method comes from actuarial science, where population tables and life tables are used to project the mortality of a group into the future. To be of sufficient rigor, such a model should include

- population tables, which contain size and the age structure of the male and female population of the country;
- life tables, which contain the mortality probabilities for each age and sex, since for different age and sex the mortality probabilities vary considerably;
- a longevity table, which models the mortality trend of the last years.

Whereas in most cases the population table is provided by the statistical office of the corresponding country, the other ingredients are more involved. Life tables are sometimes also provided yearly by the statistical offices of the corresponding country, and contain mortality probabilities for each age and sex. These are mostly based on death counts of the previous three years. Yet these life tables do not contain the mortality trend which reflects the increasing life expectancy in Western countries. It is necessary to model a mortality trend using historical life tables of the last decade or decades.

The main aim of this contribution is to provide a scientific sound computation of the expected number of deaths in Austria for the pandemic years 2020 to 2023, and thus to compute the excess mortality during the COVID-19 pandemic, using the state-of-the-art method and taking into account all necessary components. The precise results are stated in Section 2 in Table 2. In this introduction we just visualize in Figure 1 the excess mortality for the years 2010 to 2023.

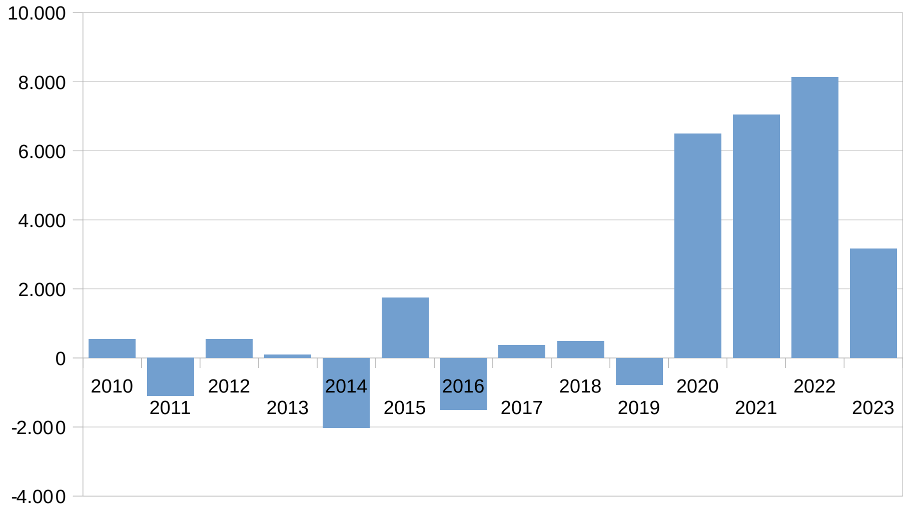

Figure 1: Excess mortality in Austria 2010 – 2023

As can be seen, the excess mortality, i.e. the difference between the observed number of deaths and the expected number of deaths, fluctuates around the x-axes with deviations up to ± 2.000 deaths in the pre-pandemic years until 2019. Starting with 2020 there is a serious jump and the excess mortality reaches more than 8.000 deaths in 2022 which shows the impact of the COVID-19 pandemic onto mortality in Austria. The empirical variance of excess mortality in pre-pandemic years is given in (2) and about 1.150 deaths.

Most of the above mentioned investigations dealing with excess mortality during the COVID-19 pandemic have certain drawbacks. First, in the estimate of the WHO World Health Organization (2022) the expected mortality is based on cubic splines interpolating pre-pandemic years which are then used for extrapolating, this is mathematical nonsense. In principle regression methods like the one used by Baum (2022) yields reasonable approximate results, but clearly do not take into account the non-smooth fluctuations of the population table, as also appears in the contribution of the EuroMOMO project Mølbak and Mazick (2013). Sometimes it is easier to use mortality probabilities only for age groups, see e.g. Levitt *et al.* (2022); Pizzato *et al.* (2022); Thum (2022). This simplified model yields approximate excess mortalities but the results depend heavily on the size of the age groups. For example, the EuroMOMO project, Mølbak and Mazick (2013), computes the expected number of deaths per week using the observed number of deaths of the last years in the age groups 0–4, 5–14, 15–64, 65+, a linear approximation of the longevity trend in each age group, with an underlying Poisson assumption with correction for overdispersion. Thus the EuroMOMO project does not take into account the non-smooth fluctuations of the population table, and ignores e.g. that the mortality probabilities for the age group 65+ are varying from 1,3% to 41,5% which leads to serious approximation errors. In Austria, excess mortality is monitored by the Austrian Agency for Health and Food Safety (AGES), using the data provided by the EuroMOMO project, and thus sharing these drawbacks.

In all mentioned contributions except COVID-19 Excess Mortality Collaborators (2022), Mølbak and Mazick (2013) and Kuhbandner and Reitzner (2023) the longevity trend of the mortality probabilities has been ignored which leads to overestimated mortality probabilities and underestimated excess mortalities. Bauer *et al.* (2022); Kuhbandner and Reitzner (2023) seem to be the only mentioned contributions which also quantify the pre-pandemic variation of excess mortality to contextualise the occurring pandemic excess mortality.

In a second step we investigate in detail the excess mortality for the Austrian federal states for each pandemic year. Hence we can localize the excess mortality during the COVID-19 pandemic years regionally and temporally. This enables us to compare the excess mortality in the Austrian federal states to several state-specific quantities. Among these are several general state-specific quantities like mean age, GDP, poverty rate, and medical care of the federal states in Section 3.2, and COVID-19 related quantities like the number of COVID-19 deaths in Section 3.3, the number of COVID-19 infections in Section 3.4, and the number of COVID-19 vaccinations in Section 3.5.

Comparing the obtained excess mortality to COVID-19 related quantities has to be done with some care. In most cases correlation may differ from year to year or even from month to month, and by a clever choice of time intervals it seems to be possible to prove arbitrary positive or negative correlations which leaves open the question whether this correlation also generalizes to other time intervals and points. And in particular when examining correlations with COVID-19 vaccination one has to avoid to estimate the COVID-19 vaccination effects using time intervals where no vaccination was available, which was done e.g. in Pizzato *et al.* (2022).

In the next section we will first develop life tables and mortality trends for Austria based on data from the years 2010 to 2019, and then use these to derive the excess mortality for Austria in the years 2020 to 2023. Based on historical data we then introduce pandemic years starting in April and ending in March next year, which is more convenient for investigations concerning pandemic excess mortality. In Section 2.4 we utilize this approach to obtain excess mortalities for the Austrian federal states during the pandemic. In Section 3 we compute the correlation with the obtained excess mortalities to several quantities.

It must be pointed out that we just investigate the total excess mortality, ignoring many interesting details. In particular, due to this general approach we cannot explain how excess mortality occurs and ignore many factors influencing excess mortality in pandemic years like healthcare disruptions, less deaths of organ donors in traffic accidents, delayed treatments, psychological stress, or changing virus variants. Including such quantities in our investigations would require much more detailed data which are maybe present in health insurance companies, but are not publicly available. Our general approach has the advantage that the obtained results are more robust, but many of the observed correlations raise important difficult questions and asks urgently for more detailed investigations using such data. Finally we want to point out, that obtained correlations between quantities do not imply causality in either direction but just a simultaneously spatial and timely occurrence or change of these quantities.

2. Excess mortality in Austria

2.1. Mortality probabilities and life tables

Life tables are a fundamental tool in actuarial science and demographic investigations, and contain as key quantity mortality probabilities for each gender and age. Here, the mortality probability q_x is the probability that a male person being alive at its x-th birthday dies within one year, and q_y the analogous probability for a female person. *Periodic life tables* contain the mortality probabilities based on a certain period, mostly either one or three years, and are constructed by counting the number of deaths of a certain age during a year, divided by the number of living of this age at the beginning of the period. (To take into account, that the age changes during a year, the method of Farr is used.) Periodic life tables are published each year by the Statistik Austria (2024c).

