Excess Mortality in Austria during the COVID-19 Pandemic

Preprint · August 2024

DOI: 10.13140/RG.2.2.29921.52321

1 author:

Matthias Reitzner
Universität Osnabrück

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Matthias Reitzner*

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 COVID-19 specific quantities, yielding correlations of excess mortality with COVID-19 infections, COVID-19 deaths and vaccination rates.

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 [2, 6, 9, 11, 12, 14, 19, 20, 22, 24, 30, 31, 33], and in particular [5] 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 as well 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.

*matthias.reitzner@uni-osnabrueck.de

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 the excess mortality for the years 2010 to 2023.

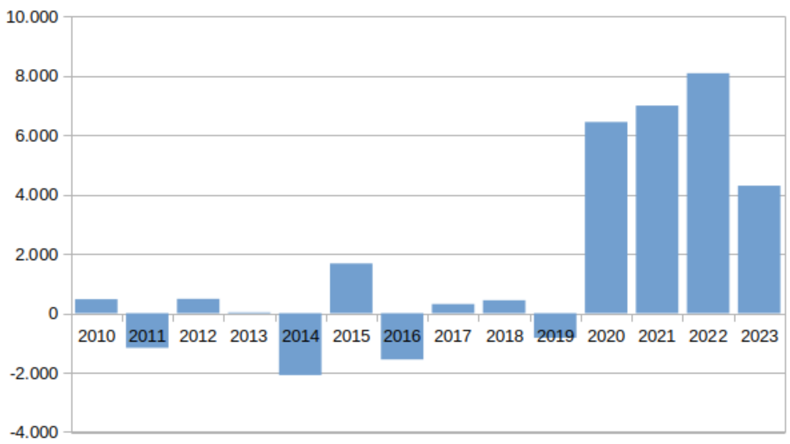

Figure 1: Excess mortality in Austria 2010 – 2023

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.

In a second step the excess mortality is computed 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 COVID-19 related quantities, like the number of COVID-19 deaths in Section 3.2, the number of COVID-19 infections in Section 3.3, and the number of COVID-19 vaccinations in Section 3.4.

Most of the above mentioned investigations dealing with excess mortality during the COVID-19 pandemic have certain drawbacks. First, in the estimate of the World Health Organization (WHO) [33] 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 [6] 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 [14]. Sometimes it is easier to use mortality probabilities only for age groups, see e.g. [22, 24, 31]. This simplified model yields approximate excess mortalities but the results depend heavily on the size of the age groups: for example, the single mortality probability for the age group 65+ used in Pizzato et al. [24] ignores that in this age group the mortality probability is varying from 1,3% to 41,5% which leads to substantial overestimates. In all mentioned contributions except [9] the longevity trend of the mortality probabilities has been ignored which leads to overestimated mortality probabilities and underestimated excess mortalities. [5, 20] seem to be the only mentioned contributions which also quantify the pre-pandemic variation of excess mortality to contextualise the occurring pandemic excess mortality.

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 the effect of COVID-19 vaccination one has to avoid to compute the COVID-19 vaccination effect using time intervals where no vaccination was available, which was done e.g. in [24].

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 generalize this the obtain excess mortalities for the Austrian federal states during the pandemic. In Section 3 we relate the obtained excess mortalities to several COVID-19 related 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 Statistical Office of Austria [26].

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 [4] where the $e^{-\cdots \arctan(\cdot)}$ 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 Austrian Actuarial Society AVÖ [3], the AVÖ 2005-R lifetable [4], the DAV2004R lifetable [18], and the books [23, 13].

We use the periodic life tables $\hat{q}_{x,t}$ from the Statistical Office of Austria [26], and model the mortality probabilities as

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

with $t_0 = 2019$ using the method of Whittaker-Henderson [4, 7]. 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. $\exp(-F_f(x)(t-t_0))$.

