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A SIMPLE FUNCTION TO FIT THE TIME EVOLUTION OF DAILY REPORTED COVID-19 DEATHS IN EU COUNTRIES

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We present a simple five-parameters function that is able to reasonably describe the evolution of the number of daily death due to COVID-19 in every country of the European Union. By extrapolation, assuming current lockdown conditions were to remain in place, this *ad hoc* fitting model is forecasting a total of about 200 000 deaths in the EU. Following this estimate, the current (May 3rd) number of death is expected to amount to two third of the total future casualty count.

1 Introduction

The current Covid-19 pandemia is a major worldwide concern since its outbreak¹ in December 2019. Although all countries are publishing their statistics in term of deaths, confirmed or recovered cases, the epidemiological modeling remains complex.

The realization of a major epidemic crisis happening in the European Union (EU) came in March 2020, and most EU countries consequently instituted some form of lockdown in a matter of days. Since then, at least in Europe, the epidemics has receded enough so that these countries have planned to lift the lockdown, at least partially, in the second week of May.

We wish to contribute to the evaluation of the incidence of such a decision based on current data. We fit an effective physical model to public Covid-19 deaths data in all 28 EU countries (including UK) in order to forecast the evolution of the epidemic if lockdown were to be maintained. Assuming that hypothesis, we estimate the total number of death due to COVID-19 at the end of the epidemic.

2 Data and method

The John Hopkins University database⁵ provides a daily report of deaths, confirmed and recovered Covid-19 patients all over the world, since January 22nd, 2020; this date is considered to be our time reference $t = 0$. Because of large variations in testing policies in different countries, in this analysis we limit ourselves to the study of daily deaths as a function of time. We are aware that this remains an imperfect proxy of the epidemic as counting policies can also vary from one country to the other.

In order to be able to compare countries, we normalize data by country population. This information is taken from the latest *United Nations Population Division* estimates⁴. Databases extraction of data and their initial analysis is ensured by the open source software CoCoA^{2,3}.

3 Analysis and extrapolation

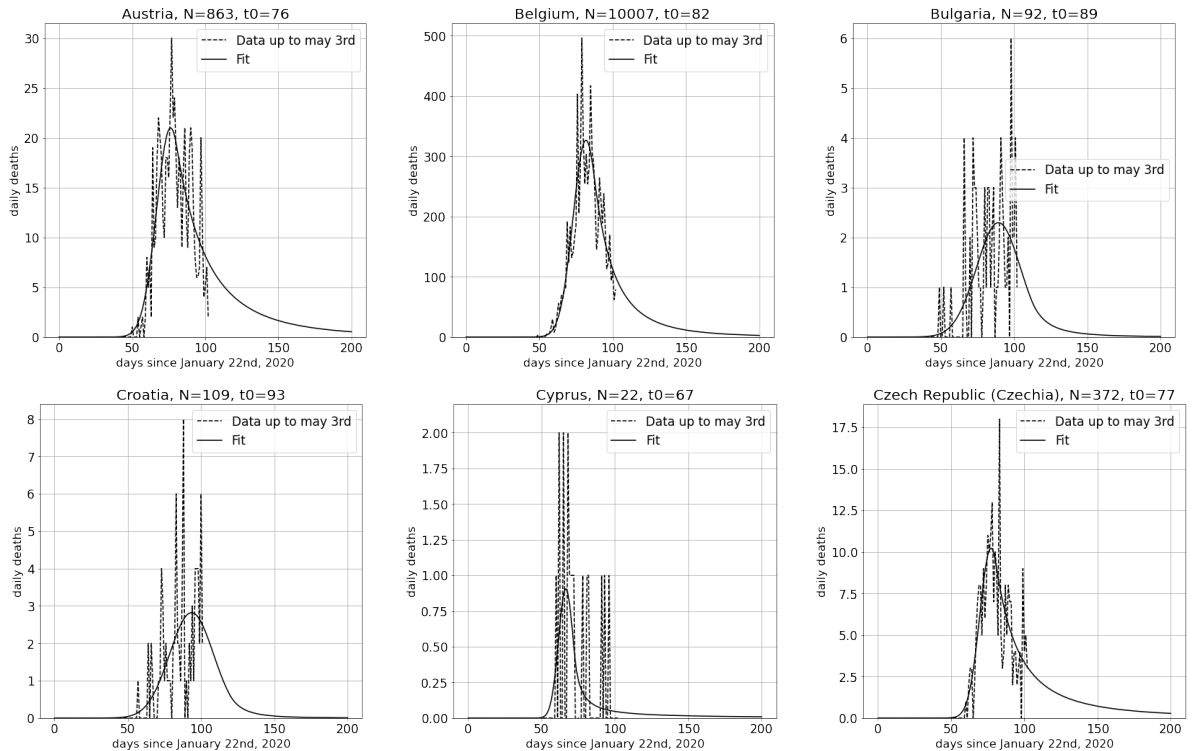
The modeling of data is done through a standard least-square fit of a Crystal Ball function⁶.