It is well known that in most western countries including Austria, the life expectancy has been increasing in the last 100 years, or analogously the mortality probabilities have been decreasing. To take care of this long term trend, it is common to use an exponentially decreasing factor based on historical data. For a notable recent development see the AVÖ 2005-R life table Aktuarvereinigung Österreich (2005) where $e^{-\cdots \arctan(\cdot)}$ is used. This yields *generation life tables* for each year t containing mortality probabilities $q_{x,t}$ for males of age $x = 0, \ldots, 100$ and mortality probabilities $q_{y,t}$ for females of age $y = 0, \ldots, 100$ in year t. Generation life tables are used in actuarial science to project the development of a population (of insured people) for up to 70 years. In this paper we are interested in the development of the Austrian population in the years 2020–2023 if there would have been no pandemic, so we take the last ten pre-pandemic periodic life tables and construct a generation life table which reflects the most recent pre-pandemic developments. For more information on life tables we refer to the AVÖ 2005-R life table of the Aktuarvereinigung Österreich (2005), the DAV2004R life table of the German Association of Actuaries (2004), and the books Ortmann (2015); Dickson, Hardy, and Waters (2019).

We use the periodic life tables $\hat{q}_{x,t}$ from Statistik Austria (2024c), and model the mortality probabilities as

$$q_{x,t} = q_{x,t_0} e^{-F_m(x)(t-t_0)}, \quad q_{y,t} = q_{y,t_0} e^{-F_f(x)(t-t_0)}$$

with $t_0 = 2019$ using the method of Whittaker-Henderson, see e.g. Aktuarvereinigung Österreich (2005); Behrens, Loebus, Oehlers-Vogel, and Zschoyan (1985). In a nutshell, the method of Whittaker-Henderson smoothens the raw historical data over age and years using logistic regression and splines, such that $\hat{q}_{x,t} \approx q_{x,t}$. The base life table contains the mortality probabilities q_{x,t_0} resp. q_{y,t_0} in the base year $t_0 = 2019$, see Figure 2, and the longevity trend is described by the parameters $F_m(x)$ resp. $F_f(y)$, see Figure 3, yielding the longevity trend functions $\exp(-F_m(x)(t - t_0))$ resp. $\exp(-F_f(x)(t - t_0))$.

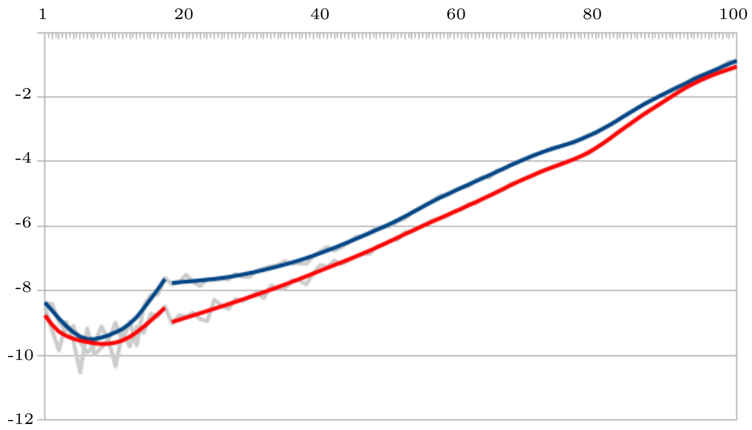

Figure 2: Raw and smoothed logarithmic mortality probabilities $\ln q_{x,2019}$ (blue curve) and $\ln q_{y,2019}$ (red curve)

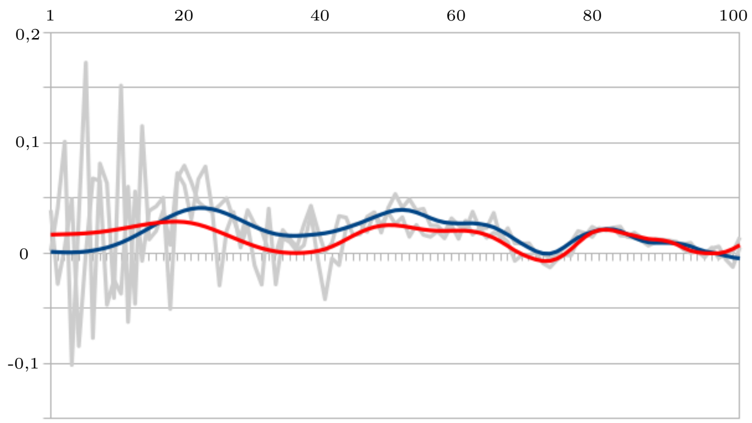

Figure 3: Raw and smoothed mortality trend F_x (blue curve) and F_y (red curve)

All these parameters are chosen to best fit the historical data. This is the standard method in actuarial science and have been computed in Bönninghausen (2024). Since it is well known that the behavior of the age groups 0 (infant mortality), 1-18 and 19-99 differ, we have chosen to treat these three groups separately. The life tables of the Statistical Office of Austria end at the age of 100, thus we assume that $q_{x,t} = 1$ for $x = y = 100$. The table is listed in the Supplement 4.

2.2. Expected number of deaths in Austria

Given the mortality probabilities, we compute the expected number of deaths for each age and year. To this end we start with the Austrian population table Statistik Austria (2024b) which consists of the number $l_{x,t}$ of x year old males, resp. $l_{y,t}$ of y year old females, on January 1st of year t. A person dying at age x could have been of age $x-1$ or x at the beginning of the year, depending on his birthday and the precise date of death. To take care of this *birthday problem*, we assume that a person dying in year t at age x either was of age $x-1$ at the beginning of the year and then died with probability $\frac{1}{2}(q_{x-1,t}+q_{x,t})$, or was of age x at the beginning of the year and then died with probability $\frac{1}{2}(q_{x,t}+q_{x+1,t})$, see Kuhbandner and Reitzner (2023). Hence the number of male deaths of age x in year t is modelled as a binomial random variable $D_{x,t}$ with expectation

$$\mathbb{E}D_{x,t} = \frac{l_{x-1,t}}{2}\frac{q_{x-1,t}+q_{x,t}}{2} + \frac{l_{x,t}}{2}\frac{q_{x,t}+q_{x+1,t}}{2}. \quad (1)$$

Analogous formulas lead to $\mathbb{E}D_{y,t}$. For $x=0$ we set $q_{-1,t} = q_{0,t}$, and $l_{-1,t} = l_{0,t+1}$ if available, and $l_{-1,t} = l_{0,t}$ for $t = 2023$. If the year t is a leap year, we add an additional day by multiplying the result by $\frac{366}{365}$. By summation we obtain the total number of expected deaths in an age group $a \subset \{0, \dots, 100\}$,

$$\mathbb{E}D_{a,t} = \sum_{x \in a} \mathbb{E}D_{x,t} + \sum_{y \in a} \mathbb{E}D_{y,t}$$

and write $\mathbb{E}D_t$ shorthand for $\mathbb{E}D_{[0,100],t}$.

The expected number has to be compared to the observed number of deaths $\hat{d}_t$ in year t, which is provided by Statistik Austria (2024d). This yields the absolute excess mortality

$$\hat{d}_t - \mathbb{E}D_t,$$

and the relative excess mortality

$$\frac{\hat{d}_t - \mathbb{E}D_t}{\mathbb{E}D_t}.$$

First we state our results for the last ten pre-pandemic years 2010-2019.

Table 1: Excess mortality in Austria 2010–2019

	excess mortality	
year	abs.	rel.
2010	470	0,6%
2011	-1.166	-1,5%
2012	482	0,6%
2013	32	0,0%
2014	-2.086	-2,6%
2015	1.675	2,1%
2016	-1.559	-1,9%
2017	308	0,4%
2018	436	0,5%
2019	-829	-1,0%

Since we use a binomial model with $q \approx 0$, one would expect that the variance npq is of the same order as the number of deaths, which is approximately 85.000, yielding a standard deviation of order ≈ 300. As is well known in actuarial science, this underestimates the variance due to the lack of full independence between deaths and asks for a correction for overdispersion. Therefore we compute the empirical variance for the total number of deaths, and obtain by taking the square root

$$\hat{\sigma}(D_x) = 1.148,5. \tag{2}$$

Also observe, that in the years 2010 – 2019 the maximal deviation of the observed value from the expectation equals 2.086 which is slightly below twice the empirical standard deviation.

In the next step we compute the expected number of deaths for the pandemic years 2020 – 2023. Note that theses numbers reflect the expected number of deaths if there would have been no pandemic. Then we compare these values to the observed number of deaths during the pandemic years which yields the absolute and relative pandemic excess mortality.