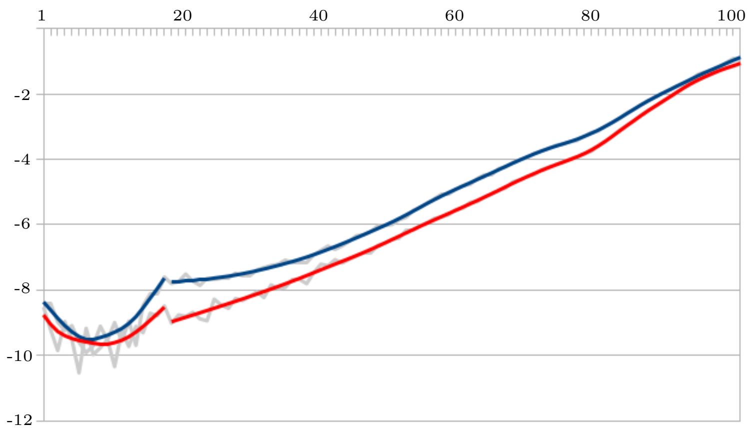

Figure 2: Raw and smoothed logarithmic mortality probabilities $\ln q_{x,2019}$ (blue curve) and $\ln q_{y,2019}$ (red curve)

All these parameters are chosen to best fit the historical data. This is the standard method in actuarial science and have been computed in [8]. 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

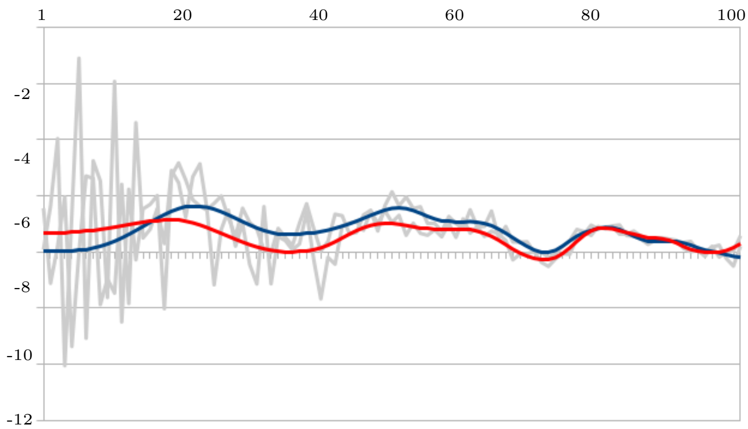

Figure 3: Raw and smoothed mortality trend F_x (blue curve) and F_y (red curve)

at the age of 100, thus we assume that $q_{x,t} = 1$ for $x = y = 100$. The table is listed in the Supplement 5.

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 [27] 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 [20]. Hence the number of male deaths of age x in year t is modelled as a binomial random variable $D_{x,t}$ with expectation

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

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 [28]. 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

year	excess mortality 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 $\approx$ 300. As is well known in actuarial science, this underestimates the variance due to the lack of full independence between deaths. 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 2010 – 2013. 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.

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%

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 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 [28, 29].

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 is dominated by the infant mortality which has huge fluctuations from year to year. Thus it seems to be difficult to draw conclusions 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 [29]. 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 mortality in the first pandemic year compared the the calendar year 2020. Still, excess mortality is increasing by approximately 600 deaths each pandemic year.

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%

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 [27], one can compute the expected number of deaths for each federal state $i = 1, \ldots, 9$ 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 use the method introduced in [21]. We introduce state factors β^i, $i = 1, \ldots 9$, 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 $i = 1, \ldots, 9$

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

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 [29].

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 [8] 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 this 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.

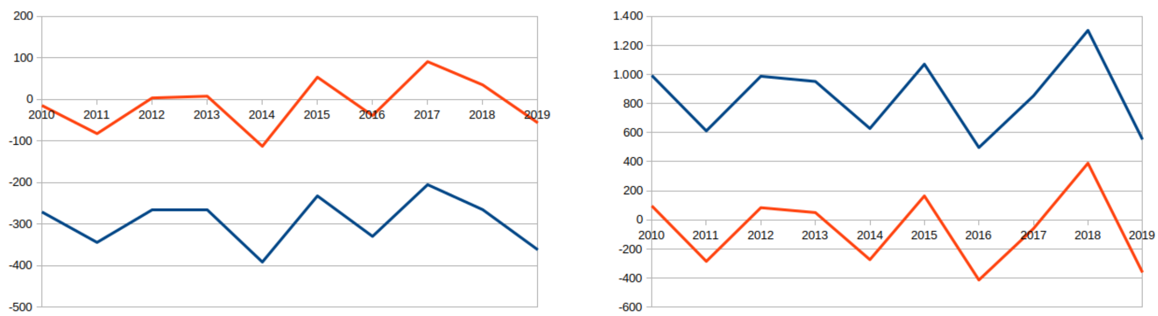

Figure 4: Unadjusted (blue) and adjusted (red) excess mortality for Vorarlberg (left) and Vienna (right)

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 $(\hat{d}^i_T - \mathbb{E}D^i_T)/(\mathbb{E}D^i_T)$.