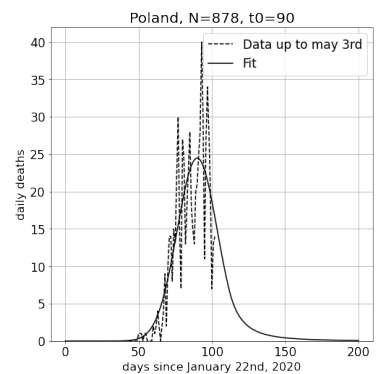
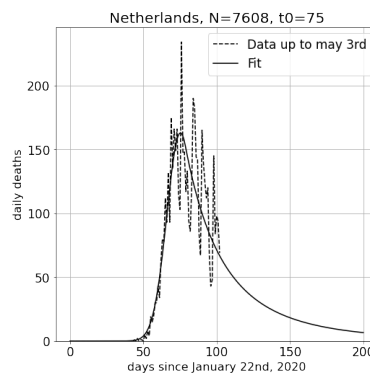
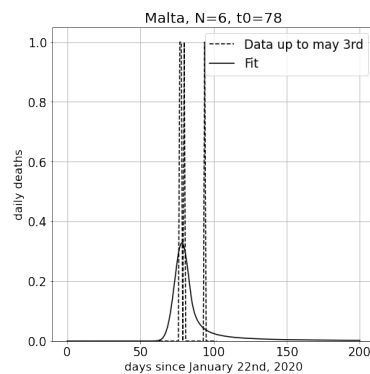
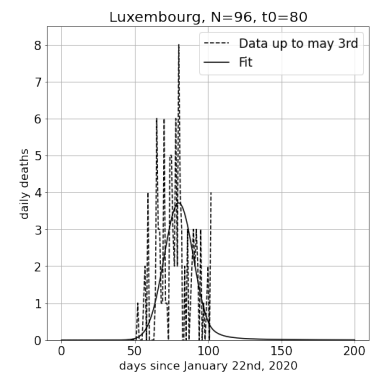
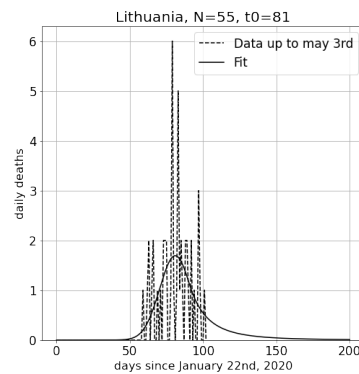
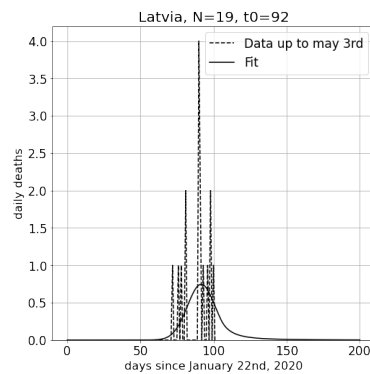
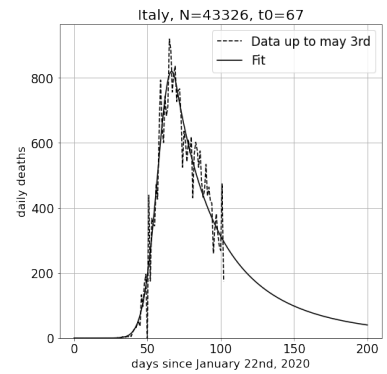
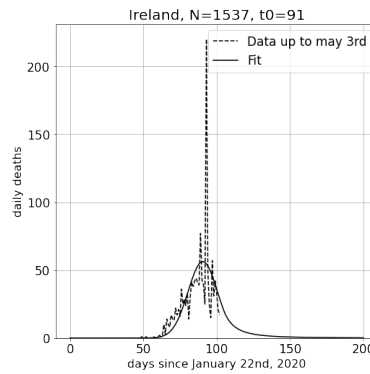
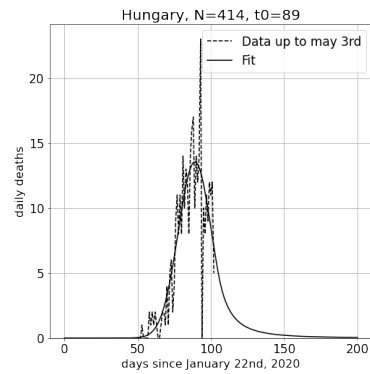
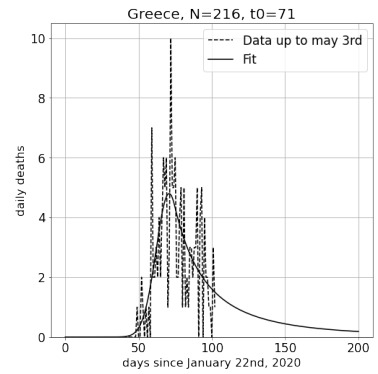
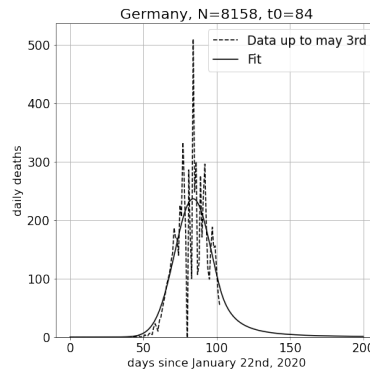
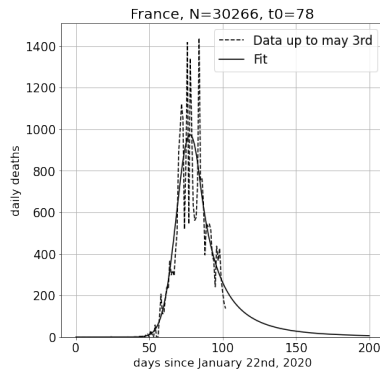
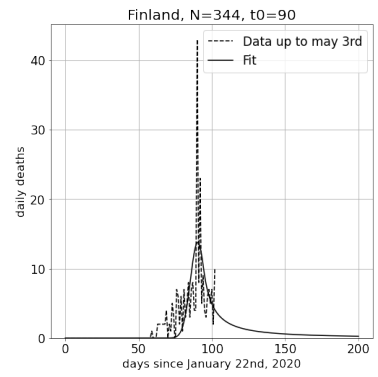
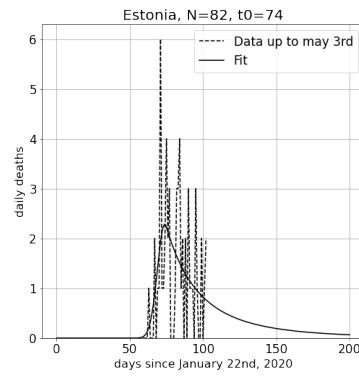
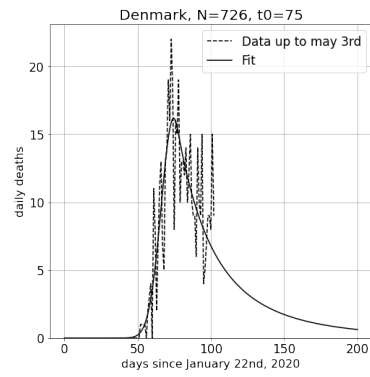
$$f(t; \alpha, n, t_0, \sigma) \propto \begin{cases} \exp\left(-\frac{(t-t_0)^2}{2\sigma^2}\right), & \text{for } \frac{t-t_0}{\sigma} > -\alpha \\ A \cdot \left(B - \frac{t-t_0}{\sigma}\right)^{-n}, & \text{for } \frac{t-t_0}{\sigma} \leq -\alpha \end{cases}$$