In all four years the excess mortality is far beyond twice the empirical standard deviation, and also far beyond the maximal deviation of the last ten years. It is also worth mentioning, that in the years 2020 to 2022 excess mortality is increasing reaching a maximum of more than 8.000 excess deaths in 2022. In 2023 excess mortality is decreasing for the first time, yet

Table 2: Excess mortality in Austria 2020–2023

2020		2021		2022		2023	
exp. obs.	abs. rel.	exp. obs.	abs. rel.	exp. obs.	abs. rel.	exp. obs.	abs. rel.
84.926 91.599	6.440 7,6%	84.969 91.962	6.993 8,2%	85.247 93.332	8.085 9,5%	85.464 89.760	4.296 5,0%

even in 2023 this is nearly four times the standard deviation and thus still far from a 'usual' year.

In principal, excess mortality is computed for each age separately. We state the relative excess mortality for certain age groups. The number of deaths in Austria is provided by Statistik Austria (2024d,f).

Table 3: Age dependent excess mortality in Austria 2020–2023

age	2020	2021	2022	2023
0-14	10,8%	0,3%	1,9%	3,9%
15-29	2,3%	22,7%	33,3%	34,1%
30-39	3,3%	12,4%	10,6%	12,1%
40-49	3,2%	12,1%	10,1%	13,5%
50-59	3,6%	9,1%	6,3%	3,9%
60-69	2,8%	9,6%	8,1%	1,0%
70-79	11,4%	13,4%	11,5%	8,6%
80-111	7,7%	5,8%	9,2%	4,1%

The results for the age group 0-14 are dominated by the infant mortality which has huge fluctuations from year to year. Thus it seems to be difficult to draw conclusions for the age group 0-14 based on these numbers.

For the first year during the pandemic, for 2020, the numbers show that the excess mortality is driven solely by the older age groups 70+ which is a well communicated fact. This changes in 2021 to 2023, in absolute numbers the excess mortality is still mainly driven by the older age groups, but nearly all age groups show a high excess mortality, in particular the relative excess mortality in the younger age groups 15-50 is extremely high. Surprisingly, the age groups 50-59 and also 60-69 seem to be most robust to the challenges of the pandemic.

For many purposes it makes sense to work with a pandemic year starting in April and ending in March. In February and March 2020 only very few COVID-19 infections and even less COVID deaths have been reported, in Austria the pandemic mainly started in April 2020. Because the strongest waves of deaths in Austria were typically observed around the turn of the year, it is reasonable to not cut the months from November to February. Also, the COVID-19 vaccination campaign mainly started in April 2021, and most people have been fully vaccinated in March 2022.

To compute the expected number of deaths between April and March we use historical data of Statistik Austria (2024f). In the pre-pandemic years 2010 – 2019 in the mean 27,37% of the deaths have been reported in the months January to March, and 72,63% of deaths have been reported between April and December, the occurring values for each year are sharply concentrated around this value. Using this we obtain the expected deaths and the absolute and relative excess mortality for the three pandemic years 04/2020 – 03/2021, 04/2021 – 03/2022, and 04/2022 – 03/2023.

Observe that excluding the pre-pandemic months January to March 2020 increases the excess

Table 4: Excess mortality in Austria 2020/21–2022/23

2020/21		2021/22		2022/23	
exp. obs.	abs. rel.	exp. obs.	abs. rel.	exp. obs.	abs. rel.
84.938 91.913	6.975 8,21%	85.045 92.638	7.593 8,93%	85.306 93.455	8.149 9,55%

mortality in the first pandemic year compared to the calendar year 2020. Still, excess mortality is increasing by approximately 600 deaths each pandemic year.

2.3. Mortality bias in Austrian federal states

The method described in the previous section can also be applied to the nine Austrian Federal states. Starting with the Austrian life table generated in Section 2.1 and with population tables $l^i_{x,t}$ for the Austrian states provided by Statistik Austria (2024b), one can compute the expected number of deaths for each federal state $i = 1, \dots, 9$ using formula (1) $\frac{l^i_{x-1,t}}{2} \frac{q_{x-1,t}+q_{x,t}}{2} + \frac{l^i_{x,t}}{2} \frac{q_{x,t}+q_{x+1,t}}{2}$. Yet it turns out that there is a serious bias for each state, due to several underlying parameters like e.g. state-specific health care, mean age of the state population, domestic gross product of the state, proportions of people in need of care, and maybe many others.

To model this systematic deviation we adapt the Austrian life table for each state using the method introduced in Kuhbandner and Reitzner (2024). We introduce state factors β^i, $i = 1, \dots 9$, to define state-dependent mortality probabilities

$$q^i_{x,t} = \beta^i q_{x,t} \quad \text{and} \quad q^i_{y,t} = \beta^i q_{y,t}.$$

This gives the expected number of deaths in each state, for $i = 1, \dots, 9$

$$\begin{aligned} \mathbb{E}D^i_{x,t} &= \frac{l^i_{x-1,t}}{2} \frac{q^i_{x-1,t} + q^i_{x,t}}{2} + \frac{l^i_{x,t}}{2} \frac{q^i_{x,t} + q^i_{x+1,t}}{2} \\ &= \beta^i \left(\frac{l^i_{x-1,t}}{2} \frac{q_{x-1,t} + q_{x,t}}{2} + \frac{l^i_{x,t}}{2} \frac{q_{x,t} + q_{x+1,t}}{2} \right) \end{aligned}$$

The state factors β^i will be chosen to best fit historical data from 2010 to 2019. Hence we determine β^i by minimizing the squared excess mortality in each state in the years 2010–2019. The necessary number of observed deaths in each Austrian federal state is provided by Statistik Austria (2024f).

We do not develop life tables for each state separately, since some of the Austrian federal states are rather small and thus have a tiny number of deaths, in some states for certain age groups the number of deaths even equals zero in several years. Thus from a statistical point of view, the life table for Austria constructed in Section 2.1 is a more robust and reliable estimate than an estimate, which would only rely on the number of deaths in one state. In addition, to take care of this higher robustness for the total number of deaths in Austria, we further assume that the β^i are chosen in such a way that the total number of expected deaths in all federal states equals the expected number of deaths in Austria,

$$\sum_{i=1}^{9} \mathbb{E}D^i_T = \mathbb{E}D_T \tag{3}$$

where T denotes one of the pandemic years. From a mathematical point of view this additional constraint is included in the computations by introducing Lagrange factors and solving a minimization problem. This yields state factors $\beta^i(T)$ depending on the pandemic year T in

Equation (3). It turns out that in fact the state factors $\beta^i(T)$ are nearly independent of the pandemic year, the difference between $\beta^i(T)$ for the three pandemic years is at most 0.0005 in all federal states. Hence in the following we use the notation β^i. The state factors have been computed in Bönninghausen (2024) and are stated in Table 5.

Table 5: State factors β^i for Austrian federal states. The listed first three digits are independent of the pandemic year.

state	state factor
Burgenland	$\beta^1 = 1,056$
Carinthia	$\beta^2 = 0,982$
Lower Austria	$\beta^3 = 1,042$
Salzburg	$\beta^4 = 0,925$
Styria	$\beta^5 = 0,984$
Tyrol	$\beta^6 = 0.913$
Upper Austria	$\beta^7 = 0,987$
Vorarlberg	$\beta^8 = 0,911$
Vienna	$\beta^9 = 1.059$

We demonstrate the effect of these state factors for the two extreme cases Vienna and Burgenland. The following Figure 4 shows for the pre-pandemic years 2010-2019 the unadjusted estimated excess deaths based on the Austrian life table, and the adjusted estimated excess deaths using the state factors β^i.

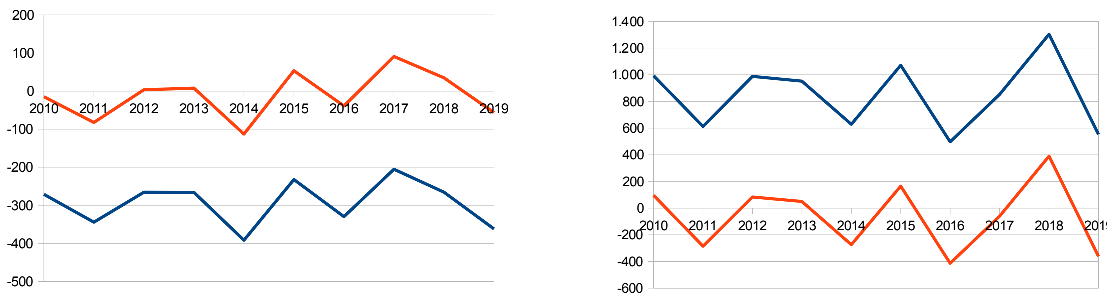

Figure 4: Unadjusted (blue) and adjusted (red) excess mortality for Vorarlberg (left) and Vienna (right)

2.4. Excess mortality in Austrian federal states

Using the state factors computed in the previous Section 2.3, we compute the expected number of deaths for each of the Austrian federal states for the three pandemic years and compare them in Table 6 to the observed number of deaths. Up to rounding errors, the sum of all states clearly equals the total number of deaths in Austria listed in in Table 4.