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

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

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.

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 use the one-sided t-test). All other correlations are minor. We also note that excess mortality is uncorrelated to the state factors β^i and thus the factors influencing β^i 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, seem not to influence excess mortality in a significant way.

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 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 Austrian Agency for Health and Food Safety AGES [1]. First we list in Table 7 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 7: 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 [32] 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 [17] 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 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 8 reflects the extent to which COVID-19 deaths have occurred in relation to the usually expected number of deaths.

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

	2020/21		2021/22		2022/23	
state	excess	COVID	excess	COVID	excess	COVID
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%
Austria	8,21%	12,24%	8,93%	8,38%	9,55%	3,91%

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. In the second pandemic pandemic year $r = 0,618$ ($p = 0,038$) and in the third pandemic year the correlations are considerably decreasing $r = 0,578$ ($p = 0,052$). 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.

3.3 Number of COVID-19 infections

The numbers of COVID-19 infections for each Austrian federal state are available on request by the Austrian Agency for Health and Food Safety AGES [1]. 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 pandemic year was divided by the population of a federal state. The results are stated in Table 9.

The correlation coefficients between COVID-19 infections and excess mortality are stated in Table 10. 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

Table 9: 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
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%
Austria	8,21%	5,98%	8,93%	37,30%	9,55%	24,11%

Table 10: Correlation between excess mortality and COVID-19 infections

	excess		
	2020/21	2021/22	2022/23
infections 2020/21	0,192	0,071	-0,476
infections 2021/22	0,361	0,598	-0,123
infections 2022/23	-0,035	0,027	0,010

maybe might indicate that infections immunize against (at least heavy) 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 high 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.

3.4 Vaccination rates

The number of people vaccinated (second vaccination, third vaccination) in each of the Austrian federal states are provided by data.gv.at [10]. 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 in Table 11.

Table 11: Excess mortality and rate of 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
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%
Austria	8,21%	–	8,93%	52,9%	9,55%	56,3%

The correlation coefficients between COVID-19 vaccinations and excess mortality are stated in Table 12.

Table 12: Correlation between excess mortality and COVID-19 vaccinations

	excess		
	2020/21	2021/22	2022/23
vaccinated 2021/22	-0,574	-0,603	-0,283
vaccinated 2022/23	-0,534	-0,634	-0,256

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 have 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 simple 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 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

$$r = 0,203 \ (p = 0,300), \quad \text{resp. } r = 0,593 \ (p = 0,046)$$

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

$$r = 0,554 \ (p = 0,061), \quad \text{resp. } r = 0,606 \ (p = 0,042).$$

Again, the increasing excess mortality is considerably *positively* correlated with the vaccination rate. 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

$$r = 0,683 \ (p = 0,021).$$

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 less a federal state was affected by excess deaths in the first pandemic year, the more 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.

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 connected to COVID-19. The estimates of excess mortality are based on the state-of-the-art method of actuarial science and data from Statistik Austria [26, 27, 28, 29] and AGES [1].

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 the reported number of COVID-19 deaths 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 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 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 3.4 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. Such a pattern would be expected if the vaccinations had caused more negative effects instead of positive effects.

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. This finding supports the suspicion that the negative side effects of the vaccination may possibly outweigh the positive effects.

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) only 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 et al. [25], Faksova et al. [15], Fraiman et al. [16], Kuhbandner et al. [20]) 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.

Acknowledgement

Part of this work was done during a stay of MR at the Trimester Program *Synergies between modern probability, geometric analysis and stochastic geometry* at the Hausdorff Research Institute for Mathematics (HIM) in Bonn (Germany).

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Statements and Declarations

Competing Interests: All authors have declared that no financial support was received from any organization for the submitted work. All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work.

Matthias Reitzner
Universität Osnabrück
Institut für Mathematik
49069 Osnabrück
Germany

5 Supplement: 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.

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

age	$q_{x,2019}$	$q_{y,2019}$	F_x	F_y
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
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

age	$q_{x,2019}$	$q_{y,2019}$	F_x	F_y
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
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