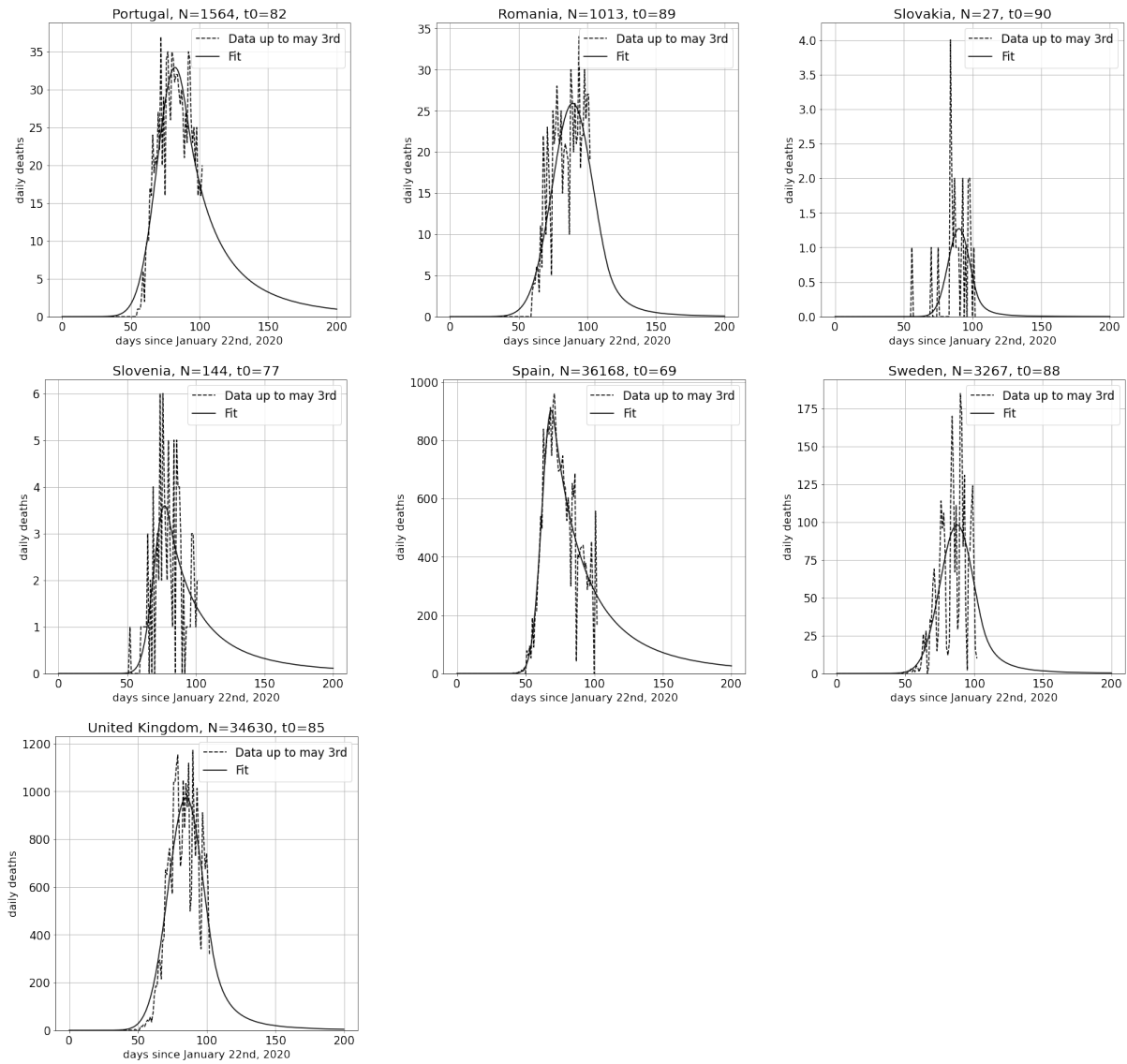
The Crystal Ball function consists of a smoothly joined Gaussian part and a power-law tail at a certain cut-off. It has 5 parameters : N is the full integral of the function over the time, n the power law parameter, α a normalized cutoff where the power-law replaces the Gaussian part, t_0 the position of the peak, σ the time scale. We are only reporting the useful parameters N and t_0 , which respectively describe the total number of death (assuming the daily death rate to follow this function) and the time at which the peak of the epidemic occurred.