Recall that the absolute excess mortality is the absolute difference between the observed values and the expected values $\hat{d}^i_T - \mathbb{E}D^i_T$ in a pandemic year T, and the relative excess mortality is $(\hat{d}^i_T - \mathbb{E}D^i_T)/(\mathbb{E}D^i_T)$.

As can be seen in Table 6, the excess mortality pattern is characterized by three particular features: First, excess mortality mainly increased from the first to the third pandemic year, with the exception of those states, where excess mortality was already extremely high in the first pandemic year. Second, with the increase in excess mortality, the variance of the relative excess mortality across federal states decreases sharply. Third, the ranking order of the federal states also changes with regard to the observed excess mortality.

Table 6: Expected and observed number of deaths and excess mortality in Austrian federal states for pandemic years

	2020/21		2021/22		2022/23	
state	exp. obs.	abs. diff. rel. diff.	exp. obs.	abs. diff. rel. diff.	exp. obs.	abs. diff. rel. diff.
Burgenland	3.430 3.476	46 1,3%	3.438 3.609	171 5,0%	3.446 3.708	262 7,6%
Carinthia	6.135 6.909	774 12,6%	6.127 6.585	458 7,5%	6.156 6.716	560 9,1%
Lower Austria	17.830 18.867	1.037 5,8%	17.922 19.635	1.713 9,6%	17.971 19.783	1.812 10,1%
Salzburg	4.806 5.326	520 10,8%	4.834 5.322	488 10,1%	4.877 5.350	473 9,7%
Styria	12.827 14.407	1.580 12,3%	12.789 13.728	939 7,3%	12.841 14.166	1.325 10,3%
Tyrol	6.343 6.677	334 5,3%	6.401 6.788	387 6,0%	6.465 6.987	522 8,1%
Upper Austria	13.847 14.829	982 7,1%	13.886 15.450	1.564 11,3%	13.921 15.242	1.321 9,5%
Vienna	16.545 18.034	1.489 9,0%	16.436 17.947	1.511 9,2%	16.378 17.972	1.594 9,7%
Vorarlberg	3.178 3.388	210 6,6%	3.215 3.574	359 11,2%	3.254 3.531	277 8,5%

3. Correlational analysis

The main aim of this article is to provide a scientific clean calculation of the excess mortality in Austria and in the nine Austrian federal states during die COVID-19 pandemic. In this short section we include a first attempt to discuss these results and to compare them to several COVID-19 specific quantities. This section should be seen as a preliminary first step for investigating the effect of several measures on excess mortality, since we just compute the correlations between excess mortality and the state-specific quantities.

3.1. Excess deaths

For completeness we first state the variance and covariance structure of the excess deaths itself. The only significant correlation between the excess deaths in different pandemic years is the correlation between the excess deaths in the first and the third pandemic year 2022/23 where $\rho = 0,68$ ($p = 0.021$, throughout the paper we state the p-value of the one-sided t-test). All other correlations are minor.

The increase in excess mortality over the pandemic years was accompanied by a decrease in the empirical standard deviation across the federal states from $3,68\%$ in the first pandemic year, $2,23\%$ in the second pandemic year to $0,93\%$ in the third pandemic year. This indicates that the new excess mortality factor must have appeared in the Austrian federal states changing the picture fundamentally.

3.2. General state-specific quantities

In this section we compare excess mortality during the pandemic years with several state-specific age-related and economic quantities. The mean age of the state population and the percentage of people in the age group 65+ is contained in the state-specific population tables. As a quantity measuring medical care, we use the number of physicians per 1000 inhabitants in the first pandemic year 2020 in each federal state provided by the Austrian Medical Association (Österreichische Ärztekammer (2020). The gross domestic product GDP of the federal states for the year 2020 is provided by the Austrian Economic Chamber (Wirtschaftskammer Österreich) (2020), the poverty rate and the unemployment rate for the pandemic years for each federal state by Statistik Austria (2024e,a). The following Table 7 contains the numbers and the correlations.

Table 7: Correlations of excess mortality in Austrian federal states

	mean age	age 65+	physician per 1.000	unemployment rate 2020	2021	2022	GDP	poverty rate
Burgenland	46,3	23,9%	4,4	4,23%	5,12%	4,27%	30.300	11%
Carinthia	45,8	23,5%	4,9	4,72%	5,58%	4,48%	37.100	16%
Lower Austria	44,5	21,3%	4,7	4,19%	5,08%	3,96%	35.300	15%
Upper Austria	43,1	19,7%	4,3	3,89%	3,76%	2,87%	44.000	13%
Salzburg	43,4	20,0%	5,9	3,04%	4,59%	3,03%	51.100	13%
Styria	44,6	21,6%	5,2	4,44%	4,32%	3,69%	39.200	16%
Tyrol	43,2	19,3%	5,7	3,05%	4,80%	3,20%	44.500	17%
Vorarlberg	42,3	18,5%	4,4	3,64%	4,07%	3,23%	46.000	20%
Vienna	41,1	16,4%	7,0	10,66%	12,09%	9,23%	50.200	27%
correlation with excess mortality								
2020/21	-0,10	-0,06	0,37	0,16	0,11	0,11	0,38	0,24
2021/22	-0,61	-0,56	-0,06	0,05	-0,04	-0,07	0,58	0,23
2022/23	-0,23	-0,21	0,29	0,27	0,17	0,18	0,27	0,19

The only noteworthy correlations occur in the second pandemic year when excess mortality correlates negative with age quantities and positive with the gross domestic product in the state.

The fact that nearly all observed correlations are more or less negligible coincides with the observation that excess mortality is also uncorrelated to the state factors β^i which depend on the state-specific factors like health care, mean age of the state population, domestic gross product of the state, etc.

3.3. Number of COVID-19 deaths

The monthly numbers of COVID-19 deaths for Austria and for each Austrian federal state are available on request by the AGES, Austrian Agency for Health and Food Safety (2024). First we list in Table 8 the total number of COVID-19 deaths for Austria in each pandemic year and compare them to the excess mortality in the corresponding pandemic year.

Table 8: Excess deaths and COVID-19 deaths in Austria 2020/21–2022/23

2020/21		2021/22		2022/23	
excess	COVID	excess	COVID	excess	COVID
6.975	10.397	7.593	7.131	8.149	3.338

From the very beginning it has been criticised that it is unclear how many COVID-19 deaths occurred 'because of' or only 'with' a COVID-19 infection. An analysis of the German COVID-19 autopsy registry from March 2020 to the beginning of October 2021, von Stillfried, Bülow, Röhrig, Boor, and for the German Registry of COVID-19 Autopsies (DeRegCOVID) (2022) claimed that in this period only 86% of the autopsied deaths with a COVID-19 diagnosis died because of COVID-19. And a study from Denmark Friis, Martin-Bertelsen, Pedersen, Nielsen, Krause, Andreasen, and Vestergaard (2023) showed that during 2022, about 70%

of the reported COVID-19 deaths were actually not caused by COVID-19. For Austria, the numbers in the first pandemic year make clear that at most 67% of the reported number of COVID-19 deaths in Austria have been 'additional' i.e. unexpected deaths. On the other hand, particularly in the third pandemic year it is impossible to explain the occurring excess deaths only by COVID-19 deaths.

Summarizing, it seems to be difficult to find a convincing pattern which explains the increasing excess mortality in the three pandemic years by the decreasing number of COVID-19 deaths.

For a more detailed analysis we compare these numbers to the excess mortality in each Austrian federal state. For this, the number of COVID-19 deaths have to be standardized since the states differ in size and age distribution. Therefore, similarly to the computation of the relative excess mortality, we divide the number of COVID-19 deaths by the expected number of deaths in this year. The ratio in Table 9 reflects the extent to which COVID-19 deaths have occurred in relation to the usually expected number of deaths.