Commonly used in high-energy physics, this function is named after a neutral particle detector initially used at the Stanford Linear Accelerator Center. The reason for choosing this function is two-fold. First we needed to describe properly the asymmetrical bell shape curve of the data (see figures below). Second we wanted a minimum number of adjustable parameters to avoid over-fitting.

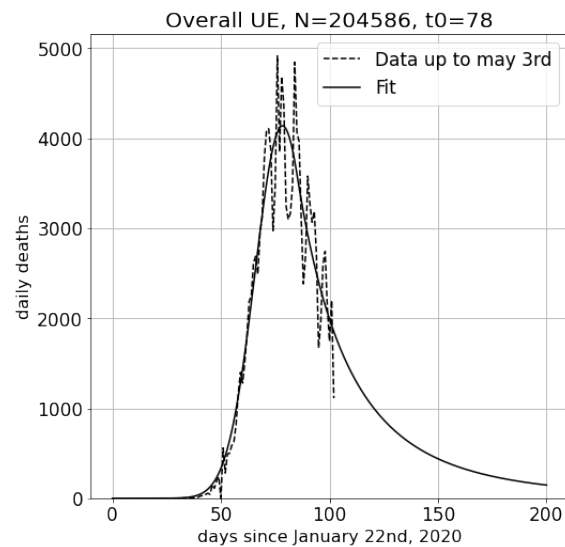
For every EU countries (and UK), we represent daily deaths as a function of time since $t=0$, together with the fitted Crystal Ball function. It is represented over 200 days to better visualize our forecast. The best fit parameters N and t_0 are given on each figure.