Table 9: Excess deaths and COVID-19 deaths in Austrian federal states 2020/21–2022/23

	2020/21		2021/22		2022/23	
	excess	COVID	excess	COVID	excess	COVID
Austria	8,21%	12,24%	8,93%	8,38%	9,55%	3,91%
Burgenland	1,35%	9,18%	4,97%	6,17%	7,61%	1,89%
Carinthia	12,62%	15,53%	7,48%	9,89%	9,09%	2,53%
Lower Austria	5,82%	9,98%	9,56%	9,39%	10,08%	5,17%
Salzburg	10,83%	12,88%	10,09%	8,27%	9,69%	3,53%
Styria	12,31%	15,71%	7,34%	7,58%	10,32%	2,87%
Tyrol	5,27%	10,55%	6,04%	6,17%	8,07%	3,16%
Upper Austria	7,09%	11,89%	11,26%	8,93%	9,48%	2,89%
Vorarlberg	6,59%	9,88%	11,18%	8,03%	8,52%	2,24%
Vienna	9,00%	12,61%	9,20%	8,32%	9,73%	5,91%
correlation excess mortality : COVID-19 deaths						
2020/21	0,93		0,56		0,14	
2021/22	-0,02		0,62		0,28	
2022/23	0,58		0,64		0,58	

As already mentioned, the excess mortality is increasing, yet the number of COVID-19 deaths is decreasing and thus cannot explain the high excess mortality. This is visible in decreasing correlation coefficients between excess mortality and COVID-19 deaths. For the first pandemic year we obtain $r = 0,931$ ($p < 0.001$) which suggests that at least a considerable part of the excess deaths is connected to COVID-19 deaths. But recall, that correlation does not imply causality. In the second ($r = 0,618$, $p = 0,038$) and in the third ($r = 0,578$, $p = 0,052$) pandemic year the correlations are considerably decreasing. This is visualized in Figure 5.

For the excess mortality in the third pandemic year the correlation with COVID-19 deaths in all pandemic years is more or less constant. And even more to the point: computing the correlation between excess mortality and COVID-19 deaths across all pandemic years and states yields only $r = 0,13$ ($p = 0,365$). Thus there must be other driving forces, i.e. other variables, which explain the increasing excess mortality, in particular in the third pandemic year, and which maybe also influences the number of COVID-19 deaths.

3.4. Number of COVID-19 infections

The numbers of COVID-19 infections for each Austrian federal state are available on request by the AGES, Austrian Agency for Health and Food Safety (2024). To investigate the relationship with excess mortality, we use the percentage of infected people per year, i.e. the cumulative number of COVID-19 infections in each federal state reported at the end of a pan-

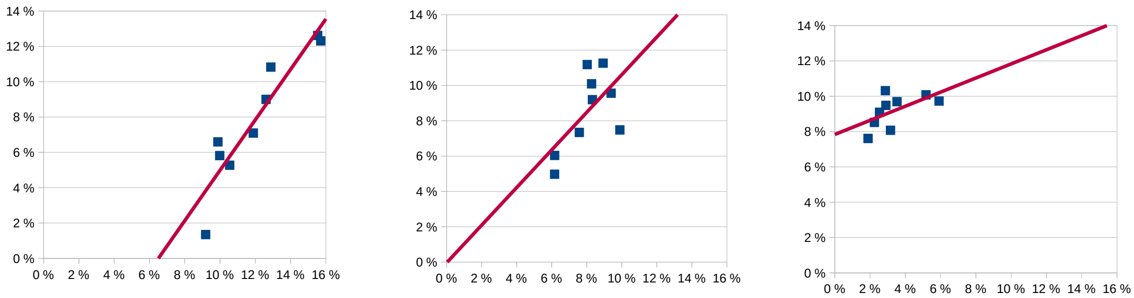

Figure 5: Linear regression of COVID-19 deaths (x-axis) and excess mortality (y-axis) in the first pandemic year (left, $a = -9,28\%$, $b = 1,42$), second pandemic year (middle, $a = 0,00\%$, $b = 1,07$) and third pandemic year (right, $a = 7,84\%$, $b = 0,4$).

demic year was divided by the population of a federal state. The results and the correlation between excess mortality and COVID-19 infections are stated in Table 10.

Table 10: Excess mortality and COVID-19 infections in Austrian federal states 2020/21–2022/23

	2020/21		2021/22		2022/23	
state	excess	infections	excess	infections	excess	infections
Austria	8,21%	5,98%	8,93%	37,30%	9,55%	24,11%
Burgenland	1,35%	5,26%	4,97%	32,58%	7,61%	28,27%
Carinthia	12,62%	5,92%	7,48%	34,41%	9,09%	18,27%
Lower Austria	5,82%	5,36%	9,56%	36,19%	10,08%	27,62%
Salzburg	10,83%	7,71%	10,09%	42,23%	9,69%	20,32%
Styria	12,31%	5,18%	7,34%	35,27%	10,32%	18,40%
Tyrol	5,27%	6,76%	6,04%	40,58%	8,07%	20,16%
Upper Austria	7,09%	6,54%	11,26%	40,25%	9,48%	21,89%
Vorarlberg	6,59%	6,04%	11,18%	40,95%	8,52%	18,07%
Vienna	9,00%	5,90%	9,20%	35,38%	9,73%	31,44%
correlation excess mortality : COVID-19 infections						
2020/21	0,19		0,36		-0,04	
2021/22	0,07		0,60		0,03	
2022/23	-0,48		-0,12		0,01	

Since the infections cannot influence excess mortality backwards in time, one is mainly interested in the correlation of COVID-19 infections with the excess mortality in the same and following pandemic years.

In the first pandemic year the excess mortality is uncorrelated to the COVID-19 infection rate. This surprisingly contrasts the high correlation of excess mortality and COVID-19 deaths in the first pandemic year. The only serious positive correlation $r = 0,598$ ($p = 0,045$) occurs in the second pandemic year, yet even this correlation is smaller than the correlation between COVID-19 deaths and excess mortality. It is also noteworthy that in the third pandemic year there is no correlation with the COVID-19 infections in this third pandemic year, and even negative correlations with previous pandemic years. This maybe might indicate that infections immunize against (at least heavy, more precisely deathly) courses of COVID-19 infections. But this also makes it very implausible that the high excess mortality in the second and especially in the third pandemic year is generated by people having been infected during the pandemic, i.e. by long COVID.

We want to point out that there are significant correlations between the state factors β^i and the COVID-19 infection rates, $r = -0,654$ ($p = 0,028$) for the first pandemic year, and even $r = -0,805$ ($p = 0,004$) for the second and $r = 0,839$ ($p = 0,002$) for the third pandemic year. It seems that there are third variables which influence both the state factors and the COVID-19 infections, yet in a way, which is not easy to explain due to the alternating signs of the correlations.

3.5. Number of COVID-19 vaccinations

The number of people vaccinated (second vaccination, third vaccination) in each of the Austrian federal states are provided by data.gv.at, Österreichisches Bundeskanzleramt (2024). To examine the relationship with excess mortality, the vaccination rates reported at the end of each of the three pandemic years in relation to the population in the corresponding state was computed. Because in Austria, only those people with three vaccinations were called 'fully vaccinated', the numbers in the following investigations refer to the percentage of the population of an Austrian federal state with at least three COVID-19 vaccinations. Corresponding results for people only twice vaccinated show no difference and therefore are omitted. We list the occurring values and the correlation coefficients between COVID-19 vaccinations and excess mortality in Table 11.

Table 11: Excess mortality and rate of triple COVID-19 vaccinated people in Austrian federal states 2020/21–2022/23

	2020/21		2021/22		2022/23	
state	excess	vaccinated	excess	vaccinated	excess	vaccinated
Austria	8,21%	–	8,93%	52,9%	9,55%	56,3%
Burgenland	1,35%	–	4,97%	62,09%	7,61%	65,69%
Carinthia	12,62%	–	7,48%	50,62%	9,09%	54,55%
Lower Austria	5,82%	–	9,56%	57,30%	10,08%	60,79%
Salzburg	10,83%	–	10,09%	49,46%	9,69%	52,66%
Styria	12,31%	–	7,34%	55,53%	10,32%	59,14%
Tyrol	5,27%	–	6,04%	51,72%	8,07%	54,92%
Upper Austria	7,09%	–	11,26%	48,99%	9,48%	52,43%
Vorarlberg	6,59%	–	11,18%	51,75%	8,52%	54,14%
Vienna	9,00%	–	9,20%	51,35%	9,73%	54,52%
correlation excess mortality : COVID-19 vaccinations						
2020/21	–		-0,57		-0,53	
2021/22	–		-0,60		-0,63	
2022/23	–		-0,28		-0,26	

All correlations are negative, yet one has to be careful to draw immediate conclusions. Since the vaccination cannot work backwards in time, the high correlations with excess deaths in the first pandemic year, where no vaccination has been available, cannot be an effect of the vaccination. This leads to the conclusion, that there is a third variable influencing both excess deaths and vaccination rate. A first attempt to measure the effect of the vaccination and to exclude the influence of the third variable, is to compare the *increase or decrease* of the excess mortality to the vaccination rate. The occurring values and correlations are contained in Table 12.

The vaccination rate in the second pandemic year correlates with the increase in excess mortality from the first to the second, resp. third pandemic year with $r = 0,203$ ($p = 0,300$), resp. $r = 0,593$ ($p = 0,046$) and thus the increasing excess mortality is *positively* correlated with the vaccination rate. For the (final) vaccination rate in the third pandemic year we observe that the increase in excess mortality from the first to the third pandemic year, resp. from the second to the third pandemic year correlates with $r = 0,554$ ($p =$

Table 12: Correlation of increase of excess mortality and rate of triple COVID-19 vaccinated people in Austrian federal states 2020/21–2022/23

increase in excess mortality	vaccinated 2021/22	vaccinated 2022/23
2020/21 – 2021/22	0,20	0,15
2021/22 – 2022/23	0,59	0,55
2020/21 – 2022/23	0,56	0,61

$0,061)$, resp. $r = 0,606$ ($p = 0,042$). Again, the increasing excess mortality is considerably *positively* correlated with the vaccination rate. This is visualized in Figure 6.

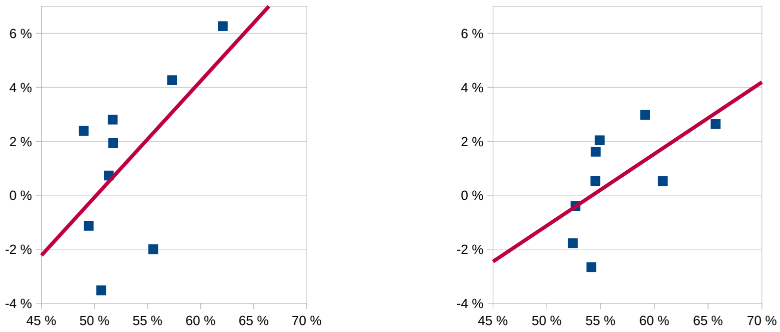

Figure 6: Linear regression of COVID-19 vaccinated people (x-axis) with increase of excess mortality (y-axis) in the second pandemic year (left, $a = -21,60\%$, $b = 0,43$) and third pandemic year (right, $a = -14,42\%$, $b = 0,27$).

To end this section we just want to note that the number of persons which got their third vaccination in the third pandemic year 2022/23 correlates to an increase in excess deaths from the second to the third pandemic year with $r = 0,683$ ($p = 0,021$). Recall that correlation does not imply causality.

The negative correlation between the vaccinations administered in the second pandemic year and the excess mortality in the first pandemic year indicates a somehow surprising fact: the more a federal state was affected by excess deaths in the first pandemic year, the less people were vaccinated in the second pandemic year. However, the most obvious expectation of an effective vaccination would be that the increase in excess mortality would be lowest in the federal states in which the most vaccinations were administered, yet the opposite is the case.

The fact, that correlation between excess mortality and COVID-19 vaccination rate is negative in the second pandemic year was also observed by Kuhbandner and Reitzner (2024) for German federal states, and by Pizzato *et al.* (2022) for 29 European countries. But in both contributions the COVID-19 vaccination rate is also negatively correlated with excess mortality in the first pandemic year, and therefore one has to investigate the increase of excess mortality as is done above. For Germany, Kuhbandner and Reitzner (2024) state a positive correlation $r = 0,85$ between the vaccination rate and an increase of excess mortality 2020/21 – 2022/23. Pizzato *et al.* (2022) compute a negative correlation between the total excess mortality in the years 2020 – 2023, and – ignoring that the vaccination cannot work backwards – they conclude that "*vaccine uptake were associated with reduced excess mortality*". Nevertheless, using their data one obtains again a positive correlation $r = 0,61$ between the vaccination rate and an increase of excess mortality 2020/21 – 2022/23. These investigations concerning Germany and Europe confirm the findings of this section.

Finally, as a remark we state in Table 13 the correlations between COVID-19 vaccinations and COVID-19 deaths.

Table 13: Correlation of COVID-19 deaths and rate of triple COVID-19 vaccinated people in Austrian federal states 2020/21–2022/23

COVID-19 deaths	vaccinated 2021/22	vaccinated 2022/23
2020/21	-0,39	-0,33
2021/22	-0,43	-0,40
2022/23	-0,13	-0,13
decrease in COVID-19 deaths		
2020/21 – 2021/22	0,17	0,13
2021/22 – 2022/23	0,28	0,23
2020/21 – 2022/23	0,25	0,22

Again, because there is a negative correlation in the first pandemic year but vaccination cannot work backward, we compare the vaccination rate to the change of COVID-19 deaths from the first to the second and third pandemic year.

Note that there are no significant correlations between COVID-19 vaccinations and COVID-19 deaths. If at all, the correlation between COVID-19 vaccinations and the change of COVID-19 deaths is even slightly positive, which is not to be expected if the vaccination is reducing heavy and even deadly courses of COVID-19 infections.

4. Discussion

The aim of the present study was to estimate excess mortality in the Austrian federal states using scientifically sound methods, and then to initiate a discussion concerning the relationship between excess mortality and several state-specific quantities which should be continued in much more detail, in particular from a medical point of view. The estimates of excess mortality are based on the state-of-the-art method of actuarial science and data from Statistik Austria (2024c,b,d,f).

The investigations first revealed, that the total number of excess deaths in Austria is increasing throughout the pandemic. This seems to be surprising due to several reasons. Most probably, many and maybe even most vulnerable persons already died in the first (and second) year of the pandemic and the number of vulnerable persons with a severe or even deathly course of disease should decrease. In addition, most people should have been infected after some while and be vaccinated in the second pandemic year, and hence should be immunized which at least should prevent severe courses of disease. Thus it could have been expected that the excess deaths should decrease over time instead of increase.

The second observation is that excess mortality substantially varied across the federal states in Austria, ranging from 1,3% to 12,6% in the first pandemic year, and is mainly increasing and much more concentrated in the third pandemic year ranging from 7,6% to 10,3%.

Comparing excess mortality to general state-specific health-related and economic quantities yielded no significant correlations. The data have been provided by the Austrian Medical Association (Österreichische Ärztekammer (2020), Austrian Economic Chamber (Wirtschaftskammer Österreich) (2020), and Statistik Austria (2024e,a).

Comparing excess mortality to the reported number of COVID-19 deaths (data provided by AGES, Austrian Agency for Health and Food Safety (2024)) reveals that the number of COVID-19 deaths largely exceeds the observed amount of excess mortality in the first pandemic year. Then excess mortality is increasing and the number of COVID-19 deaths is decreasing, which amounts in the fact that in the third pandemic year the observed huge excess mortality largely exceeds the number of COVID-19 deaths. This implies that at least in the second and third pandemic year the excess mortality cannot be explained by COVID-19 deaths.

Given the federal state data provided by AGES, Austrian Agency for Health and Food Safety (2024) on excess mortality and COVID-19 infections, what can probably be ruled out as a possible factor influencing excess mortality are long-term mortality effects following SARS-CoV-2 infections (i.e., long COVID) because in the third pandemic year the correlation between infection rate and excess mortality turns out to be negative. I.e. the higher the number of infections in the first and second year of the pandemic in a federal state, the lower the excess mortality was in the third year of the pandemic.

With regard to the connection between excess mortality and vaccination rate (data provided by Österreichisches Bundeskanzleramt (2024)) the picture is more complex. Because there is a third variable influencing excess mortality and vaccination rate, one is forced to investigate the decrease resp. increase of excess mortality as soon as the vaccination campaign started. The observation from Section 3.5 that the increase in excess mortality in the second and third year of the pandemic are positively correlated to the vaccination rate is an irrefutable empirical fact, and means that the more people have been vaccinated in a federal state the more excess mortality increased.

The observed correlation pattern for the pandemic years regarding Austrian federal states reflects a spatial observation, whereas the increase of excess mortality over the pandemic years is a temporal observation. In other words, particularly high and increasing excess mortality occurs both in regions and in time windows with high vaccination rates. Such a pattern is in contrast to the expectation that COVID-19 vaccinations should prevent heavy or even deadly courses of COVID-19 and thus should decrease mortality.