The same procedure has also been applied to European Union (including UK) as a whole.



4 Discussion

Our modeling yields an estimation of the expected overall number of deaths for each country. We provide these numbers in the table below, and compare them with the total number deaths reported until May 3rd, 2020, to infer the progress of the epidemic at this date. We normalize the figures by population to facilitate comparison between countries.

Country	Population	Deaths (May 3rd)	Total forecast N	Peak date t_0	Deaths (May 3rd) per 100k pop	Total forecast per 100k pop	Extent (May 3rd) in %
UE + UK	513 136 525	137 796	204 586	78	26.9	39.9	67.4
Germany	83 783 942	6 993	8 158	84	8.3	9.7	85.7
United Kingdom	67 886 011	28 809	34 630	85	42.4	51.0	83.2
France	65 273 511	25 204	30 266	78	38.6	46.4	83.3
Italy	60 461 826	29 079	43 326	67	48.1	71.7	67.1
Spain	46 754 778	25 428	36 168	69	54.4	77.4	70.3
Poland	37 846 611	698	878	90	1.8	2.3	79.5
Romania	19 237 691	818	1 013	89	4.3	5.3	80.8
Netherlands	17 134 872	5 098	7 608	75	29.8	44.4	67.0
Belgium	11 589 623	7 924	10 007	82	68.4	86.3	79.2
Czech Rep.	10 708 981	252	372	77	2.4	3.5	67.7
Greece	10 423 054	146	216	71	1.4	2.1	67.6
Portugal	10 196 709	1 063	1 564	82	10.4	15.3	68.0
Sweden	10 099 265	2 769	3 267	88	27.4	32.3	84.8
Hungary	9 660 351	351	414	89	3.6	4.3	84.8
Austria	9 006 398	600	863	76	6.7	9.6	69.5
Bulgaria	6 948 445	78	92	89	1.1	1.3	84.8
Denmark	5 792 202	493	726	75	8.5	12.5	67.9
Finland	5 540 720	240	344	90	4.3	6.2	69.8
Slovakia	5 459 642	25	27	90	0.5	0.5	92.6
Ireland	4 937 786	1 319	1 537	91	26.7	31.1	85.8
Croatia	4 105 267	80	109	93	1.9	2.7	73.4
Lithuania	2 722 289	46	55	81	1.7	2.0	83.6
Slovenia	2 078 938	97	144	77	4.7	6.9	67.4
Latvia	1 886 198	16	19	92	0.8	1.0	84.2
Estonia	1 326 535	55	82	74	4.1	6.2	67.1
Cyprus	1 207 359	15	22	67	1.2	1.8	68.2
Luxembourg	625 978	96	96	80	15.3	15.3	100.0
Malta	441 543	4	6	78	0.9	1.4	66.7

With merely five free parameters, our model fits reasonably well all data for the 28 EU countries (and UK). Fitting seems all the more accurate that the peak can be easily identified, and that the total number of daily death is high.

Some countries plan lifting the lockdown in early May 2020, such as Germany (May 4th), or France (May 11th). One can assume that without lifting the lockdown, the evolution of the daily rate of death could have followed the trend we have exhibited.

On May 3rd, EU countries (and UK) have recorded a total of 136 391 deaths due to Covid-19. Our effective model is projecting 204 586 deaths if all conditions remain as current. In this hypothesis, 2/3 of the total number of Covid-19 victims have already perished. It will be interesting to compare these figures with the total number of death at the end of the epidemic.

We should stress that our proposal is prospective and not predictive, in the sense that it

does *not* rely on epidemiological modeling. We merely describe data through *ad hoc* fitting of mathematical functions, a methodology similar to what is used in economic forecasts.

5 Conclusion

We provide an minimal model, within the CoCoA framework, that reasonably fits the daily rate of death as a function of time with only five free parameters. Assuming lockdown is not lifted, we estimate that at the beginning of May 2020 about two third of deaths have already occurred in Europe before the end of the epidemic. This implies a final total death rate of 1 over 2500 people. In the future, lockdown lifting policies could be evaluated with regard to our projection. In any case, our model provides a simple tool to reasonably describe the evolution from inception to the current stage of the epidemic.

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