Yet it must be pointed out that all these results are correlative relationships, these observations do not necessarily mean that the observed differences in mortality between federal states can be causally attributed to the different vaccination rates or are independent of other causes of death.

To summarize, from a statistical perspective, the observed pattern is the following: In the first year of the pandemic, excess mortality and the reported number of COVID-19 deaths are highly correlated, suggesting a connection between excess mortality and COVID-19 deaths. But note, that the reported number of COVID deaths greatly overestimates the excess mortality that has occurred. In the second and third pandemic year the reported number of COVID-19 deaths decreases, but excess mortality increases. The increase of the excess mortality is positively correlated (both temporally and spatially) with the number of vaccinations. This suggests that side effects of the COVID-19 vaccinations may have a negative impact on mortality. These findings support recent concerns about the COVID-vaccinations Schwab, Domke, Hartmann, and et al. (2022); Faksova, Walsh, Jiang, and et al. (2024); Fraiman, Erviti, Jones, Greenland, Whelan, Kaplan, and Doshi (2022); Kuhbandner and Reitzner (2023) and urgently ask for more detailed investigations concerning the high excess mortality in the second and third pandemic year and the connection with the vaccination rates.

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References

AGES, Austrian Agency for Health and Food Safety (2024). "COVID-19 data." (all data received on July 2, 2024).

Aktuarvereinigung Österreich (2005). "Life Table AVÖ 2005-R and Documentation." URL www.avoe.at/Rententafel/AVOe2005R.xls.

Australian Bureau of Statistics (2023). "Measuring Australia's Excess Mortality during the COVID-19 Pandemic until the First Quarter 2023." *ABS*, (accessed 7 December 2023). URL https://www.abs.gov.au/articles/measuring-australias-excess-mortality-during-covid-19-pandemic-until-first-quarter-2023

Austrian Economic Chamber (Wirtschaftskammer Österreich) (2020). "WKO Statistik – Bruttoregionalprodukt 2020. Data by Statistik Austria." (all data received on October 27, 2024). URL https://www.wko.at/statistik/bundesland/brpabseinwohner.pdf.

Austrian Medical Association (Österreichische Ärztekammer (2020). "Ärztestatistik für das Jahr 2020." (all data received on October 27, 2024). URL https://www.aerztekammer.at/statistik-2020.

Bauer R, Speringer M, Frühwirt P, Seidl R, Trautinger F (2022). "Assessing Excess Mortality in Vienna and Austria after the First Year of the COVID-19 Pandemic." *Vienna Yearbook of Population Research*, **20**. doi:10.1553/populationyearbook2022.dat.1.

Baum K (2022). "Considerations on Excess Mortality in Germany in the Year 2020 and 2021." *Deutsche Medizinische Wochenschrift*, **147**.

Behrens HG, Loebus H, Oehlers-Vogel B, Zschoyan B (1985). *Methodik von Sterblichkeitsuntersuchungen*, volume 15. Verlag Versicherungswirtschaft e.V.

Bönninghausen B (2024). "Parameterschätzungen für Sterbewahrscheinlichkeiten (Parameter Identification of Life Tables) (Supervisor: M. Reitzner)." *Bachelor's thesis and research project*.

COVID-19 Excess Mortality Collaborators (2022). "Estimating Excess Mortality due to the COVID-19 Pandemic: A Systematic Analysis of COVID-19-Related Mortality, 2020–21." *The Lancet*, **399**. doi:10.1016/S0140-6736(21)02796-3.

De Nicola G, Kauermann G (2022). "An Update on Excess Mortality in the Second Year of the COVID-19 Pandemic in Germany (Ein Update zur Übersterblichkeit im Zweiten Jahr der COVID-19 Pandemie in Deutschland)." *AStA Wirtschafts- und Sozialstatistisches Archiv*, **16**. doi:10.1007/s11943-022-00303-9.

De Nicola G, Kauermann G (2024). "Estimating Excess Mortality in High-Income Countries during the COVID-19 Pandemic." *Journal of the Royal Statistical Society Series A*, (qnae031). doi:10.1093/jrsssa/qnae031.

Dickson D, Hardy M, Waters H (2019). "Actuarial Mathematics for Life Contingent Risks (3rd ed.)."

Faksova K, Walsh D, Jiang Y, et al (2024). "Covid-19 Vaccines and Adverse Events of Special Interest: A Multinational Global Vaccine Data Network (GVDN) Cohort Study of 99 Million Vaccinated Individuals." *Vaccine*, **42**, 2200–2211. doi:10.1016/j.vaccine.2024.01.100.

Fraiman J, Erviti J, Jones M, Greenland S, Whelan P, Kaplan RM, Doshi P (2022). "Serious Adverse Events of Special Interest Following mRNA COVID-19 Vaccination in Randomized Trials in Adults." *Vaccine*, **40**. doi:10.1016/j.vaccine.2022.08.036.

Friis NU, Martin-Bertelsen T, Pedersen RK, Nielsen J, Krause TG, Andreasen V, Vestergaard LS (2023). "COVID-19 Mortality Attenuated during Widespread Omicron Transmission, Denmark, 2020 to 2022." *Eurosurveillance*, **28**(2200547). doi:10.2807/1560-7917.ES.2023.28.3.2200547.

German Association of Actuaries (2004). "Life Table DAV 2004R." URL https://aktuar.de/Dateien_extern/DAV/LV/UT_LV_7.pdf.

Kowall B, Standl F, Oesterling F, Brune B, Brinkmann M, Dudda M, Pflaumer P, Jöckel K, Stang A (2021). "Excess Mortality due to Covid-19? A Comparison of Total Mortality in 2020 with Total Mortality in 2016 to 2019 in Germany, Sweden and Spain." *PLoS ONE*, **16**(8: e0255540). doi:10.1371/journal.pone.0255540.

Kuhbandner C, Reitzner M (2023). "Estimation of Excess Mortality in Germany during 2020-2022." *Cureus*, **15**((5): e39371). doi:10.7759/cureus.39371.

Kuhbandner C, Reitzner M (2024). "Differential Increases in Excess Mortality in the German Federal States during the COVID-19 Pandemic." *Submitted*. doi:10.13140/RG.2.2.13098.18880.

Levitt M, Zonta F, Ioannidis JPA (2022). "Comparison of Pandemic Excess Mortality in 2020–2021 across Different Empirical Calculations." *Environmental Research*, **213**(113754). doi:10.1016/j.envres.2022.113754.

Mølbak K, Mazick A (2013). "European Monitoring of Excess Mortality for Public Health Action (EuroMOMO)." *European Journal of Public Health*, **23**(suppl. 1, ckt126.113). doi:10.1093/eurpub/ckt126.113.

Ortmann KM (2015). *Praktische Lebensversicherungsmathematik*. Springer, Wiesbaden. doi:10.1007/978-3-658-10200-5.

Österreichisches Bundeskanzleramt (2024). "Zeitreihe der Verabreichten Impfungen der Corona-Schutzimpfung." (Accessed on August 22, 2024). URL https://www.data.gv.at/katalog/dataset/covid-19-zeitreihe-der-verabreichten-impfdosen-der-corona-schutzimpfung-2022-11-22/resource/93baf4ba-a9e6-444a-8189-6e80a9b8bcef#resources.

Pizzato M, Gerli AG, La Vecchia C, et al (2022). "Impact of COVID-19 on Total Excess Mortality and Geographic Disparities in Europe, 2020–2023: A Spatio-temporal Analysis." *The Lancet Regional Health - Europe*, **to appear**(100330). doi:10.1016/j.lanepe.2024.100996.

Schwab C, Domke LM, Hartmann L, et al (2022). "Autopsy-based Histopathological Characterization of Myocarditis after Anti-SARS-CoV-2-vaccination." *Clinical Research in Cardiology*, **112**. doi:10.1007/s00392-022-02129-5.

Statistik Austria (2024a). "Arbeitslose und Arbeitslosenquoten nach Alter und Geschlecht seit 1974." (Accessed on July 25, 2024). URL https://www.statistik.at/statistiken/arbeitsmarkt/arbeitslosigkeit/arbeitslose-arbeitssuchende.

Statistik Austria (2024b). "Bevölkerung Österreich." (Accessed on July 5, 2024). URL https://www.statistik.at/fileadmin/pages/406/Bev_nach_Alter_Geschlecht_Staatsangeh_Bundesl_Zeitreihe.ods.

Statistik Austria (2024c). "Jährliche Sterbetafeln 1947 bis 2022 für Österreich." (Accessed on August 22, 2024). URL https://www.statistik.at/fileadmin/pages/413/Jaehrliche_Sterbetafeln_1947_bis_2022_fuer_Oesterreich.ods.

Statistik Austria (2024d). "Österreich Zeitreihenindikatoren: Todesfälle." (Accessed on August 22, 2024). URL https://www.statistik.at/statistiken/bevoelkerung-und-soziales/bevoelkerung/demographische-indikatoren-und-tafeln/demographische-zeitreihenindikatoren.

Statistik Austria (2024e). "Quote der Armuts- oder Ausgrenzungsgefährdung in Österreich nach Bundesländern im Dreijahresdurchschnitt 2021 bis 2023." (Accessed on July 25, 2024). URL https://www.statistik.at/statistiken/arbeitsmarkt/arbeitslosigkeit/arbeitslose-arbeitssuchende.

Statistik Austria (2024f). "Todesfälle nach Ereignismonat Österreich." (Accessed on August 22, 2024). URL https://www.statistik.at/fileadmin/pages/428/neu_Gestorbene__nach__demographischen__Merkmalen.ods.

Staub K, Panczak R, Matthes KL, et al (2022). "Historically High Excess Mortality during the COVID-19 Pandemic in Switzerland, Sweden, and Spain." *Annals of Internal Medicine*, **175**. doi:10.7326/M21-3824.

Thum M (2022). "Übersterblichkeit im Zweiten Halbjahr 2021 in den Deutschen Bundesländern." *ifo Dresden Berichtet*, **29**. URL https://www.ifo.de/DocDL/ifoDD_22-02_03-05_Thum.pdf.

von Stillfried S, Bülow RD, Röhrig R, Boor P, for the German Registry of COVID-19 Autopsies (DeRegCOVID) (2022). "First Report from the German COVID-19 Autopsy registry." *The Lancet Regional Health - Europe*, **15**(100330). doi:10.1016/j.lanepe.2022.100330.

World Health Organization (2022). "Global Excess Deaths Associated with COVID-19, January 2020–December 2021." (Accessed on May 6, 2022). URL https://www.who.int/data/stories/global-excess-deaths-associated-with-covid-19-january-2020-december-2021.

Appendix: A recent generation life table for Austria

In this supplement we provide an Austrian generation life table 2019 based on the mortality trend of the last ten pre-pandemic years 2010 to 2019.

Table 14: A generation life table for Austria

age	$q_{x,2019}$	$q_{y,2019}$	F_x	F_y
0	0,00296	0,00250	0,03197	0,02691
1	0,00023	0,00016	0,00122	0,01679
2	0,00018	0,00012	0,00091	0,01702
3	0,00014	0,00009	0,00071	0,01721
4	0,00011	0,00008	0,00069	0,01737
5	0,00009	0,00008	0,00091	0,01763
6	0,00008	0,00007	0,00145	0,01801
7	0,00007	0,00007	0,00232	0,01854
8	0,00007	0,00007	0,00352	0,01925
9	0,00008	0,00006	0,00509	0,02009
10	0,00008	0,00006	0,00709	0,02103
11	0,00009	0,00007	0,00954	0,02210
12	0,00010	0,00007	0,01242	0,02322
13	0,00012	0,00008	0,01564	0,02438
14	0,00015	0,00009	0,01913	0,02551
15	0,00019	0,00011	0,02274	0,02655
16	0,00026	0,00013	0,02639	0,02744
17	0,00035	0,00016	0,02995	0,02811
18	0,00048	0,00020	0,03328	0,02851
19	0,00043	0,00013	0,03626	0,02861
20	0,00043	0,00014	0,03861	0,02827
21	0,00044	0,00015	0,04020	0,02738
22	0,00045	0,00016	0,04097	0,02595
23	0,00046	0,00017	0,04085	0,02403
24	0,00047	0,00018	0,03987	0,02173
25	0,00048	0,00019	0,03815	0,01919
26	0,00050	0,00021	0,03583	0,01658
27	0,00051	0,00022	0,03306	0,01394
28	0,00053	0,00024	0,03005	0,01130
29	0,00055	0,00026	0,02701	0,00878
30	0,00058	0,00028	0,02405	0,00644
31	0,00061	0,00030	0,02135	0,00442
32	0,00064	0,00032	0,01907	0,00279
33	0,00067	0,00035	0,01738	0,00152
34	0,00071	0,00037	0,01634	0,00067
35	0,00075	0,00041	0,01583	0,00019
36	0,00080	0,00044	0,01578	0,00006
37	0,00086	0,00048	0,01611	0,00030
38	0,00092	0,00052	0,01664	0,00092
39	0,00099	0,00057	0,01727	0,00196
40	0,00107	0,00062	0,01814	0,00362

Table 15: A generation life table for Austria

age	$q_{x,2019}$	$q_{y,2019}$	F_x	F_y
41	0,00116	0,00068	0,01942	0,00603
42	0,00127	0,00074	0,02109	0,00905
43	0,00138	0,00081	0,02299	0,01244
44	0,00151	0,00088	0,02507	0,01585
45	0,00166	0,00096	0,02743	0,01897
46	0,00182	0,00106	0,03003	0,02160
47	0,00200	0,00116	0,03264	0,02363
48	0,00220	0,00128	0,03510	0,02492
49	0,00243	0,00142	0,03734	0,02547
50	0,00268	0,00157	0,03888	0,02532
51	0,00299	0,00174	0,03933	0,02462
52	0,00334	0,00193	0,03868	0,02357
53	0,00376	0,00214	0,03695	0,02247
54	0,00424	0,00237	0,03452	0,02145
55	0,00478	0,00261	0,03182	0,02071
56	0,00536	0,00289	0,02950	0,02033
57	0,00599	0,00318	0,02792	0,02025
58	0,00664	0,00350	0,02722	0,02039
59	0,00735	0,00386	0,02699	0,02047
60	0,00811	0,00426	0,02705	0,02036
61	0,00895	0,00470	0,02713	0,01970
62	0,00989	0,00519	0,02651	0,01846
63	0,01092	0,00575	0,02536	0,01652
64	0,01205	0,00638	0,02346	0,01391
65	0,01334	0,00710	0,02033	0,01052
66	0,01476	0,00790	0,01675	0,00652
67	0,01632	0,00880	0,01264	0,00243
68	0,01798	0,00975	0,00866	-0,00096
69	0,01975	0,01077	0,00498	-0,00366
70	0,02163	0,01185	0,00174	-0,00576
71	0,02354	0,01301	-0,00026	-0,00712
72	0,02546	0,01420	-0,00049	-0,00704
73	0,02737	0,01543	0,00149	-0,00503
74	0,02928	0,01673	0,00528	-0,00133
75	0,03134	0,01814	0,00986	0,00364
76	0,03376	0,01975	0,01415	0,00946
77	0,03679	0,02173	0,01715	0,01477
78	0,04045	0,02426	0,01921	0,01877
79	0,04479	0,02758	0,02094	0,02087
80	0,05020	0,03183	0,02178	0,02138
81	0,05672	0,03715	0,02164	0,02057
82	0,06459	0,04361	0,02006	0,01887
83	0,07396	0,05108	0,01708	0,01728
84	0,08456	0,05965	0,01407	0,01591
85	0,09646	0,06960	0,01151	0,01427

Table 16: A generation life table for Austria

age	$q_{x,2019}$	$q_{y,2019}$	F_x	F_y
86	0,10933	0,08073	0,00982	0,01292
87	0,12295	0,09296	0,00940	0,01235
88	0,13753	0,10683	0,00943	0,01171
89	0,15327	0,12285	0,00939	0,01037
90	0,17068	0,14138	0,00897	0,00799
91	0,18987	0,16228	0,00794	0,00480
92	0,21137	0,18425	0,00617	0,00220
93	0,23554	0,20651	0,00375	0,00073
94	0,26024	0,22899	0,00172	-0,00003
95	0,28574	0,25179	0,00050	-0,00014
96	0,31380	0,27512	-0,00080	-0,00011
97	0,34531	0,29788	-0,00246	0,00123
98	0,37926	0,32109	-0,00386	0,00382
99	0,41525	0,34593	-0,00480	0,00725
100	1,00000	1,00000	0,00000	0,00000

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